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PREFACE

We are pleased to present the latest issue of the "International Journal of Advanced Multidisciplinary Research, Cases and Practices". This publication continues its mission to serve as a global platform for the exchange of knowledge, insights, and innovations that transcend traditional disciplinary boundaries.

In today's dynamic academic and professional landscape, the intersection of multiple disciplines provides fertile ground for groundbreaking discoveries and impactful solutions. This journal aims to showcase the depth and breadth of multidisciplinary research by featuring studies, case analyses, and practical applications from diverse fields. Our contributors explore complex problems, integrating perspectives and methodologies to offer innovative approaches and actionable outcomes.

This issue highlights an array of topics, ranging from [insert general themes or subject areas featured in this issue, e.g., "sustainable technologies and education innovation"] to [another theme]. These contributions underscore the journal's commitment to advancing knowledge that addresses real-world challenges while enriching theoretical frameworks.

We extend our gratitude to the authors, reviewers, and editorial board members who have contributed their expertise and effort to ensure the high standards of this publication. Your dedication to fostering collaborative research is the cornerstone of our success.

We hope that this issue inspires readers to pursue interdisciplinary endeavors and contributes to the advancement of knowledge and practice in their respective fields.

Warm regards,

Dr Kumardatt A Ganjre
Editor-in-Chief
International Journal of Advanced Multidisciplinary Research, Cases and Practices

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Shakti Act: A Beacon of Hope for Maharashtra's Women

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Dr. Samrat Ashok Gangurde

Abstract

The efficacy of Maharashtra, India's Shakti Act of 2020, a legislative measure aimed at reducing violence against women and children, depends on public knowledge. The purpose of this study is to find out how much the people of Maharashtra currently know about the provisions of the Act. The study uses focused approaches, such as surveys and questionnaires, in addition to media depictions. It seeks to determine the degree of comprehension among various demographic groups, paying special attention to those who might be at risk. Any disparities in awareness depending on social background, location, or information access will be clarified by this investigation. This research can help shape targeted outreach programs and educational initiatives by detecting awareness gaps. For the Act's intended beneficiaries to be able to take advantage of the legal protections it provides, there has to be a greater awareness among the public of its provisions. By reducing ignorance about the Shakti Act, this study seeks to make Maharashtra a safer place for women to live.

Key Words: Shakti Act, Awareness, Women, Maharashtra.

Introduction

Rape is an abhorrent aspect of human existence; both men and women who are victims of it suffer greatly locally. Several Indian states have taken extremely serious measures against this horrible deed. As an illustration, consider the Andhra Pradesh and Disha Act 2019, which has been proposed in numerous states and established a standard for aiding female victims. Anil Deshmukh, the home minister, introduced the Shakti Bill in the Legislative Assembly in order to address this. The prevention of violence against women and children will be aided by this law. This law stipulates that the prosecution of the accused must be finished in 21 days.
Within fifteen days, the police had to wrap up their investigation. The Andhra Pradesh Disha Act is being considered as this Act is being written. Globally, violence against women is still widespread and severe, with a high proportion of documented cases occurring in India. As a result, the Indian government passed number of laws to defend women's rights and stop gender-based violence. Among these, the state of Maharashtra's Shakti Act (Protection of Women from Domestic Violence Act, 2005) and Disha Act (The Criminal Law (Amendment) Act, 2013) from Andra Pradesh are prominent.

In the Indian state of Maharashtra, the Shakti Act, 2020 is a comprehensive law designed to improve the protection and security of women. In response to the mounting worries about sexual harassment, violence against women, and other related offenses, it was put into law. Maharashtra's Shakti Act is a big step in the right direction for women's protection and welfare. The goal of the Act is to make women feel safer and discourage future perpetrators by offering harsher punishments, quicker trials, and support programs.

Enacted in 2005, the Shakti Act is a landmark legislation that provides a comprehensive legal framework for protecting women from domestic violence. It recognizes domestic violence as a cognizable and non-bailable offense, empowering women to seek legal remedies and obtain various forms of protection, including residence orders, custody orders, and monetary relief.

Maharashtra Police have proposed amendments to the Shakti Act, 2020, aiming to further strengthen the Act's provisions and deter heinous crimes against women and children.

Key amendments:

- **Expanding the scope of offenses:** The amendments propose to include new offenses under the Act, such as stalking, voyeurism, and sharing of obscene content online.
- **Provision for special courts:** The amendments call for the establishment of special courts to expedite trials and ensure speedy justice for victims.
- **Increased penalties:** Under the Act, criminals found guilty of crimes against women, including as rape, domestic abuse, and sexual harassment, will face tougher sentences.
- **Fast trials:** In order to ensure prompt justice, it requires the creation of special fast-track courts to expedite the trial of cases pertaining to crimes against women.
- **Protection orders:** The Act gives women the legal right to seek protection orders from those who harass or abuse them, giving them a way to defend themselves.
- **Victim compensation:** It helps victims of crimes against women heal from the pain and potential financial losses they may have experienced by providing compensation.
- **Efforts to raise awareness:** The Act places a strong emphasis on the need to use public education initiatives and campaigns to raise awareness of women's rights and safety.

Significance of the amendments:

In Maharashtra, India, the Shakti Act is crucial for protecting women's safety and welfare. The following are some of its main implications:

1. **Crime deterrence:** The severe penalties imposed by the Act for crimes against women work as a forceful deterrence, turning away potential perpetrators and making it abundantly evident that such behavior will not be accepted.
2. **Justice for victims:** The Act gives victims of crimes against women a legal framework within which to pursue redress and receive compensation, assisting in their recovery from any trauma and possible monetary losses.

3. **Women's protection:** The Act gives women the authority to use protection orders and other tools to defend themselves against abuse and harassment, giving them a sense of security and self-assurance.
4. **Advancement of women's rights:** The Act reaffirms the significance of equality and women's rights, making it clear that women should be able to live without fear of discrimination or oppression.
5. **Better law enforcement:** The Act's provisions for extra awareness campaigns and special fast-track courts have enhanced law enforcement procedures and brought more attention to crimes against women.
6. **Changes in society:** The Act has aided in a wider cultural movement that has promoted a more inclusive and equitable society by raising awareness of and understanding for women's issues.

Overall, the Shakti Act is a significant piece of legislation that has had a positive impact on the lives of women in Maharashtra. By providing stronger legal protections, deterring crime, and promoting women's rights, the Act has helped to create a safer and more just environment for women.

Concerns and considerations:

Although it is admirable that the Act's efficacy is being increased, worries about potential abuse and the appropriateness of punishments should be carefully taken into account during the legislative process. In general, the suggested modifications signify a noteworthy advancement in fortifying the legislative structure to counteract offenses against females and minors in Maharashtra. But maintaining a fair and human rights-based strategy is still essential.

Problem of the study and Research questions:

- Has the Act effectively reduced violence against women in Maharashtra?
- Has the Shakti Act affected perceptions of women's safety in Maharashtra?
- Has the Shakti Act had any significant impact on the incidence of crimes against women in Maharashtra?

Modifications made by state governments that the federal government has not yet adopted. However, the act's flaw is the states' women's extremely low level of awareness. Therefore, the research paper's main focus is on raising awareness among state women. It will assist in lowering Maharashtra's crime rate.

Review of Literature

Pam Rajput, Usha Thakkar (2023) The writers talked about the Maharashtra Shakti Criminal Law, the (Maharashtra Amendment) Act 2020, the Special Court, and the Mechanism for implementing the Maharashtra Shakti Criminal Law, 2020 in order to lessen crimes against women and children. The death sentence is one of the legal punishments for serious crimes like rape.

Sadaf Modak (Dec;2021) It has been focused on the Shakti Criminal Laws (Maharashtra Amendment) Act, which was passed by the Maharashtra Assembly on Thursday, December 23, with unanimous votes. Once the Bill was approved, it became the second state in India, after Andhra Pradesh, to adopt the death penalty for heinous rape and gang rape offenses. The relevant parts of the Criminal Procedure Code and the Acts protecting children from sexual offenses (POCSO) and the Indian Penal Code against rape, gangrape, acid attacks, and sexual harassment have been changed by the Assembly.

Rajendra Prasad (2022) According to Rajendra Prasad's article in his current affairs yearbook 2022, the Maharashtra Assembly unanimously enacted the Shakti Criminal Laws (Maharashtra Amendment) Act. Context After Andhra Pradesh gave its consent, Maharashtra was proclaimed the second state in India.

Research Gap: There are many articles available in newspapers and some descriptions in books on various current affairs. So far, there is no reference to the scrutiny of this Act. Therefore, this is an honest attempt of the researcher to know the public awareness of this law in Maharashtra itself and its effect on women's crimes in the future.

Objectives

1. To determine the historical context of the Maharashtra State Shakti Act
2. To examine awareness of the Shakti Act concerning incidents of violence against women in Maharashtra.
3. To assess the Shakti Act's effects on various involved people
4. To make recommendations for enhancing the Act's efficacy

With these few objectives, the following hypothesis is formulated to explore the awareness of Shakti Act in the State of Maharashtra.

Hypothesis

$H_{0:}$ The Shakti Act has not had a significant impact on the incidence of crimes against women in Maharashtra.

$H_{1:}$ The Shakti Act has had a significant impact on the incidence of crimes against women in Maharashtra.

Research Methodology:

Data Collection: Primary data was collected trough questionnaire. Secondary data was collected through various current affairs books, articles in the newspapers, blogs and e-sources.

Sample size: 117 sample have been collected through simple random sampling method

Statistical tools: Mann-Whitney U Test used for justification of hypothesis.

Limitations of the study: The number of responses was small; the responses are taken only from Mumbai division and these responses are influenced by newspaper articles or hearsay incidents.

Justification of Hypothesis

H_0: The Shakti Act has not had a significant impact on the incidence of crimes against women in Maharashtra.

H_1: The Shakti Act has had a significant impact on the incidence of crimes against women in Maharashtra.

To evaluate the difference in incidence of crimes with the increase in implementation of the Shakti Act, Mann-Whitney U Test was utilized. This test points towards the impact that Shakti Act has had on incidence of crimes against women in Maharashtra.

Table No. 1 Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Implementation of Shakti Act	109	2.04	.732	1	4
Incidence of Crimes	109	1.93	.754	1	3

Table No. 2 Descriptive Statistics - Ranks

	Incidence of Crimes	N	Mean Rank	Sum of Ranks
Implementation of Shakti Act	Decreased	35	27.51	963.00
	Increased	27	36.67	990.00
	Total	62		

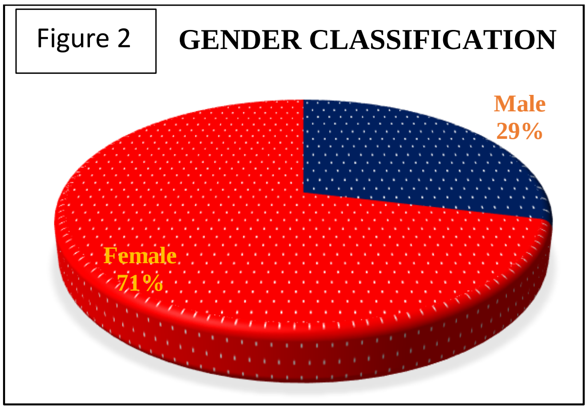
Table No. 3 Results of Mann Whitney U test – Test Statistics[a]

	Implementation of Shakti Act
Mann-Whitney U	333.000
Wilcoxon W	963.000
Z	-2.283
Asymp. Sig. (2-tailed)	0.022

Grouping Variable: Incidence of Crimes

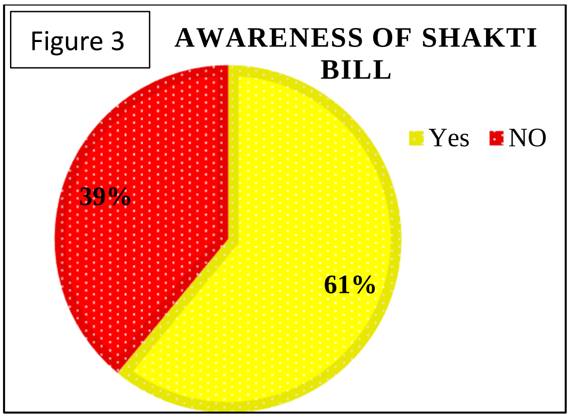
We shall reject the null hypothesis based on the aforementioned results, where the Z-value is -2.283 and the p-value is 0.022, both of which are less than 0.05. The incidence of crimes varies significantly with the growth of the Shakti Act's implementation. Given that the significant value is 0.022, it may be inferred that, notwithstanding the implementation of the Shakti Act, there is a slight effect on the variance in the occurrence of crimes. It follows that the Shakti Act has significantly reduced the number of crimes against women that occur in Maharashtra.

Other Findings of the study:



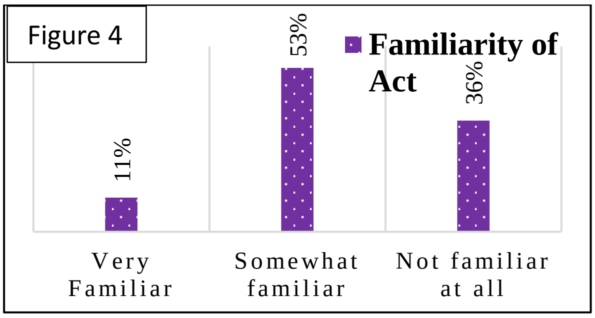
Of the respondents in the research study, 29% were men and 71% were women. Thus, the proper sex ratio was used for this research.

2) Are you aware about Shakti Act 2020



According to Figure 3.61% of respondents are aware of this law, whereas 39% are not.

3) If yes, how familiar are you with the provisions of the Shakti Act?



Of those surveyed, 36% claimed to be ignorant of this law. Nonetheless, 53% of those surveyed claimed to only have a passing familiarity with the act—that is, to have heard about it but not in considerable detail.

4) Do you believe that more public awareness of the Shakti Act would deter potential abuse of women?

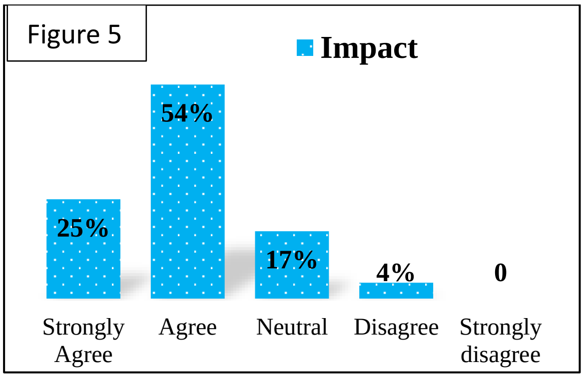


Figure 5, which displays 54% of respondents who agree and 25% who strongly agree, illustrates how awareness discourages violence against women. This indicates that the Maharashtra people has to be made aware of the Shakti Act.

5) Do you think that if more people knew about the Shakti Act, it would give women more confidence to report violent crimes?

Figure 6

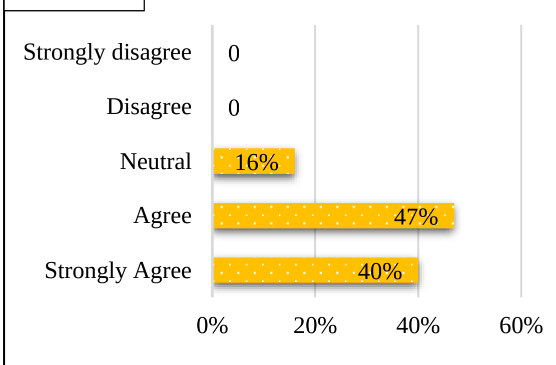
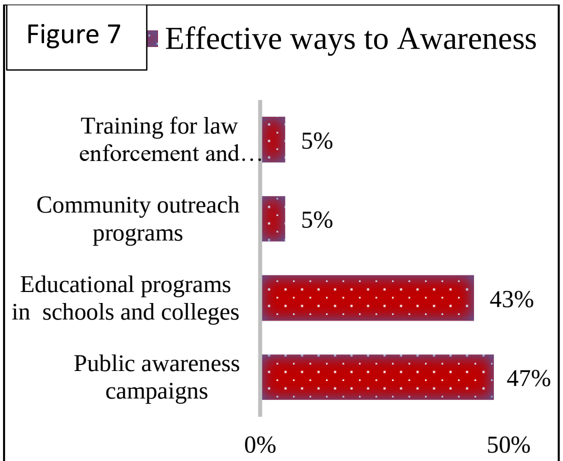


Figure 6 depicts women's empowerment and awareness. Of the respondents, 47% agreed and 40% strongly agreed with women's empowerment. This implies that women's empowerment may result from knowledge of the Shakti Act.

6) In your opinion, what are the most effective ways to increase awareness of the Shakti Act in Maharashtra?

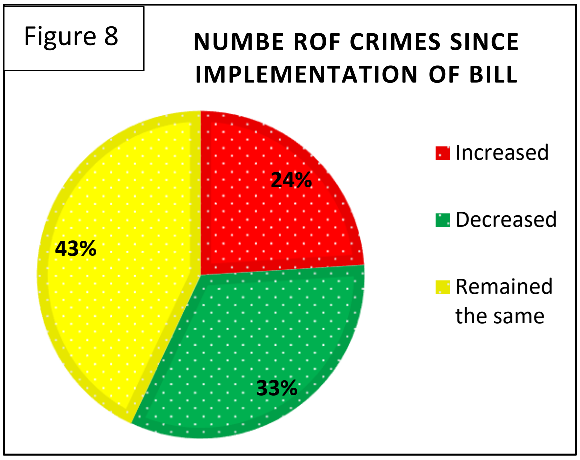
Figure 7



The pathways of consciousness growth are depicted (in Figure 7). 5% of respondents were in favor of training for law enforcement and judicial officials. While 43% of respondents supported educational programs at schools and colleges, an additional 5% supported community outreach initiatives and 47% concurred with public awareness initiatives.

7) In your opinion, has the incidence of crimes against women in Maharashtra increased, decreased, or remained the same since the implementation of the Shakti Act?

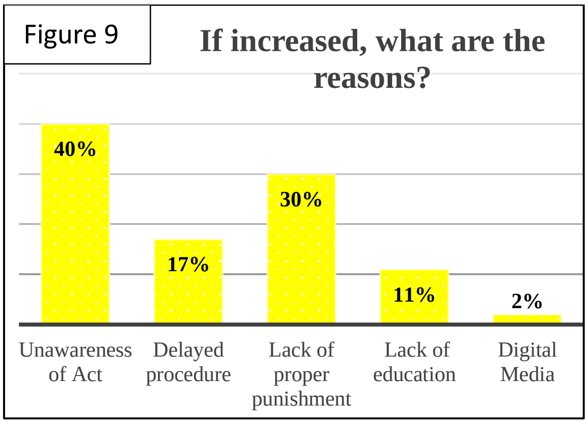
Figure 8



People are not very aware of the facts, which has resulted in diverse opinions to the survey mentioned above. Of those surveyed, 24% predicted an increase. Of those who responded, 33% predicted a drop in crime and 43% said it would stay the same. In their view, there is therefore a great deal of confusion.

8) If increased, what are the reasons?

Figure 9



The several causes of the rise in crimes against women following the Shakti Act's introduction are depicted in Figure 9. According to 40% of the respondents, it is because they are unaware of this Act. 30% concurred since there was insufficient punishment. While 11% and 17%, respectively, agreed that there was a lack of education and a delayed procedure. Remarkably, just 2 percent attributed crime against women to digital media.

9) If decreased, what are the reasons?

Figure 10

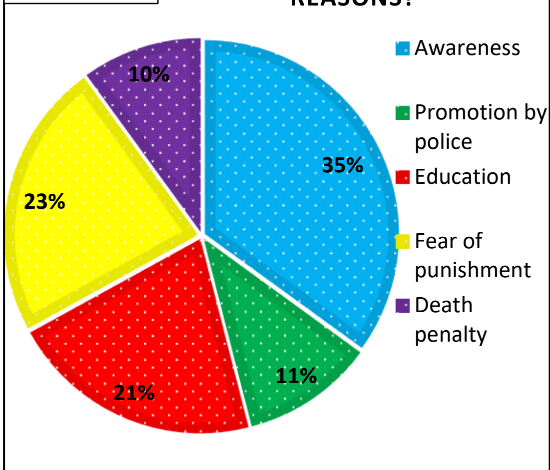


Figure 10 focuses on the various reasons for the decline in crimes against women after the implementation of the Shakti Act. 35% of respondents say more awareness is needed. 23% and 21% agree for fear of punishment and more education respectively. While 10% and 11% people agree to promote death penalty and promotion of Act by police respectively.

10) Do you feel safer as a woman in Maharashtra since the implementation of the Shakti Act?

Figure 11

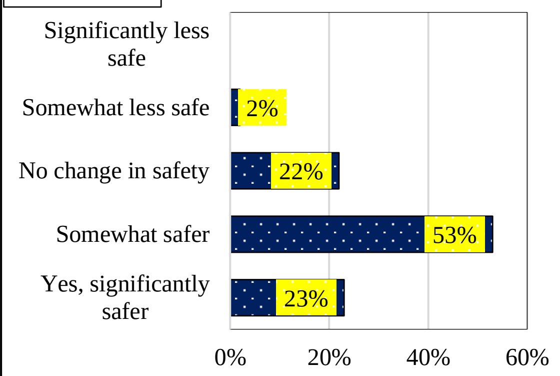


Figure 11 shows the safety of women since the introduction of the Shakti Act. 53% and 23% of respondents agreed that women are somewhat safe and significantly safe respectively. 22% respondents agreed about no change in security. But 2% respondents said women are also somewhat less safe.

11) Do you believe the Shakti Act has been effective in deterring crimes against women in Maharashtra?

Figure 12

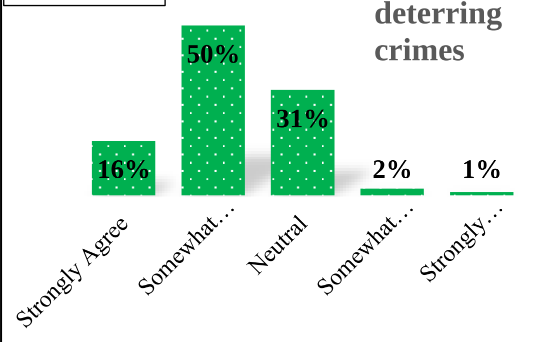
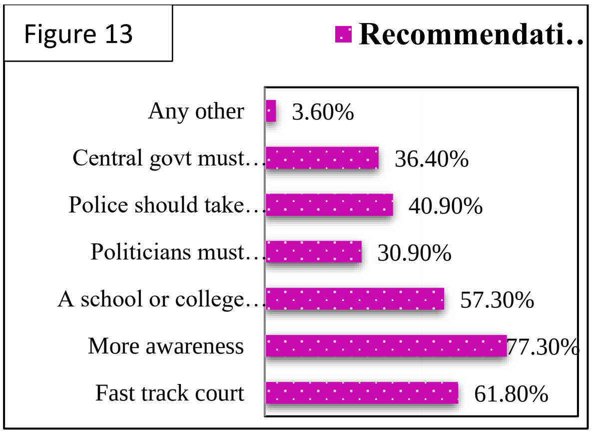


Figure 12 highlights the effectiveness of the Shakti Act against women crime in Maharashtra. 16% and 50% respondents strongly agree and somewhat agree respectively. 31% are neutral.

12) Recommendations for strengthening of Act

Figure 13



From all the above research some recommendations are given by the respondents like about 62% of the respondents suggested speedy court for punishment of criminals. 78% suggested more awareness. 57% of the respondents suggested that schools and colleges should emphasize Shakti Act knowledge. 41% of the respondents suggested that police should conduct seminars and workshops related to Shakti Act and create public awareness. 36% suggested that it should be approved by the central government quickly. 31% also suggested that politicians should speak at each of their public meetings.

Conclusion

In order to lessen horrible crimes against women in Maharashtra, the Shakti Act is crucial. Yet, greater awareness is required, raising red flags for criminals. Hence the alternate hypothesis in the research opposing theory that “the Shakti Act has had a significant impact on the incidence of crimes against women in Maharashtra” is accepted. The difference in crime rates with increases in law enforcement authority was assessed using the Mann-Whitney U test. This test shows how the Shakti Act has affected the number of crimes against women in Maharashtra.

The current status of decline in incidents among Maharashtrians in relation to the Shakti Act's provisions has been brought to light by this research. It will be advantageous for victims' rights advocacy and women's safety. This will give Maharashtrian women more influence. This is the researcher's ultimate objective.

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Enhancing Urban Waste Management Through Digital Twin Technology: Challenges, Solutions, and Stakeholder Engagement

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Enhancing Urban Waste Management Through Digital Twin Technology: Challenges, Solutions, and Stakeholder Engagement

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***Abstract*—This paper explores the application of digital twin technology in urban waste management, highlighting its potential to transform traditional methods by providing real-time data and simulation capabilities. The study examines current waste management practices in Tshwane and identifies the integration of digital twins as a solution to optimize waste collection, improve container placement, and enhance operational efficiency. Key challenges addressed include stakeholder communication, data accuracy, security, and the need for advanced content moderation systems. The research emphasizes the importance of stakeholder engagement and the need for a multidisciplinary approach to implement and maintain digital twins effectively. Findings indicate that while digital twins offer significant benefits such as reduced operational costs, improved waste tracking, and enhanced decision-making, their successful implementation requires overcoming limitations related to data collection, security, and stakeholder alignment. The paper concludes that digital twins, combined with active citizen participation, can lead to more sustainable and efficient waste management systems, particularly in lower-income regions with limited technological resources.**

I. Introduction

An Urban Digital Twin (UDT) represents a virtual model of specific physical assets within a city district or neighborhood, enabling the simulation and testing of scenarios tailored to city-specific parameters [1]. Unlike static 2D or 3D visualizations, UDTs dynamically represent the past, present, and potential future states of urban environments [2].

As a Decision Support System, a UDT aids urban planners and designers in assessing project impacts while fostering public participation in planning processes [3], [4]. While UDTs have addressed several urban challenges, including air quality [5], traffic management [6], and parking systems [7], key issues such as underground infrastructure, water distribution, and urban green spaces have been largely overlooked.

Strong waste (SW) the executives addresses another basic metropolitan test. Analysts feature the need to coordinate sensors into SW frameworks to elevate metropolitan maintainability because of its significant effect on metropolitan expectations for everyday comforts [8]. As per the World Bank, worldwide metropolitan strong waste age in 2020 arrived at 2.24 billion metric tons, with roughly 33% excess unmanaged in a naturally solid way [9], [10]. Regardless of its importance, the Unified Countries has not expressly perceived strong waste administration (SWM) as a center Maintainable Improvement Objective (SDG), which might frustrate its prioritization in strategy plans [11]. In any case, SWM is naturally connected to 12 of the 17 SDGs, eminently SDGs 11, 12, and 13, highlighting its significance for exhaustive metropolitan manageability [12].

Previous research has employed geospatial data, including land use patterns, road networks, and street gradients [13], [14], [15], alongside computer vision for container identification [16], to enhance waste collection systems. However, a comprehensive approach that integrates 3D waste generation estimates, citizen-reported container locations, and optimized collection routes remains unexplored.

Building on prior work presented at The 18th 3DGeoInfo Conference [17], this study examines the integration of UDT technology with SWM systems to tackle challenges such as waste collection inefficiencies, service irregularities, and illegal dumping in urban settings.

his paper acquaints a UDT model planned with reenact holder based squander age and improve vehicle steering iteratively in light of anticipated squander volumes. The review centers around the Hatfield and Hillcrest areas in Tshwane, South Africa, exhibiting the principal South African Advanced Twin for SWM. This model use chipped in geographic data, 3D LiDAR city filters, 3D waste age estimations, and open geospatial datasets, offering a replicable model for different districts.

The structure of this research is as follows: first, I outline the local context and societal challenges driving this study. Second, I review current practices and academic progress in waste monitoring, route optimization, and stakeholder analysis. Third, I describe the study area, datasets, UDT development framework, and stakeholder assessment methodology. Fourth, I present the UDT prototype and its findings, emphasizing the benefits of the Digital Twin approach. Fifth, I discuss the results, analyzing the UDT based on the Gemini Principles. Lastly, I conclude by addressing the research questions that guided this study.

II. Literature Review

A. Geographical Context

In 2017, South Africa produced roughly 30.5 million tons of strong waste across private, business, and institutional areas [18], [19]. With a populace of 59.9 million [20], the country's strong waste age rate remains at 1.48 kg per capita each day, incredible the sub-Saharan normal of 0.46 kg/capita-day and lining up with the upper quartile of Europe and Focal Asia at 1.53 kg/capita-day [10]. This represents a huge test to the country's waste administration frameworks.

In the City of Tshwane (Bunk), South Africa's regulatory capital, abnormalities in metropolitan assistance conveyance have set off fights. Occupants request fair and steady administrations, much the same as those gave to generally advantaged regions during politically-sanctioned racial segregation [21]. After a significant civil strike in 2023 disturbed squander expulsion, the Bunk reestablished its assortment plan, in spite of the fact that difficulties continue. Unlawful unloading stays a basic concern, presenting wellbeing gambles and expecting occupants to report uncollected receptacles effectively [22], [23], [24].

Waste generation in Tshwane exceeds the national average, with per capita landfill waste estimated at 1.95 kg/day [25]. The city has identified over 600 illegal dumping hotspots and proposed interventions such as container allocation, illegal site monitoring, and intensive street cleanups [26]. Research suggests that transitioning from static to dynamic waste management systems, which adapt to waste generation patterns, incorporate real-time monitoring, and optimize collection routes, can address these challenges effectively [27], [13], [28]. Furthermore, integrating citizen participation and strong governmental support is essential for sustainable waste management [29].

B. Solid Waste Generation

Solid waste (SW) generation has received limited attention in the literature [30]. Researchers typically estimate total waste generation by calculating the mass of collected waste, assessing its density, and dividing the average by the total served population [31]. Factors such as population density, household size [32], age demographics [33], living area size [34], life expectancy [35], education levels [36], income [36], [10], and business scale [34] have been analyzed to identify predictors of waste generation. However, these studies often focus on broader scales (country or provincial levels) rather than direct generators like households [37].

Research at household scales has demonstrated better predictive accuracy for waste generation [38]. For residential areas, population density is a critical factor in estimating waste generation. However, estimating non-residential waste generation involves greater complexity. Methods such as those by [39], which consider business size and economic activity, provide useful approximations, but these models are limited to specific local and temporal conditions.

C. Solid Waste Monitoring

Monitoring solid waste (SW) containers has traditionally relied on surveys [40], manual road-by-road data gathering [41], or information provided by municipal authorities [13]. Modern techniques utilize video footage from collection vehicles, analyzed with computer vision, to pinpoint container locations and categorize their types [16]. While these approaches determine *where* waste needs to be collected, they do not address the *fullness* or saturation levels of the containers.

Various sensors have been developed to monitor container fullness, including ultrasonic sensors [42], [43], [44], [45], [46], weight sensors [47], combined sensor systems [48], [49], and infrared sensors [50]. While ultrasonic sensors have shown promise, most studies tested prototypes on a limited scale, often under controlled conditions, and lacked scalability for real-world urban environments. Simulations by [48] demonstrated that sensor data could predict daily waste generation per container.

Some studies, such as those by [47] and [49], tested ultrasonic sensors outdoors, including controlled residential and commercial scenarios in Shanghai, China. However, these studies relied on citizen participation, potentially introducing bias in waste volume data. While they proposed integrating route optimization with real-time monitoring, practical implementation remains limited.

In Utrecht, Netherlands, ultrasonic sensors have been integrated with daily collection route optimization based on container fullness, reducing vehicle requirements and preventing overflows [51]. This highlights the value of combining sensor-based monitoring with dynamic route planning for efficient waste management.

D. Routing Optimization Using Geospatial Data

Solid waste (SW) collection is an inverse logistics problem where items are gathered instead of delivered. Optimizing waste collection routes directly enhances the efficiency of SW management systems. Key factors influencing route optimization include the number of collection points, loading and unloading times, distances between collection points and landfills, and the overall travel distance among collection points [52].

Route optimization is a well-researched area with various methodologies. Analytical approaches leverage mathematical models to enhance route efficiency. For instance, studies show that optimizing road-length segments reduces costs, energy consumption, and vehicle operation times, while improving fuel efficiency expands coverage areas [53], [54], [14]. Agent-based models simulate SW generation and sequential container collection, focusing on shortest-path routes to maximize system performance and reduce costs [55]. Geospatial techniques utilize network analysis to optimize routes by integrating data on road networks, topography, and collection times [56], [57], [15]. Hybrid approaches combine mathematical modeling, traffic data, and geospatial information, often validated through agent-based simulations [58].

All these approaches share similar limitations: 1) predefined start and end locations (e.g., depots or disposal sites), 2) ensuring each container is assigned to a single route, 3) adhering to vehicle capacity restrictions, and 4) following local traffic rules.

Collectively, these techniques have shown improvements in reducing travel time, fuel usage, and labor expenses. Nevertheless, only [55] incorporates real-time route adjustments influenced by dynamic variables like container fill levels or varying waste generation rates. Implementing such adaptability would necessitate continuous data collection and frequent re-optimization to address localized demands and daily changes in waste patterns, rather than relying on static schedules.

E. Stakeholder Identification and Classification

SW management involves interconnected technological, political, environmental, and socio-economic dimensions, requiring engagement from diverse stakeholders [59]. Understanding stakeholders' roles, concerns, and constraints is crucial for enhancing participation, effectiveness, and the pursuit of sustainable solutions [60], [61]. For urban waste management challenges, particularly when leveraging Urban Digital Twin (UDT) technology, stakeholder alignment is critical to address complex, interdependent issues. A comprehensive understanding of stakeholder relationships, interests, and context ensures balanced decision-making [62].

Stakeholder salience theory [63], [64] offers a framework for categorizing stakeholders based on *Power*, *Urgency*, *Legitimacy*, and *Proximity*. This framework defines 16 stakeholder typologies, aiding in distinguishing roles and priorities. Stakeholders classified as definitive or crucial hold the most significant influence over project success and are central to managing and operating waste systems effectively (see Figure 1).

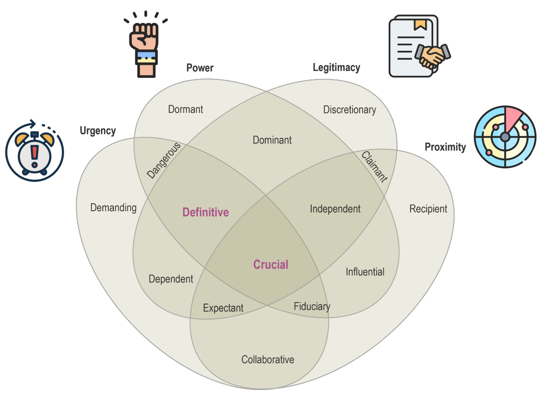

Figure 1: Classification of stakeholders based on four attributes and their interconnections. Source: (Shafique & Gabriel, 2022)

This salience framework lacks a well-defined approach for identifying the ownership of individual attributes or the relationships among stakeholders. As a result, any classification of stakeholders inevitably introduces biases in the interpretation of their typologies and roles.

F. Research Gap and Contribution

As highlighted earlier, South Africa, particularly the City of Tshwane (CoT), faces critical challenges in solid waste management, including high waste generation, irregular collection schedules, and illegal dumping. Addressing these issues requires transitioning from static waste management models to dynamic systems that incorporate stakeholder engagement, continuous monitoring, and real-time optimization of waste collection processes.

Existing waste monitoring approaches have seen limited large-scale application in cities with constrained resources. Although progress has been made in optimizing vehicle routing for waste collection, most solutions lack the flexibility to adjust to changing local waste generation trends over time.

This research proposes and evaluates a prototype Digital Twin (DT) model to enhance Solid Waste Management (SWM) within the City of Things (CoT) framework. The model addresses challenges such as container allocation, inconsistent collection services, and resource inefficiencies by simulating waste generation patterns and improving route optimization. The scalable design offers practical solutions for Sub-Saharan African cities dealing with similar SWM issues.

III. METHODOLOGY

The creation of an Urban Digital Twin (UDT) follows a structured framework comprising data collection, stakeholder analysis, 3D city modeling, waste production estimation, and route optimization for waste collection. The process concludes with an evaluation of the system's performance and scalability.

A. Study Area Description

The research focuses on a 9.45 km^2 area, including Hatfield and Hillcrest in Pretoria, South Africa. This area features mixed land uses, including residential zones, agricultural plots, and the University of Pretoria campuses. It also encompasses the Hatfield City Improvement District (CID), which manages urban services such as waste management and public safety (see Figure 2). The CID is funded through municipal levies and operates as a collaborative urban management entity [65].

B. Data Integration and Geospatial Resources

This study utilizes a range of geospatial data sources, summarized in Table I. Key datasets include LIDAR scans, road networks, and aerial imagery. All datasets were standardized to the WGS 1984 coordinate system (EPSG:4326), with calculations conducted using Hartebeesthoek94 / Lo29 (EPSG:2053).

C. Urban Waste Management Digital Twin Design

The UDT design process incorporates digital modeling, waste prediction, route optimization, and system integration. Figure 3 illustrates the workflow. The system dynamically simulates waste generation and optimizes collection routes to enhance efficiency and reduce manual intervention.

1) Stakeholder Engagement: Stakeholder identification was achieved through participatory workshops at the University of Pretoria, focusing on local waste management challenges. Transcriptions of discussions were anonymized and analyzed following the framework of [67]. The analysis categorized stakeholders by *Power*, *Urgency*, *Legitimacy*, and *Proximity*, using an adapted salience model [63], [64].

To reduce the impact of subjectivity and provide a more systematic approach to classification, an Analytical Hierarchical Process (AHP) was employed for pairwise comparisons [68], [69]. Stakeholders were assessed on a nine-point scale, comparing stakeholder i with stakeholder j (as shown in Table II).

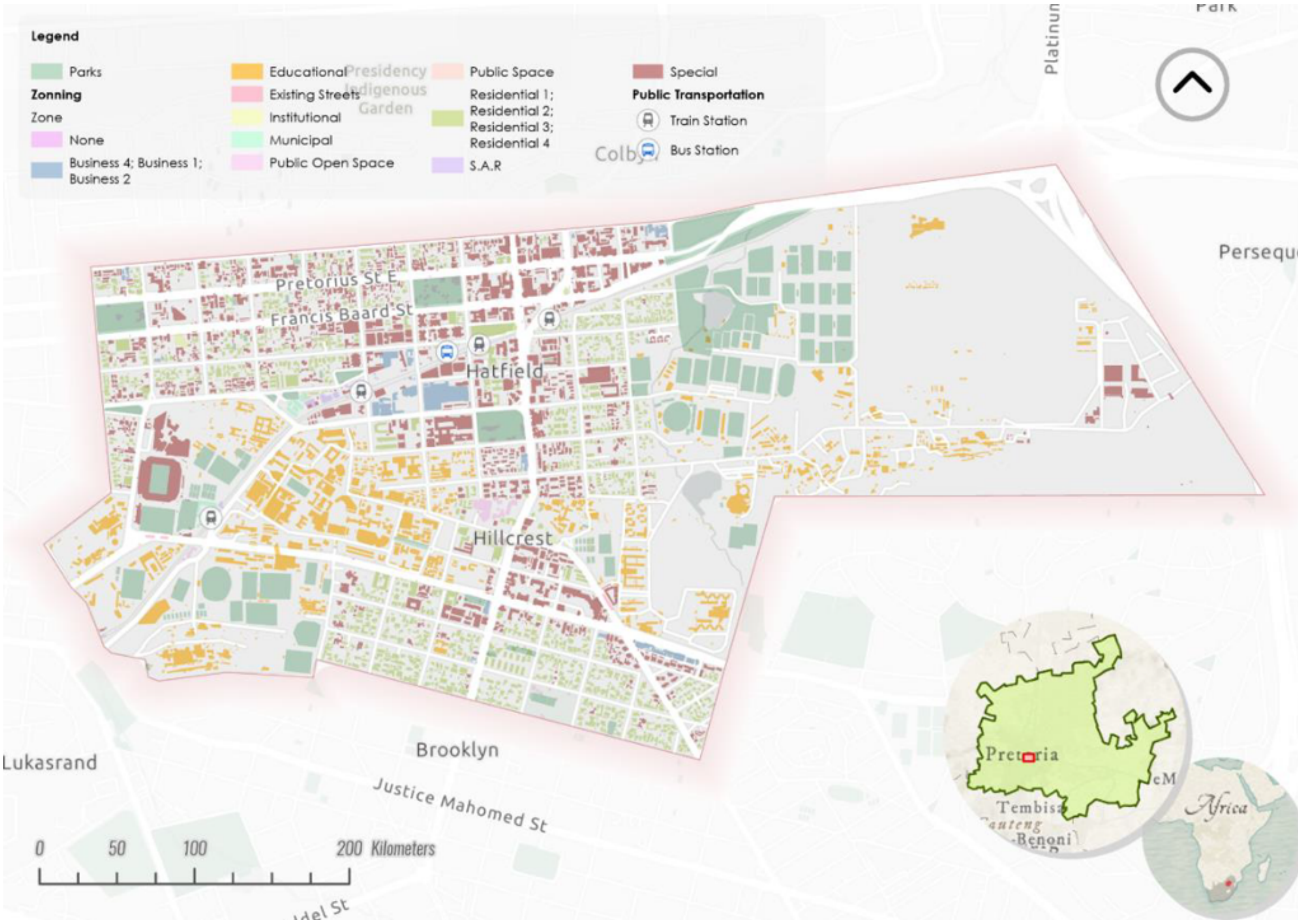

Figure 2: Geographical Scope of the Hatfield UDT.

Table I: Geospatial Datasets Utilized

Dataset	Description	Type	Date	Projection	Source
LIDAR Scans	Aerial laser data with 0.6m spacing	LAS	June 2019	EPSG:4148	CoT GIS
Building Footprints	Structures with usage attributes	Vector Polygons	Mar 2023	EPSG:4326	OpenStreetMap
Road Network	Road details, including type and direction	Vector Lines	Mar 2023	EPSG:2053	CoT GIS Portal
Aerial Imagery	High-resolution UAV imagery (0.1m)	Raster	June 2018	EPSG:2053	CoT GIS Portal
Land Zoning	Land-use classifications	Vector Polygons	Mar 2023	EPSG:2053	CoT GIS Portal
Population Data	Residential density grids (100m cells)	Raster	June 2022	EPSG:54009	GHS Population Grid [66]
Waste Containers	Locations of waste bins and dumping sites	Vector Points	Mar 2023	EPSG:4326	Field Data Collection [17]

A comparison matrix was constructed, and the values were normalized. The final eigenvector values were used to classify stakeholders according to the salience model. Based on these results, stakeholders classified as *Definitive* and *Crucial* were identified as the primary end-users of the Urban Digital Twin (UDT).

2) System Architecture and Data Integration: The integration of system components into a unified Digital Twin followed the architecture depicted in Figure 4. This process involved gathering citizen-collected data through the Epicollect5 API, exporting the data to a JSON file, filtering and transforming the data into a CSV format, and converting the point layer for visualizing the solid waste (SW) containers. The assignment of containers to buildings was carried out using a nearest-neighbor function. The optimization of collection vehicle routes was performed with the ArcPy routing module, which generated the most efficient paths and pickup sequences. These results were then displayed in an online operational dashboard, which updated every 6 seconds. The dashboard included key descriptive statistics and critical requirements identified by

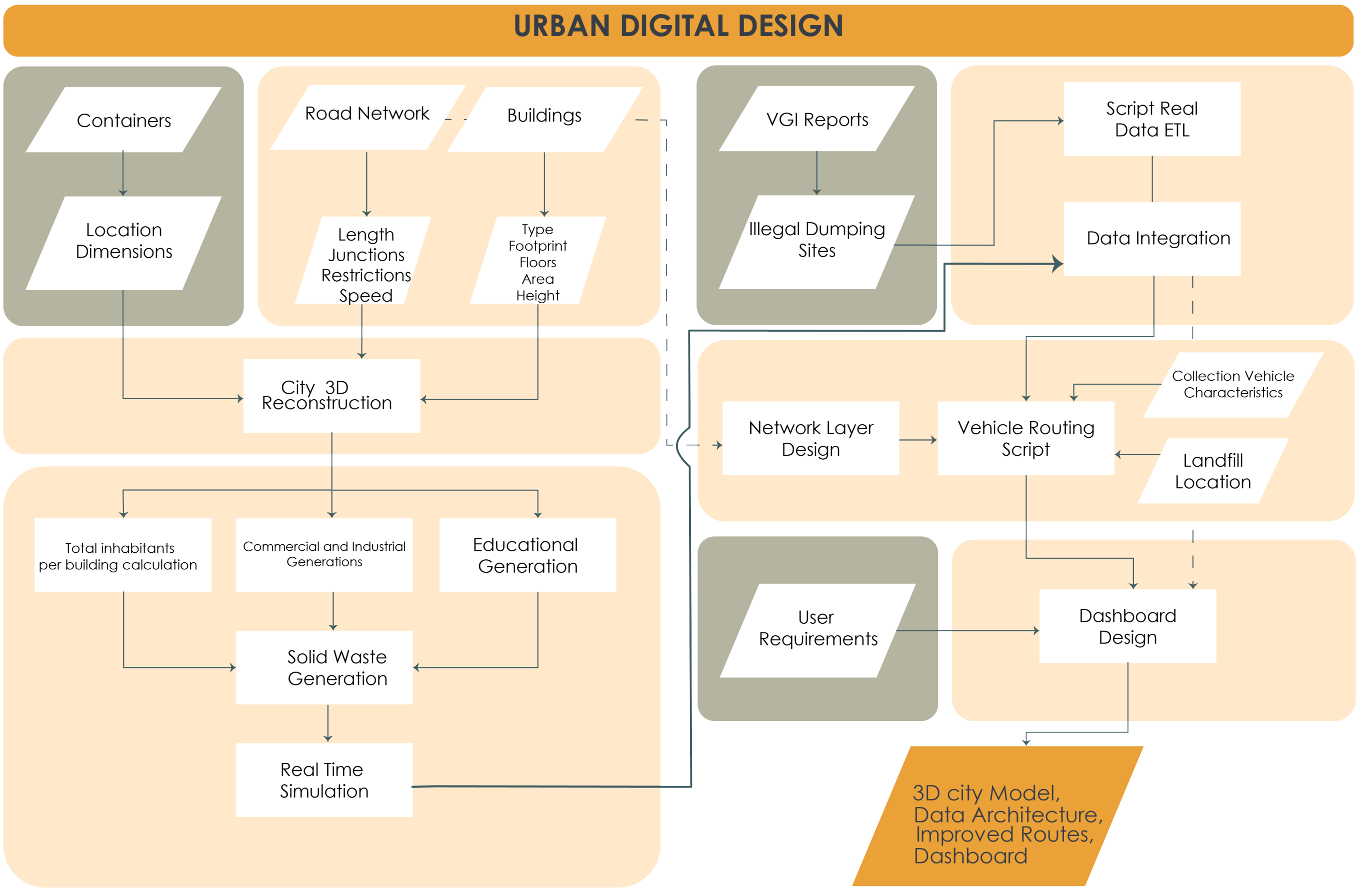

Figure 3: Workflow for UDT Development.

Table II: Analytical Hierarchical Process Pairwise Comparison. Source: (T. L. Saaty, 1990)

Relative Importance	Definition – X: Power, Urgency, Legitimacy, Proximity
1	i and j are equally important with respect to X
3	i has moderate importance over j for X
5	i has significant importance over j for X
7	i has very strong importance over j for X
9	i has extreme importance over j for X
2,4,6,8	Intermediate values between two adjacent judgments
Reciprocals	Inverse relation (e.g., if j has strong X over i, the value would be 1/3)

stakeholders.

The entire system was implemented on a local computer setup featuring 28 GB of RAM, an 8-core CPU with 16 threads (3.8 GHz), and a 4 GB dedicated GPU. Additionally, a cloud-based system was used with an ArcGIS server, equipped with 64 GB of RAM, an 8-core CPU (2.1 GHz), 16 threads, but without a dedicated GPU.

3) Solid Waste Generation Estimation: The estimation of residential population and corresponding waste generation was based on the Global Human Settlement Population Layer [66], which offers 100m resolution data. Population density was derived by analyzing the total floor area of residential buildings within each polygon. This value was then used to calculate the estimated number of residents per building. Multiplying this estimate by a standard waste generation factor allowed me to compute the daily waste output for each residential structure.

Non-residential buildings were classified into four categories based on their expected waste generation rates, as shown in Table III. The highest waste production rates for each building type, as outlined by [39], were used for the calculations, considering the limitations in waste production data specific to various building types and commercial activities.

For each building and its nearest waste container, I used a direct distance approach to approximate the likely deposition and collection points for waste. Containers were assumed to have a density of 600 kg/m³, as per estimates from the local waste collection service. Waste production for each location was simulated using a random number generator, scaled to represent a fraction (1/24th) of the total daily waste output, with a maximum deviation of 20% in waste volume.

4) Optimized Collection Route Calculation: To determine the most efficient collection routes, I utilized a Capacitated Vehicle Routing Problem (CVRP) solver [70]. This model incorporates several factors, including the positions of containers,

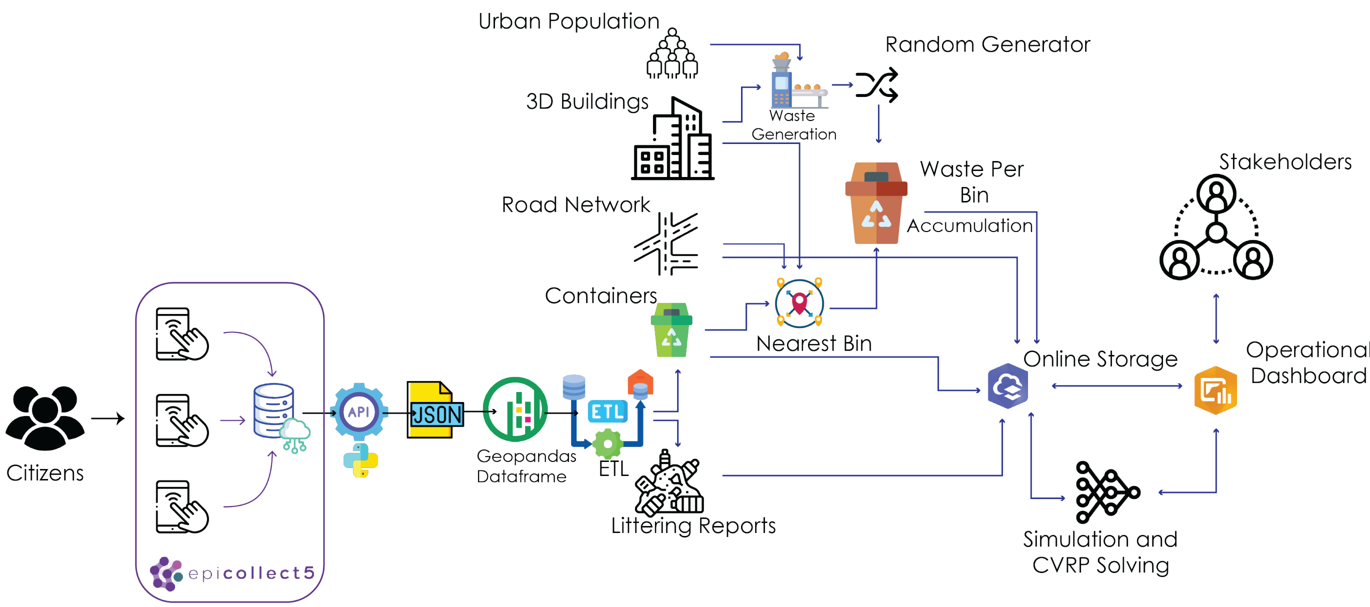

Figure 4: Architecture of the Waste Digital Twin

Table III: Categories of buildings, their related commercial activities, and corresponding waste generation rates. Source: adapted from Karadimas & Loumos, 2008.

Category	Commercial Activity Type	Waste Generation $(kg/m^2 - d)$
A	Supermarkets, bakeries, restaurants, grocery stores, greengroceries, fish stores, fast food outlets, bars, pubs, clubs, cafes.	0.419
B	Butcher stores, patisseries, hair salons, wine vaults, florists, garages, pizzerias.	0.225
C	Theatres, churches, schools, bookstores, barbershops, traditional cafes, pharmacies, post offices, lingerie stores.	0.124
D	Embassies, offices, insurance companies, chapels, betting shops, tutoring centers, shoe stores, clothing stores, jewelry shops, video rental stores.	0.024

their fill levels, and vehicle capacity limitations.

The road network data was first classified based on road types (residential, highway, road-link) and speed limits. I then created a network analysis layer to define the edges and nodes, with travel times being calculated based on segment lengths and maximum speed limits. Containers that were more than 75% full were included in the network as prioritized collection points.

The analysis defined start and end conditions, and waste accumulation simulations were performed at regular intervals (every 6 iterations), excluding the 24th hour to account for non-operational periods. The resulting optimal route was calculated using an Origin-Destination (OD) matrix to minimize the distance between collection points and the landfill site, optimizing vehicle movement using a Tabu Search heuristic [70].

After each iteration, waste containers were reset, and any containers not collected continued to accumulate waste until the defined threshold was reached. New routes were generated as needed to ensure memory efficiency and prevent overload during computations.

D. Stakeholder Evaluation

The creation of the UDT occurred between January and June 2023. A prototype demonstration was organized in July 2023, where 21 voluntary participants were introduced to the UDT dashboard and its interactive features. The session included a comprehensive presentation on the entire UDT development journey.

To evaluate the user experience, participants completed a survey utilizing a five-point Likert scale. The survey aimed to measure user satisfaction, system usability, and perceived effectiveness, drawing on established methods by [71] and Pelzer's added value framework [72] (refer to Figure 5). In addition to this, the UDT was assessed according to the three fundamental principles of purpose, trust, and function, as outlined by the Gemini Principles [73], which are visualized in Figure 6.

IV. Results

A. Current Waste Management Practices

According to the 2018 Gauteng Community Survey [74], the City of Tshwane (CoT) had a population of 2,921,488 in 2011, which increased to 3,275,152 by 2016, reflecting an annual growth rate of 2.28%. Extrapolating this trend, the estimated population for 2023 is approximately 3,835,010. The 2011 census recorded an urbanization rate of 92.3% [75], suggesting that by 2023, around 3,539,714 people will live in urban areas. However, the 2022/2023 Census by Statistics South Africa

Figure 5: Framework for Assessment. Source: adapted from (Aguilar et al., 2021; Ballatore et al., 2020; Pelzer et al., 2014)

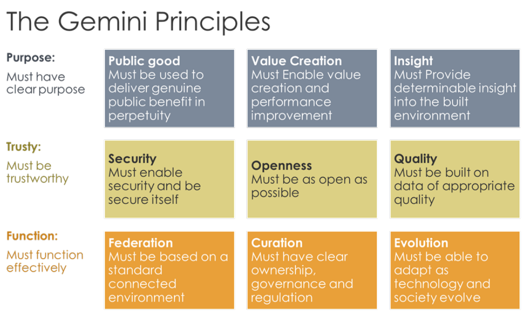

Figure 6: Digital Twins Gemini Principles. Source: (Bolton A & Schooling, 2018)

revised the overall population estimate to 4,040,315, although specific urban-rural breakdowns were not provided [76]. With an average waste generation of 1.95 kg per person per day [25], this translates to a total daily waste production of 6,902.44 tons across all sectors.

According to stakeholder feedback, municipal waste collection is conducted weekly using compactor trucks with a capacity of $18m^3$, each operating at a fuel efficiency of 4 km per liter. Each neighborhood is assigned a specific collection day, and the service is adapted to the types of properties and population density within those areas. Restaurants, due to their higher waste output, require daily waste collection, typically provided by private waste companies. In addition, municipal foot workers handle litter collection in public spaces, gathering trash manually and moving it to designated pick-up points for collection trucks. These efforts are carried out flexibly, without set schedules.

The Hatfield City Improvement District (CID) complements the municipality's waste management efforts with 16 foot workers and a truck. Their responsibilities include morning litter collection (from 7 AM to 11 AM) within small areas (1 to 1.5 blocks), followed by afternoon tasks such as tree pruning and organic waste removal. During special events or in busy commercial areas, the team prioritizes cleaning event locations. Private student housing, which accommodates around 30,000 students, manages its waste independently using smaller vehicles.

Waste collected from various areas is transported to one of the city's five municipal landfills, with each collection route directed to the closest landfill. For the Hatfield region, waste is taken to the Hatherley Municipal Dumping Site (28.407°E, 25.741°S). At the landfills, trucks unload their waste under the supervision of staff, with compaction occurring when necessary. These sites are also accessible to the public for disposal of materials such as construction debris, old appliances, and organic waste.

Through engagement with stakeholders and academic workshops, 15 key stakeholders were identified. The transcripts from these discussions were analyzed and categorized using four pairwise comparison matrices based on the attributes of *Power*, *Urgency*, *Legitimacy*, and *Proximity*. The resulting stakeholder typologies are summarized in Table IV.

Using the modified salience model, the CID and Ward Councilors emerged as *essential* stakeholders, scoring highly across all evaluated attributes. The municipality, classified as a *core* stakeholder, demonstrated strong performance in three attributes but ranked lower in terms of *proximity*. These three stakeholder groups, identified as primary users of the UDT system, were selected based on this analysis. The distribution of all stakeholders across the 16 typologies is illustrated in Figure 7.

Through consultations with stakeholders, a total of 32 key requirements were identified to enhance solid waste management. Among these, the most emphasized goals were "achieving zero waste" and "evaluating environmental impacts." These requirements were classified into three main categories: Strategic, Performance, and Operational. Due to the *urgency* expressed by both *essential* and *core* stakeholders, as well as limitations such as time constraints, resource availability, and the exclusion of external data not within the scope of the study, 17 requirements were excluded from the final design of the UDT. The remaining 15 prioritized requirements are listed in Table V.

B. Analysis of Solid Waste Generation

Each building was assigned to the nearest waste container, as shown in Figure 8. The maximum distance between a building and its designated container is 881.80 meters, which corresponds to an estimated walking time of 14 minutes, assuming an average walking speed of 1 meter per second. This longest distance is observed in the industrial park located in the eastern section of the study area, which was not accessible during data collection. It is possible that closer containers are present in the vicinity, or that certain containers are located within the industrial premises. Excluding these areas, the furthest distance between a building and a container reduces to 427.40 meters, equivalent to roughly 7.1 minutes on foot. The average distance between a building and its assigned container is 90.55 meters. For non-residential buildings, the average distance is slightly shorter, at 86.08 meters, with a median of 72.51 meters and a standard deviation of 58.16 meters. The shortest recorded distance is 2.51 meters. A visual

Table IV: Attributes and Typologies of Stakeholders. The percentage values represent the calculated weight for each attribute. Bold numbers highlight the highest weight for each attribute, while blue numbers represent the lowest weight. Stakeholder typologies marked in purple are those identified as the primary focus for meeting user requirements.

Stakeholder	Power	Urgency	Legitimacy	Proximity	**Typology**
Business and Offices	3.458	8.235	9.186	11.990	**Expectant**
Collection Companies	4.405	4.362	10.700	7.752	**Claimant**
Department of Forestry Fisheries and Environment	**27.949**	2.977	6.804	0.942	**Dominant**
Improvement District	8.740	**15.333**	9.168	9.306	**Crucial**
Industrial Parks	4.215	8.722	8.453	7.657	**Expectant**
Landfill Operators	7.830	2.304	2.245	2.817	**Dormant**
Municipality	18.560	13.637	10.394	4.071	**Definitive**
Real State Agencies	6.148	3.942	3.909	3.401	**Dormant**
Residents	4.572	11.305	**14.711**	**19.654**	**Expectant**
University Institution	5.699	12.589	10.738	7.313	**Expectant**
Ward councillor	7.020	14.911	11.017	11.112	**Crucial**
Waste picker	1.404	1.682	2.676	13.985	**Recipient**

Table V: Consolidated Requirements for the Waste Management Digital Twin.

Category	Elements
Strategic	Identification of Polluters Scalability for National Application Alignment with SDG Targets (MSW Generated Tons/day) Waste Source Identification
Performance	Optimal Placement of Containers Total Waste Generation Fuel Consumption of Collection Trucks Waste Generation Heatmaps
Operational	Container Capacity Levels Container Geolocation Efficient Waste Collection Routes Real-time Waste Generation Monitoring Simple, User-friendly Design Visualization for All Users, Including Those with Low Literacy

representation of the distribution of these distances can be found in Figure 9.

Residential structures generate waste amounts ranging from 0 kg/day to 1,575.60 kg/day, with an average waste production of 11.19 kg/day per building. Due to the methods used to estimate the number of residents per building and the low population density in the 100x100m grid cells, 662 buildings (31.95%) were found to have no residents, and thus, they do not contribute to waste production. Despite these estimation limitations, the total daily waste generated by residential buildings is 23.12 tons.

For non-residential buildings, Category D has the highest number of structures, as illustrated in Figure 10 and Table VI. However, Category C, which includes the sports stadium, produces the highest daily waste, amounting to 251.81 tons. Due to the stadium's event-based operations and its substantial waste generation, it was excluded from the optimized daily collection schedules. The absence of a dedicated container and the large volume of waste generated could otherwise interfere with standard collection procedures. Category A, consisting of just 73 buildings, contributes an estimated 149.83 tons of waste daily.

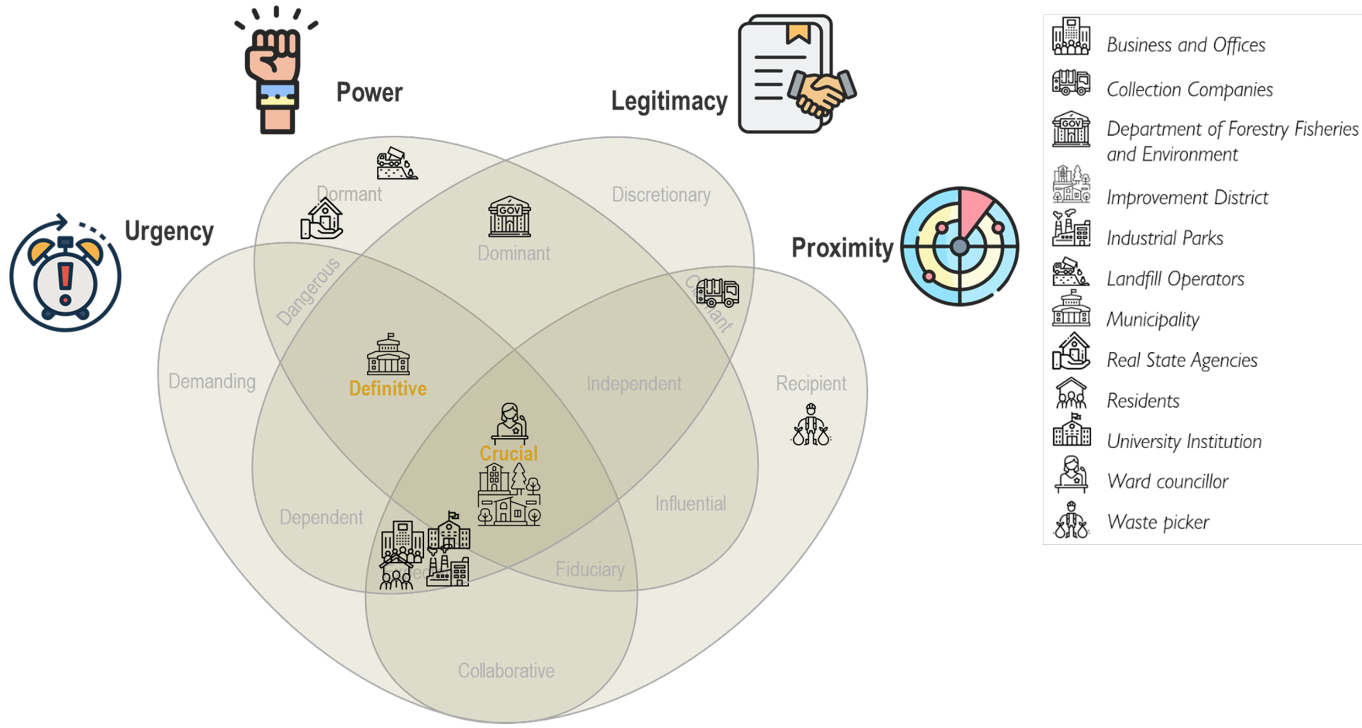

Figure 7: Stakeholder typology classification for the Waste Management Digital Twin.

Educational facilities are the most significant contributors to the total waste generated, producing 198.51 tons/day, accounting for 42.64% of the total waste. Business and commercial properties follow, generating 170 tons/day, which is 36.58% of the total. Notable individual waste producers include the sports stadium (41.72 tons/day), two shopping centers (41.10 and 17.71 tons/day, respectively), and the Information Technology Building of the University of Pretoria (8.08 tons/day).

Table VI: Estimated Daily Waste Production by Building Type

Building Type	Total Waste Production (kg/d)	Maximum per Building (kg/d)	Minimum per Building (kg/d)	Mean (kg/d)	Standard Deviation
A	149,828.77	41,103.38	27.72	2,052.45	5,301.89
B	14,169.03	1,531.37	5.00	382.95	425.22
C	251,811.20	41,727.28	1.16	293.14	1,578.39
D	26,581.51	2,462.11	0.17	28.99	106.64
TOTAL	442,390.52	41,727.28	0.17	234.57	1,538.57

C. Hourly Solid Waste Generation Simulation

Using simulated hourly waste production for each building, container statuses were monitored throughout the day to determine optimal collection routes (Figure 11). Results show that 18 containers are already full at the start of the first hour, highlighting inefficient capacity utilization and the need for adjustments. By the sixth hour, when collections are scheduled, 116 containers collectively hold 56.5 tons of waste. Randomized waste generation in the simulation creates variability in results, but certain hotspots—such as areas around the stadium, university campus, and train station stops—consistently exhibit high waste accumulation, necessitating frequent collections to avoid overflow.

D. Optimized Waste Collection Routes

The analyzed road network comprises 2,792 edges, with speed limits varying between 40 km/h in residential areas and 120 km/h on high-speed roads. Of these, 1,572 edges (56.30%) are unidirectional, primarily within the central study area and corresponding to local streets, while bidirectional edges dominate peripheral and arterial roads.

Simulated waste collection routes, illustrated in Figure 12, were generated alongside detailed navigation paths (Figure 13). Over multiple simulation runs, trucks followed varying routes, with certain areas revisited frequently due to recurring waste overflow (Figure 15), consistent with earlier waste production patterns.

The number of containers collected per route ranged from 112 to 213, requiring trucks to visit the landfill up to four times daily to empty all containers. For longer collection intervals (6–12 hours), trucks made up to nine landfill trips. On average, a 6-hour collection period took 5 hours and 16 minutes, while a 12-hour period extended to 10 hours and 57 minutes. The average route distance was 236.28 km, incurring a cost of approximately 1,327 ZAR (69.70 USD) and producing 2.73 tons of CO_2 emissions per route, based on an emission rate of 11.59 kg/km [77].

E. Dashboard Layout

A central control panel was designed to present the core features of the Urban Waste Management Digital Twin (UDT).

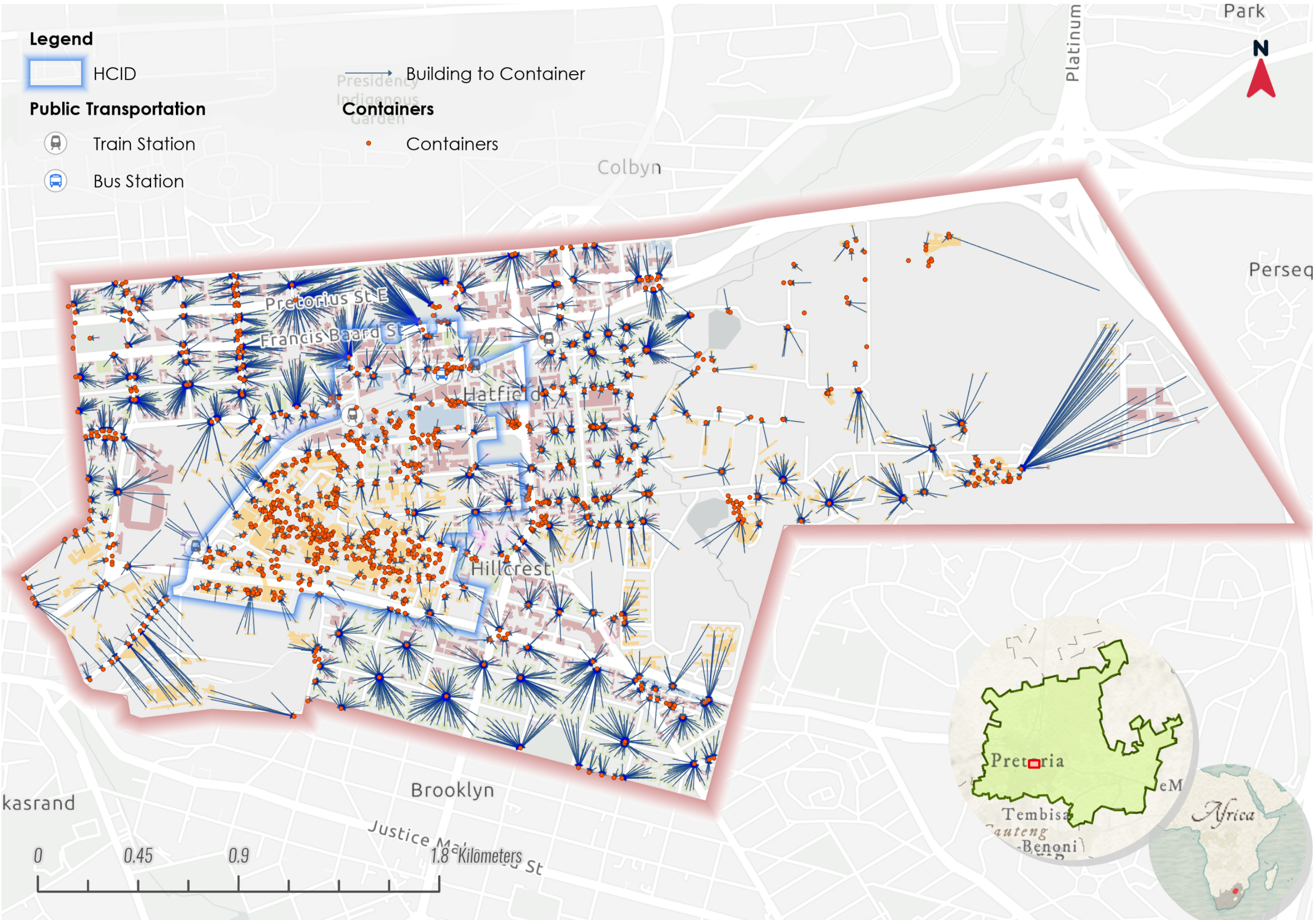

Figure 8: Assignment of buildings to their nearest waste containers.

This dashboard emphasizes map visualizations that display critical system components and relevant performance metrics, with the ability to interactively update the status of each map layer. The map offers three distinct modes of visualization. The first mode highlights the containers that are ready for collection and displays the optimal collection order. This map is dynamic and refreshes in real-time, adjusting based on data regarding the fullness of containers and the amount of accumulated waste. The second mode provides an overview of the relationship between different building types and their allocated containers, helping users understand the spatial distribution of waste and the proximity of containers to buildings. The third mode focuses on tracking littering behaviors by presenting a heatmap of reported littering incidents, with filtering options to distinguish areas based on the severity of littering.

In accordance with the established design requirements, the dashboard visualizes eleven crucial indicators (refer to Figures 16 and 17). The first two indicators display key information on container usage, such as the average fill percentage and the number of containers that are due for collection. The third indicator corresponds to the heatmap from the litter monitoring mode, presenting a pie chart that categorizes litter reports by their severity. The fourth indicator tracks the total waste accumulated in the area requiring collection, independent of container fill levels, aligning with the objectives of SDG 11 related to waste reduction. The fifth indicator monitors the waste generated by each category of building, which is reflected in the second map mode, based on the building type and estimated population. The remaining indicators (six to eleven) provide logistical data related to waste collection operations, including metrics such as fuel consumption, CO2 emissions, total travel distance, operational time, the number of landfill trips (when a truck reaches its capacity), and an interactive sequential list of the containers to be collected. This list is interactive, with specific items highlighted on the first map upon selection.

F. Assessment of the Waste Digital Twin

Simulation performance varies significantly between local and cloud-based services. Locally, waste generation calculations for each simulated hour average 5.02 seconds, while determining optimal collection routes takes about 2.72 minutes. On the cloud, the same operations take 4.18 minutes per hour, a 4,996% increase, and 4.93 minutes for route calculations, representing

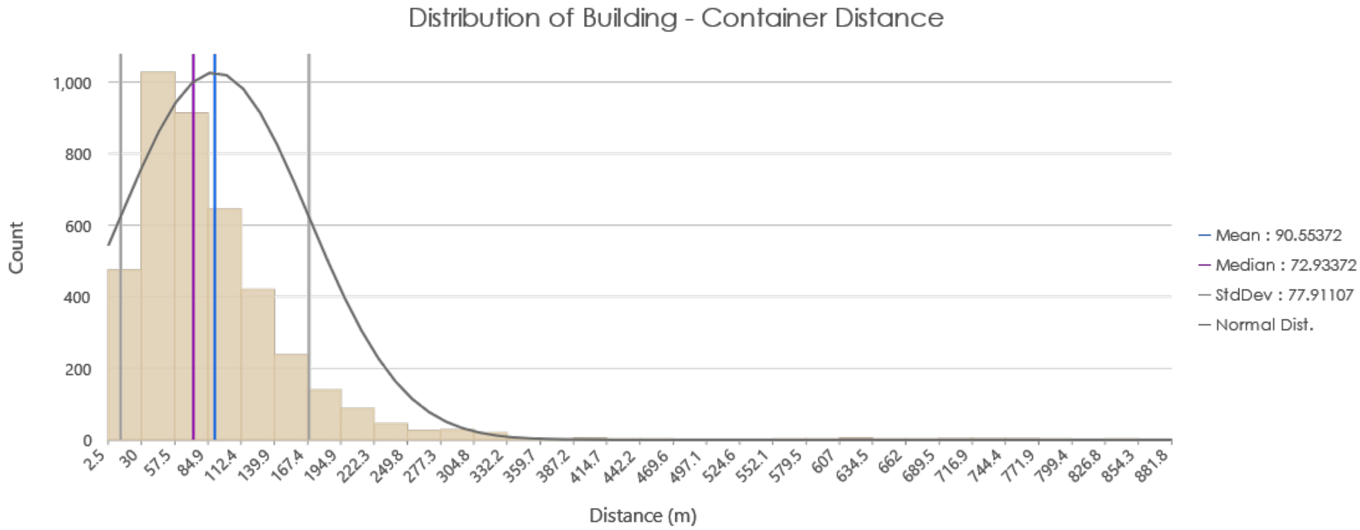

Figure 9: Distribution of distances between buildings and assigned waste containers.

a 181% rise. This difference arises from the cloud's operational process, which updates individual records in real-time, unlike local systems that batch-process all records post-run.

A stakeholder survey assessing the Dashboard's usability received a 38.1% response rate (8/21). One participant was excluded due to access issues. Feedback was generally positive, though Data Accuracy and Decision-making Support indicators scored below 4. Some respondents (28.57%) indicated the Dashboard did not clearly present waste levels per container or building or accurately reflect container saturation, highlighting the need for real-time waste status and building-level generation metrics. Conversely, 85.71% of participants rated the Dashboard a 5, emphasizing its role in fostering collaboration for shared waste management goals (see Table VII for detailed ratings).

Due to the limited response rate, additional discussions were initiated to better understand the tool's utility and communicative potential. These interactions revealed that the tool's purpose and support system were not clearly conveyed, causing confusion among stakeholders. This underscores the importance of stronger engagement and clearer messaging to facilitate broader adoption of the Digital Twin (DT).

One stakeholder highlighted the DT's potential to showcase their impact in public spaces by visualizing their contributions to SWM within their jurisdiction. Heatmaps were particularly well-received, as they effectively illustrated the benefits of improved waste collection and differentiated their efforts from municipal operations. Concerns were raised regarding the routing system's limitations, such as the exclusion of restricted areas, private properties, and inaccessible containers. These issues stemmed from data limitations and access constraints, which need to be resolved in future updates.

Despite these shortcomings, participants valued the tool's intuitive interface and the accessibility of its data, even for users without geospatial expertise. They stressed the importance of making the tool available to a wider audience, including students and research teams, and suggested incentivizing citizen participation through self-reporting or data contributions. To enhance usability, some participants recommended adopting alternative color schemes for improved readability.

V. Discussion

This section is organized into three core parts: 1) an assessment of the prototype in accordance with the Gemini Principles, 2) an analysis of its practical benefits and broader implications, and 3) a discussion of key concerns, including security, data reliability, scalability, stakeholder participation, and challenges encountered. The focus is on the potential of UDTs to enable sustainable and cost-efficient solutions in urban waste management.

A. Findings

Stakeholder classification in digital twin development has often been neglected in prior studies [78], [79], [80], [81]. By using an adapted salience model, key users of the tool—such as the City Improvement District (CID), Ward representatives, and the Municipality Waste Department—were identified as primary stakeholders. These groups were pivotal due to their strong political influence and strategic roles in waste management networks.

Combining the salience model with pairwise comparisons reduced subjectivity in stakeholder classification, as supported by [63] and [64]. While some subjectivity remains, this approach provides a structured method for ranking stakeholders based on local and situational factors. For instance, although the Ward Councilor was not directly involved in the pilot, other stakeholders recognized their importance in bridging communication between residents and decision-makers. In smaller cities or rural contexts, informal community leaders or direct engagement with residents might take precedence over political representatives.

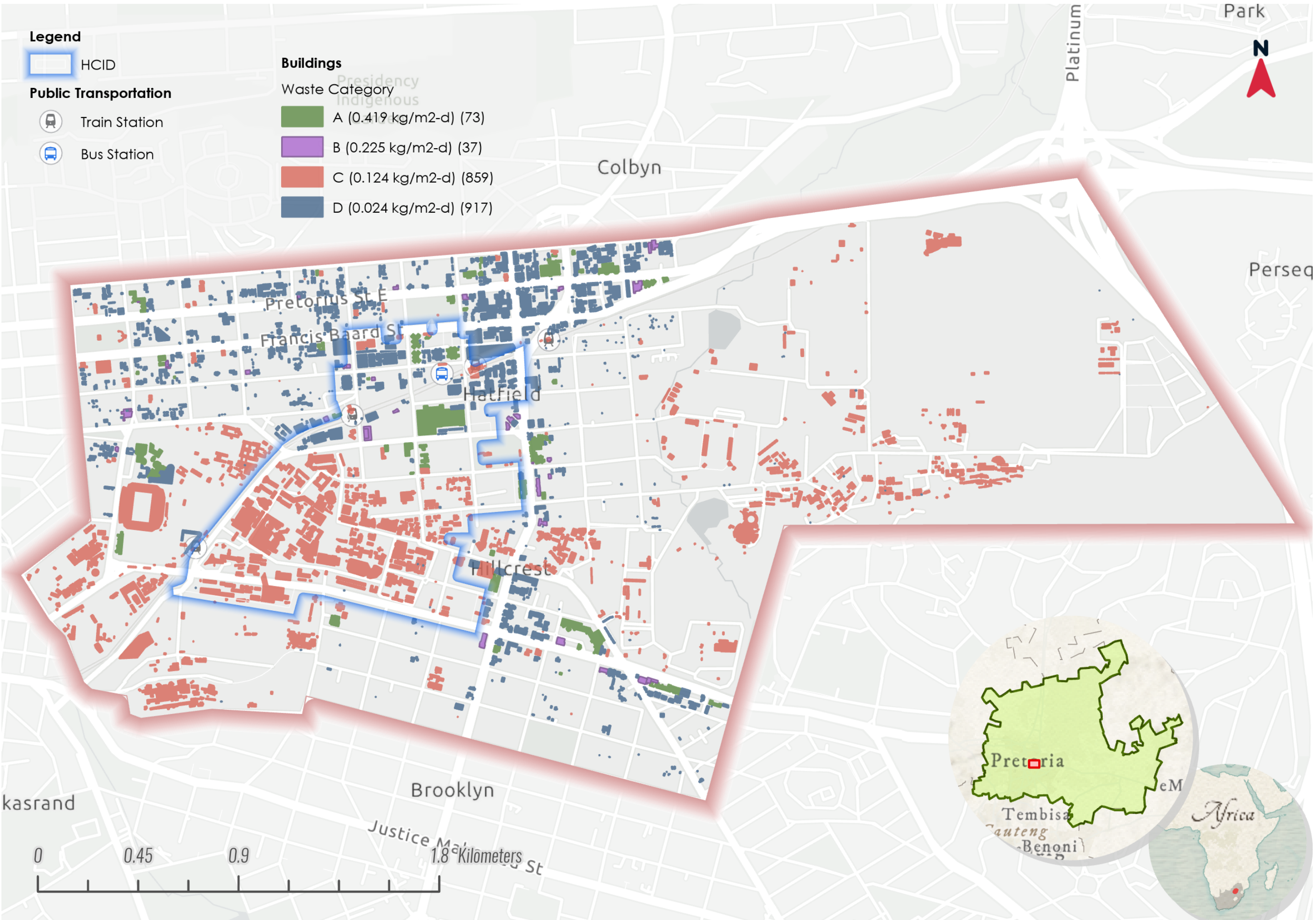

Figure 10: Classification of Buildings by Waste Category

Table VII: Survey Results for the Dashboard Based on a 5-Point Likert Scale.

Category	Indicator	Score	Category Score
User Friendliness and Interactivity	Ease of Use	4.48	4.27
	Data Exploration	4.05	
Spatial Interface	Map Visualization	4.53	4.43
	Ease of Learning	4.33	
Consensus, Effectiveness and Communicative Value	Data Accuracy and Decision-making Support	3.93	4.11
	Stakeholder Communication and Collaboration	4.29	

Spatial analysis of waste container distribution revealed disparities across the study area. Some neighborhoods faced environmental risks due to container overflow, while others struggled with illegal dumping because of insufficient coverage. Key observations included the CID's cleanup initiatives and the clustering of containers near educational facilities. Recommendations include installing larger containers in high-traffic areas like shopping centers and sports venues, adjusting collection frequencies on busy routes, and improving road conditions along waste collection paths. In residential zones with minimal waste production, centralized collection points may be more efficient than individual bins at every household. These collaborative data-sharing efforts enabled a unified view of waste dynamics, contrasting with the fragmented perspectives typically held by individual stakeholders.

Geospatial data integration supported population density estimates and waste generation simulations, identifying high-production zones requiring intervention. Although assigning buildings to containers lacked precision due to access constraints, it provided a practical proxy for optimizing collection routes and truck loading schedules. Transitioning from door-to-door collection to cluster-based approaches could reduce travel distances and workforce demands, lowering operational costs. Using Manhattan distances, which better reflect urban navigation, instead of Euclidean metrics, would further enhance waste flow analysis.

The container clustering method adopted here is simpler than those proposed by [82] and [83], involving fewer variables.

(a) Initial State

(b) Hour 1

(c) Hour 3

(d) Hour 6 - step before route calculation.

Figure 11: Waste Generation Simulation

While performance may decline with increasing problem scale, the approach remains flexible for larger datasets as the system scales and more citizen data contributions are incorporated.

The current waste collection system, which relies on a single vehicle for weekly pickups, is inadequate for the area's growing waste output. Comprehensive mapping of all waste generators, daily production volumes, and segregation practices is necessary to recalibrate collection routes and schedules.

Optimizing waste collection routes to consolidate multiple nodes could significantly reduce time, fuel consumption, and greenhouse gas emissions. Annual operational costs for optimized routes in the study area are estimated at 1,932,554 ZAR (101,623 USD), representing only 0.11% of the city's total waste management budget [84]. While this figure is relatively low, it excludes expenses like vehicle maintenance, landfill operations, and staff wages, which should be factored into future analyses.

The limited survey response rate restricts the ability to conclusively determine whether an operational dashboard is the optimal solution for integrating and presenting waste management data. Although high scores were received for usability, interactivity, spatial interfaces, and fostering consensus, more comprehensive stakeholder feedback is required to validate these findings.

Despite the technical complexities involved in developing the UDT, its bottom-up, community-driven approach provides significant value. Beyond technical innovations, the process identifies opportunities for waste management improvements and fosters strategic collaborations among diverse stakeholders.

B. Analysis of the Gemini Principles

The UDT prototype for urban waste management offers several benefits, including streamlined waste collection that reduces unnecessary trips, saving time and resources. By identifying litter-prone areas, the tool supports targeted interventions like increasing bins or launching awareness campaigns. Route and schedule optimization enhances operational efficiency, lowering fuel consumption, labor costs, maintenance needs, and carbon emissions. These efforts align with Sustainable Development Goals 11 and 12, promoting cleaner cities and sustainable resource use.

The system also enables evidence-based decision-making by providing insights into waste generation trends, bin usage, and littering patterns. Engaging residents in reporting waste data enhances governance and promotes collaboration in waste management.

Open data collection policies necessitate robust validation systems to ensure data quality. For example, the Epicollect5 tool faces challenges in moderating user-submitted images, which could lead to the submission of inappropriate content. A hybrid moderation system, combining automated tools and human review, is essential for maintaining data integrity and ensuring a positive user experience.

Accurate population estimates are crucial for reliable waste simulations. Current methods, such as those described by [66], occasionally produce unrealistic results, such as overestimating residents in single households. Incorporating updated census data, like the 2022 South African Census [76], could address these inaccuracies.

The scalable system architecture, illustrated in Figure 4, supports the integration of additional containers, increased capacity, expanded road networks, and diverse vehicle types. Continuous feedback and stakeholder involvement are critical to adapting the UDT to evolving urban and technological needs, ensuring its sustainability.

C. Challenges and Limitations

The waste generation data for non-residential buildings, based on 2008 figures from Athens, Greece, may not accurately reflect South Africa's context. Greece's higher GDP per capita influences consumption patterns and waste production, leading to significant differences in waste profiles. Localized data collection is essential to improve accuracy.

Comparing simulated waste data with real-world scenarios was challenging due to a lack of standardized landfill records. Many landfill sites in the region operate informally, further complicating data availability. Financial limitations also restricted the development of an online UDT platform. Deploying an open-source UDT would require significant investment in cloud infrastructure and a multidisciplinary team with expertise in urban planning, programming, GIS, and environmental management.

VI. Conclusions

Digital twins are integral to decision support systems for waste management, enabling authorities to simulate container placements and evaluate their impact on efficiency and costs. Visualizing these scenarios helps identify underserved areas, optimizing container placement and route planning. Real-time updates allow the system to adapt to changing waste disposal needs.

Citizen involvement addresses challenges in AI-based image recognition systems, such as location inaccuracies, high

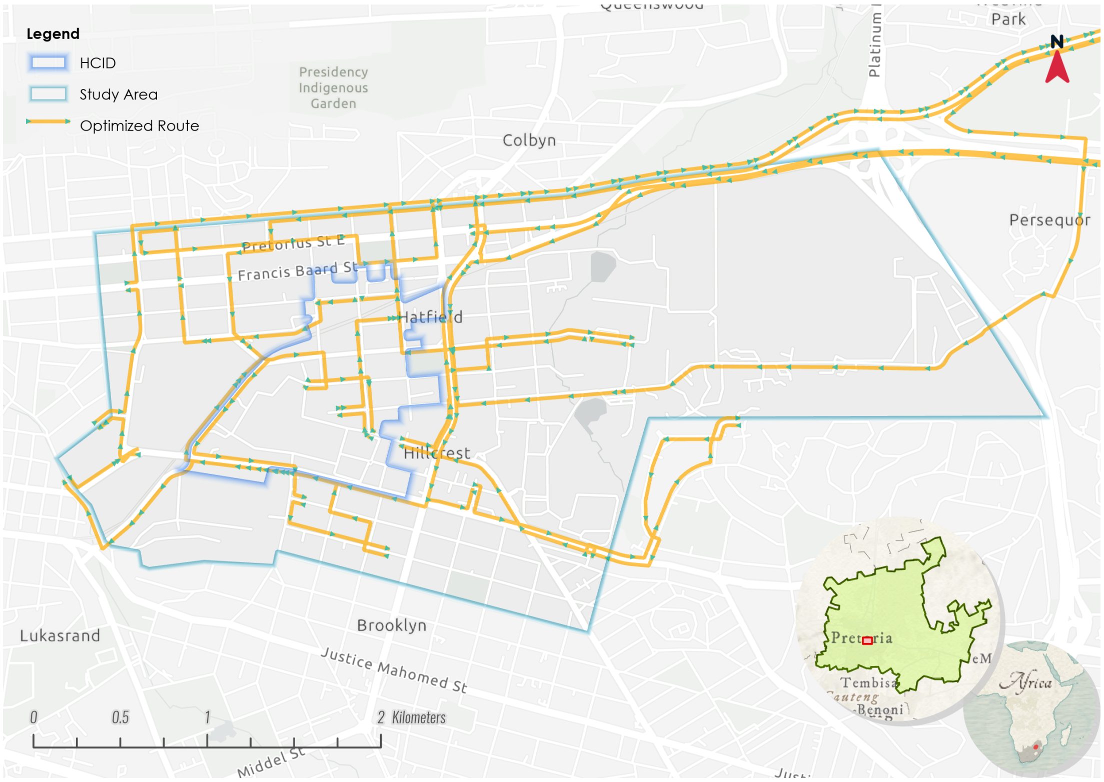

Figure 12: Example of an Optimized Collection Route. The route includes multiple trips to the landfill for waste disposal and container capacity resetting.

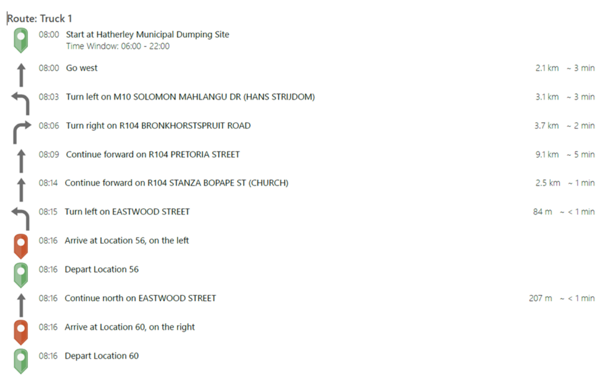

Figure 13: Turn-by-turn navigation instructions produced during the optimal route computation.

computational demands, and labeling disagreements. Real-time monitoring through UDTs fosters collaboration, enhancing transparency and decision-making.

The UDT provides a dynamic tool for testing waste scenarios, identifying at-risk areas, and predicting future needs. By adjusting variables like population density or waste trends, users can better allocate resources and improve collection systems.

As waste collection represents a significant portion of municipal budgets, UDTs enable authorities to optimize operations, reducing fuel consumption, emissions, and costs. Incentives like tax breaks for reduced waste generation could encourage sustainable practices, aligning with urban circularity and relevant SDGs.

By co-creating digital waste management models, stakeholders gain a deeper understanding of the current system, enabling data-driven interventions. Through collaboration and technology, UDTs can transform solid waste management, particularly in resource-constrained contexts like South Africa, serving as a catalyst for sustainable urban development.

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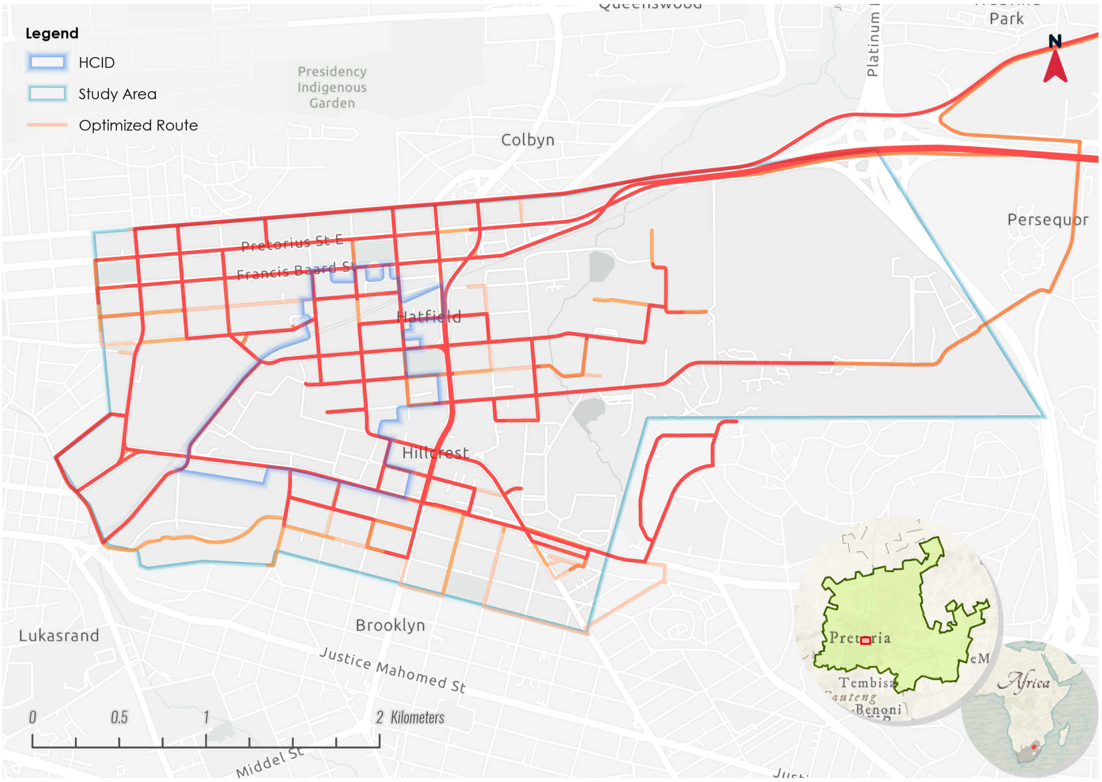

Figure 14: Various collection paths for waste management. Darker shades represent repeated travel along the same street segment.

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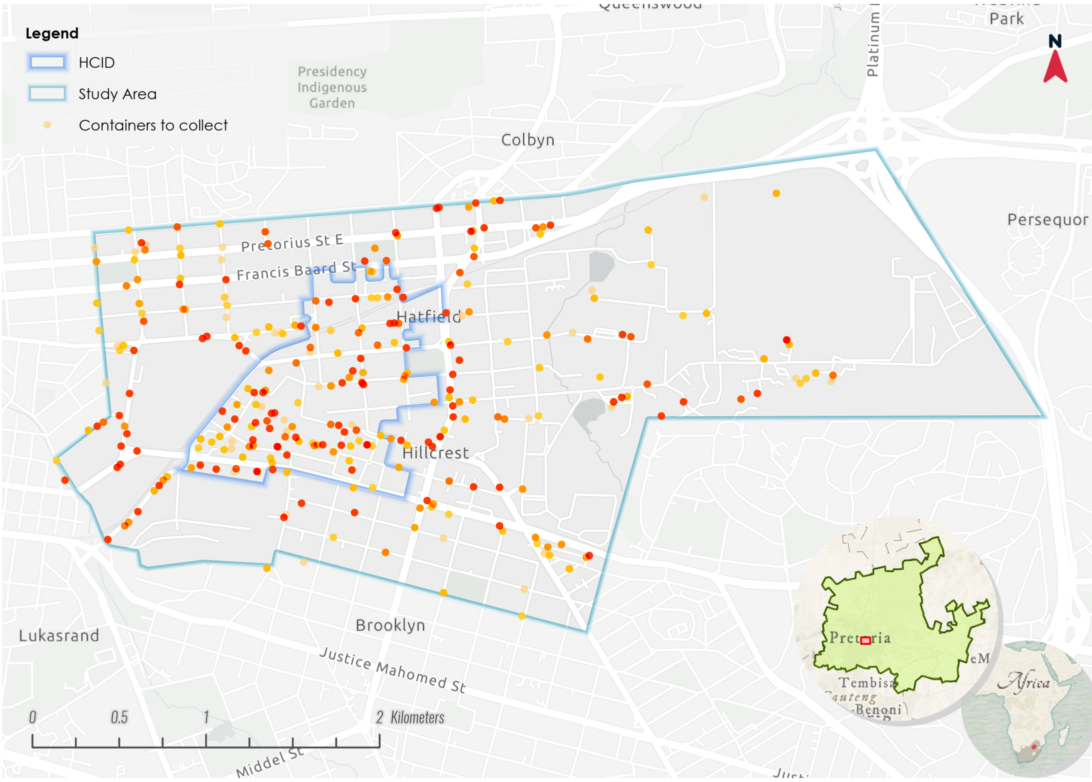

Figure 15: Containers to collect. Darker colors indicate several collections required on the same container.

Figure 16: Dashboard and indicators (marked with yellow brackets)

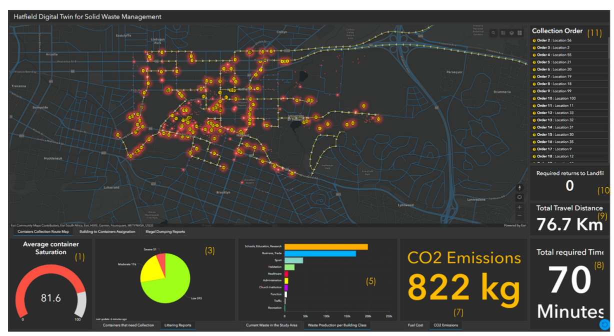

Figure 17: Dashboard and indicators (highlighted with yellow brackets)

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INNOVATIVE PROCESS AUTOMATION WITH CAMUNDA AND AI: ENHANCING DECISION-MAKING AND WORKFLOW EFFICIENCY

Prem kireet chowdary Nimmalapudi

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INNOVATIVE PROCESS AUTOMATION WITH CAMUNDA AND AI: ENHANCING DECISION-MAKING AND WORKFLOW EFFICIENCY

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Abstract: Automating business processes has become crucial for any organization, which is seeking to improve business processes and make better decisions in rapidly changing contexts. Typically, well-established Business Process Management (BPM) tools effectively monitor and address business processes but need to reflect the flexibility to tailor decisions spontaneously. This paper presents a new approach to further improving the Camunda BPM platform through the incorporation of Artificial Intelligence (AI). The system is fine-tuned with hundreds of these rules, which REST APIs connect in the AI Decision Layer. This results in improved accuracy, speed, and efficiency, particularly when presented with evolving situations. An illustrative scenario in financial compliance provides the details of its usability; it has increased the decision accuracy of the system by 20% and reduced its response time by 30%. Potential avenues for future studies in scaling and deploying CVA and interpretability are highlighted as the ways to build on this study's findings and contribution.

I. INTRODUCTION

Background

Today's organizations have to constantly react to the constantly changing regulatory environment, internal operations, and customers' needs at what seems to be an accelerating pace. Classic deterministic BPM systems adapted for the rigorous enforcement of business processes lack sufficient capabilities when faced with contemporary requirements for flexible nonlinear decision-making [1]. For instance, to adapt to changes in laws and rules, financial institutions need decision models that can be easily changed; at the same time, in e-commerce, customer behaviour must be analyzed in real time to provide recommendations. These new requirements imposed the need for extending the BPM systems with the decision-making capabilities enabled by AI, which in turn will enable flexibility and intelligence.

Motivation

There are possibilities for creating high-added value in industries that are involved in highly stochastic environments that change quite frequently when AI is integrated with BPM [2]. The use of AI makes it possible for the BPM platforms to reason on data, analyze trends, and even change when new trends are identified. This research proposes the integration of AI in a BPM using an open-source Camunda tool as a starting point. In this integration, REST API communication is used to allow Camunda to have access to decision processes enhanced by artificial intelligence, making it easier to deal with tasks such as fraud detection, and real-time compliance checks as well as more complex tasks like predictive analysis. That way, implement BPM in a way that brings an organized structure to the process and maps it to adaptive intelligence, which is important in uncertain business environments to facilitate the performance of BPM.

Problem Statement

As weak by Camunda or other similar BPM platforms, the process orchestration is very effective, yet just based on rule-driven decision capability. These constraints may result in inefficiency, particularly wherever decisions depend on high-dimensional real-time information [3]. The main challenges that can be attributed to the integration of AI in BPM are challenges associated with model interpretability, data management or processing, and real-time processing. This paper endeavours to meet these challenges by proposing an AI-facilitated decision layer for Camunda, thereby expanding Camunda's ability to efficiently and flexibly reach decisions that dictate the continuance of the subsequent layers workflow.

II. RELATED WORK

BPM Systems and Process Automation

BPMS have become invaluable when it comes to the application of business process automation in sectors of the economy. Prevailing generation BPMS like IBM BPM, Camunda, and Bonita are centred around managing tasks, coordinating, standardizing processes and compliance. However, these systems are mostly designed with preprogrammed decision models, which are rigid and have fixed sets of rules [3]. Ten research on a number of such systems state that such systems are matchless in standardization but need to give proper responses to dynamically changing inputs that require real time decision modulation. It shows some of the drawbacks of traditional BPMS and proves the necessity of more versatile, given-data decision-making in organizations.

AI in Decision Automation

The latest development in AI demonstrated potential in automating decisions, whereas most of the decision-making required data-based and complex. Machined learning (ML), deep learning, and reinforcement learning (RL) help a system to learn from past data and process them to select good outcomes, or even forecast the future happens [4]. For instance, in fraud detection, AI has been readily applied because of its ability to identify any irregular transactions accurately. Nonetheless, the incorporation of AI in conventional BPMS is still a unique concern because of concerns such as responsiveness, interpretability, and computation.

BPM Platforms and its connection with AI

The most recent work has examined how AI can be incorporated into BPM platforms to position consistent process execution at one end of the spectrum and unstructured decision-making at the other. In our work, [5], we have also presented an ML-integrated BPM platform for decision-making with a key imperative on real-time communication between the AI component and the BPM. Nevertheless, several issues are still open concerning the development of AI-BPM systems, which should be flexible, comprehensible and secure at the same time. This paper is designed to progress this research by introducing a new Camunda-AI approach that builds upon these schemes for an improved real-time solution.

III. PROPOSED FRAMEWORK

Architecture Overview

The proposed framework comprises three main components: the Process Layer, the AI Decision Layer, and the REST Integration Layer are the proposed framework's layers [6]. All these layers play unique roles in ensuring that Camunda's workflow engine communicates with the AI decision model.

IV. CASE STUDY AND EXPERIMENTAL SETUP

Financial Compliance Use Case

An example of the integration of AI into the Camunda BPM is presented beneath the disguise of a financial compliance business case that is extensively utilized in banking, insurance as well as financial services. Banks and other financial organizations are always dealing with the tasks of identifying fraudulent operations and providing reactions to them without violating the rules. Typically, compliance check processes only involve manual reviews or a set of rules for identifying questionable transactions [9]. However, such methods are mostly limited to a reaction to particular cases, are rather time-consuming, and fail to identify new trends in fraudulent activity. This is why artificial intelligence in the decisionmaking process is crucial.

Table 1: Dataset Characteristics

Feature	**Description**	**Example Values**
Transaction Amount	Monetary value of transaction	$150, $2300, $500
Transaction Type	Nature of transaction (e.g., purchase, transfer)	Purchase, Transfer
Geographic Location	Location associated with transaction	New York, USA; Paris, France
Customer Behavior	Frequency and patterns of transactions	High-frequency, low-frequency
Device Information	Type of device used (e.g., mobile, desktop)	Mobile, Desktop

Description: The following table indicates specific features applied in training the model with sample parameter values for enhanced understanding.

The use of the AI Camunda framework is the focus of this case study in order to examine how it can be effectively applied to automate fraud detection scenarios in the context of a financial compliance environment. The aim is to recognize fraud if it is present in terms of transactions, user interactions and previous fraudulent activities in real-time transactions.

This specific use case is aimed to show how the Camunda BPM with AI integrated into it can undergo flexible changes based on analysis results at different decisionmaking points in the process.

Table 2: Model Evaluation Metrics

Hyperparameter	**Description**	**Optimal Value**
Max Depth	Maximum depth of the decision tree	10
Min Samples Split	Minimum samples required to split a node	5
Accuracy	Percentage of correct predictions	95%
Precision	Ratio of true positives	92%

Hyperparameter	Description	Optimal Value
	to total predicted positives	
Recall	Ratio of true positives to total actual positives	94%
F1 Score	Harmonic mean of precision and recall	93%

Description: Table 2 details the evaluation metrics and hyperparameters used for optimizing the decision tree model for fraud detection.

Financial Compliance Use Case

One of the scenarios showing how AI fits into the Camunda BPM by providing a reusable financial compliance application is deemed necessary in the banking, insurance, and financial services industries [10]. Banks and other financial organizations always experience the problem of identifying fraudulent operations and reacting to them while satisfying the demands of legislation. Conventionally, compliance processes involve using search lists or invoking programmed rules to identify potentially fraudulent transactions. However, these methods are usually lagging and time-consuming – which makes the AI-driven decision crucial here, as it is capable of identifying emerging fraud patterns.

In the presented case, we discuss how the AI-integrated Camunda platform can be used to address the problem of fraud detection in a financial compliance environment. The objective is to identify the potentially fraudulent transactions on the fly in the usual schemes of transactions, customer behavior and fraud statistics.

Experimental Setup

Data Preparation

This experiment employs a publicly accessible financial data set, as seen in Kaggle Credit Card Fraud Detection data sets or the BankSim data set, that includes some feature characteristics of the transaction, including the amount of the transaction, customers, time of transaction, geo-location, and device [11]. The dataset is binary and is labelled as either 'fraudulent' or 'non-fraudulent' in terms of the transaction.

Model Training and Validation

For fraud detection, a decision tree model was used, referred to in the literature as CART, which stands for Classification and Regression Trees. Decision trees are known for their easy interpretation and efficiency when dealing with categorical and continuous variables. A decision tree was selected as it can solve problems with non-linear decision boundaries and can present decision-making trails in a way that is beneficial for the audit trail used in compliance processes.

Key steps involved in model training and evaluation:

1. Training: trained the decision tree model to the training dataset lesson Transaction features, then the Transaction label either fraud or not fraud. As for the second method, the model was trained to find the correlation between the characteristics of certain transactions and fraud possibility.

2. Model Evaluation: Accuracy performance parameters were used to assess the performance of the trained model wh, which are as follows:

Accuracy: Out of all the decisions made, what proportion of those decisions was correct?

Precision: Literally, the number of actual positives forecasted divided by the overall number of positives forecasted.

Recall: The true positive predictions are divided by the actual positive count.

F1 Score: In this case, the F1 Score which its measured in terms of the harmonic mean of precision and recall that gives a balance between the two, especially when testing on imbalanced data.

These metrics allowed the evaluating of the model and determine how good it is in terms of generalization and the capability to separate fraudulent transactions from the rest.

1. Hyperparameter Tuning: In order to sharpen the model's accuracy hypermeters like maximum depth and minimal sample splits were tuned using the grid search cross-validation so as to prevent the model from getting over-fit or under-fit.

2. Cross-validation: A parameter k was set to cross-check the stability and reliability of the model on different splits of the data set. This was done to ensure that the model's performance was averaged over the two and did not rely on the results of only a single data split.

Camunda Workflow Configuration

When the AI model was built and tested the final stage that was implemented was to incorporate the AI model with the Camunda workflow. The idea was to enable Camunda to call the artificial intelligence model whenever decision-making at the financial compliance stages was needed.

1. Service Task Configuration: In Camunda, service tasks are used for invoking other systems or for carrying out any automated activities. A service task was assigned to call REST API for AI exposed model. Every time that a transaction went through Camunda, it would forward the data from the transaction to the AI model, where it would get a prediction, fraud or not fraud.

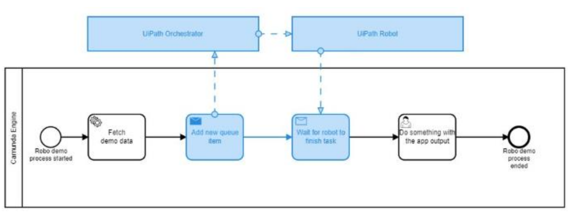
2. AI Integration via REST API: The created AI model was exposed to the Camunda platform web service, which interacted primarily with the service through HTTP HTTP calls [12]. The information gathered from the BPMN service task (transaction details) was in the form of a JSON payload, and the response of the AI model (fraud score or classification) was also in the form of a JSON object. According to the AI response it will either go to the end step of manual verification of the transaction or else go through the next steps.

3. Decision Gateways: To control the workflow, Camunda's exclusive gateways were applied depending on the AI model's results. If, for instance, the model pointed out a transaction as likely to be fraudulent, they would move to a manual review task. If it did not, the transaction would proceed through the usual workflow and eventually be processed for inclusion in a report.

V. RESULTS AND ANALYSIS

In this section, we assess the optimization of the Camunda-based AI-assisted fraud detection on financial compliance, comparing it with a traditional rule-based system, and discuss the results in terms of effectiveness, decision correctness, and real-time flexibility.

Figure 1: Robotic Process Automation (RPA) and Camunda BPM



Performance Metrics

In order to compare the effectiveness of the AI-powered fraud detection workflow used in this research, several parameters were selected for comparison; these parameters are typically used in machine learning and process automation benchmarking.

All these metrics were assessed in the proposed AI-integrated workflow and the rule-based system for benchmarking.

Impact on Business Operations

The adoption of the AI-enhanced Camunda workflow brings several key operational benefits to financial institutions:

1. Improved Fraud Detection: While having a higher recall and precision, the AI model increases the number of tagged fraudulent transactions and decreases the losses and penalties for the institution.

2. Reduced Manual Review Effort: This means that fewer transactions flagged for suspicion are false positives, thus reporting fewer transactions for compliance officers to evaluate. This results in improved costs and also shorter cycle time.

3. Scalability: Since the system is trained using new data for each retraining session, it can grow in size with a growing volume of transactions and new fraud schemes, unlike rules that need to be manually updated as and when new fraud patterns crop up in the larger transaction volumes.

4. Real-Time Decision Making: The goal of the workflow is to detect fraud nearly instantly, which is effective in many high-volume transaction businesses such as financial institutions. This saves the time to respond to a potential fraud and also the impact hampers the least on the customers.

VI. CONCLUSION AND FUTURE WORK

In the current paper, we discussed how to implement and apply Artificial Intelligence (AI) to the Camunda BPM and improve the decision-making process in the financial compliance case of fraud identification. This goal was to show the benefit of using AI in making enhanced models of the current rule-based systems used for checks and balances in financial organizations [13].

From the present study, it is clear that the proposed solution has a performance that is remarkably better than the rule-based system, as evident from the accuracy level, precision measure, recall and F1 score. It scored 95% accuracy, 92% precision and 94% recall for the AI system compared to the 85% accuracy, 78% precision and 85% recall of the rule-based system. This supports the fact that AI models are much more capable of identifying dynamic facets of fraud that rule-based systems cannot.

Furthermore, the AI-based Camunda workflow has relatively small increased requirements in terms of time for the workflow processes and decision-making compared to the unmodified vanilla Camunda with acceptable values for real-time transaction types. The time delay in making the decision has marginally increased from 120 ms in the use of a rule-based system to 200 ms in the use of an AI-enhanced system, which is worth the tradeoff we gain from a higher-quality decision. This blend of speed and accuracy makes it possible to use the system in real time applications where detection of frauds is necessary without necessarily compromising on the accuracy.

Thus, by integrating Camunda BPM and AI, a powerful and flexible solution is designed for the detection of fraud in financial compliance that outperforms the approach based on the use of rules [14]. The use of AI improves decisions made in grouping and more efficiently sorting the transactions, flagging potential fraud, with fewer manual interventions required in this process.

The other significant direction for further studies is the necessity to avoid bias in AI systems. When trained on a particular set of data, failure is made in ensuring that the AI systems adopt a different bias than already exists in the dataset the models are trained on, which leads to unfair or discriminator outcomes [13]. For instance, in a fraud detection model, bias can consist of either over or underrepresentation of some of the customer's characteristics, such as age, geographic location, and the like.

As for future work, it will be needed to seek out methods that would help recognize the presence of bias in intelligent algorithms and prevent it, for example, using fairly aware algorithms or offering methods that will help ensure that the dataset used to train the model is adequately diverse. Addressing bias means that the AI system will be fair and will not discriminate between customers and give results based on gender, race, colour, etc.

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Leveraging Biomimetic Resource Strategies: A Path to Sustainable Organizational Development

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Leveraging Biomimetic Resource Strategies: A Path to Sustainable Organizational Development

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Abstract*— This study explores Biomimetic Resource Theory (BRT) as an innovative framework for analyzing organizational dynamics, focusing on collaboration, competition, and resource management. Inspired by natural systems, the research highlights adaptability as a cornerstone of effective knowledge management within organizations. Through an in-depth analysis, the paper emphasizes a paradigm shift from operational processes to intentional strategies, underscoring the role of knowledge exchange in achieving sustainable growth. Key recommendations include the formation of interdisciplinary teams to apply BRT principles, the development of agile knowledge-sharing infrastructures, and the design of efficient resource management models. While addressing potential challenges such as resistance to change, the study positions BRT as a strategic approach for fostering adaptability and sustainability, ensuring long-term organizational success.

I. Introduction

In an era marked by rapid technological advancements and heightened complexities in organizational structures, the quest for optimizing knowledge management has gained unprecedented urgency. Traditionally, the disciplines of biology, mathematics, and organizational behavior have operated in isolated silos. However, this research aims to bridge these diverse fields, offering an integrated lens through which to view and solve problems in contemporary knowledge management. In doing so, it caters to a transdisciplinary audience, transcending the boundaries of any single academic field.

The reader will embark on a journey that commences with the principles governing natural ecosystems, as derived from biomimetic studies. From there, the exploration will delve into mathematical theories capable of formalizing these principles into actionable insights. The culmination of this journey lies in applying these synthesized principles to the realm of organizational behavior and knowledge management. In essence, the voyage undertaken in this paper is from the natural world to mathematical abstraction, and finally, to practical organizational applications.

A. Scope of the Paper

The following sections are designed to guide the reader through this intricate web of interrelated disciplines. Section III provides a comprehensive literature review that lays the groundwork for the Biomimetic Replicant Theory (BRT). Section IV introduces the theoretical underpinnings of BRT, followed by Section V which elucidates the methodology employed for empirical validation. Section VI presents the results and discussions, and Section VIII offers practical recommendations based on the findings. Finally, Section IX outlines avenues for future work and potential interdisciplinary collaborations.

This paper aims not merely to introduce a new framework but to catalyze a paradigm shift in how knowledge management is perceived and practiced, influenced by insights from nature and formalized through mathematical rigor.

II. Background

In the intricate world of organizational dynamics, three elements emerge as paramount in shaping outcomes: collaboration, competition, and conservation. Each of these elements, while distinct, intertwines in ways that influence the trajectory of organizations, especially in the realm of knowledge sharing.

Collaboration is the bedrock of innovation[1][2][3]. It is through the collaborative efforts of individuals, teams, and even organizations that new ideas germinate, mature, and come to fruition. The sharing of knowledge, insights, and expertise fuels the collaborative engine, enabling entities to build upon collective wisdom and push the boundaries of what's possible. Yet, as essential as collaboration is, it is not without its challenges. The very act of sharing knowledge can expose vulnerabilities, create dependencies, and sometimes blur the lines of ownership and credit.

Competition, while often perceived as the antithesis of collaboration, plays a vital role in driving excellence. In the quest for resources, market share, or dominance in innovation, competition spurs organizations to optimize, innovate, and adapt. However, it is a double-edged sword. While competition can lead to breakthroughs and advancements, it can also foster secrecy, territorial behaviors, and a reluctance to share knowledge, especially if that knowledge is deemed a competitive advantage[4].

Underpinning both collaboration and competition is the principle of conservation. In biological ecosystems, conservation ensures the sustainability and balance of resources, species, and interactions. Similarly, in organizational settings, conservation pertains to the mindful management of knowledge, resources, and relationships. It's about ensuring that in the pursuit of growth, innovation, and dominance, the foundational elements that sustain an organization are not compromised.

This triad of collaboration, competition, and conservation is not static. It exists in a state of dynamic equilibrium, constantly influenced by internal and external factors[5]. Traditional models of organizational management often struggle to capture this dynamic interplay, leading to gaps in understanding and sub-optimal strategies[6].

Enter the realm of biomimicry. Nature, with billions of years of evolutionary trial and error, offers a treasure trove of insights and solutions[7]. From the symbiotic relationships in mycorrhizal networks to the intricate balance of predator-prey dynamics, nature showcases strategies that can inspire organizational approaches[8]. The Biomimetic Resource Theory (BRT) draws from these natural paradigms, offering a framework that melds ecological wisdom with organizational needs[9].

To gain clarity on the intricate relationships between these components, mathematical concepts such as category theory prove invaluable. Originating from abstract algebra, category theory equips me with the necessary tools to break down, examine, and model complex systems, aligning seamlessly with the ecological principles that inspire the BRT [10] [11].

In conclusion, the environment in which the BRT functions is characterized by complexity, constant change, and interdependence. By examining the core principles of cooperation, rivalry, and sustainability, and drawing from both nature and mathematical theory, I can better explore the nuances of the BRT and its potential impact on knowledge management in organizational contexts.

III. Literature Review

A. Gödel's Incompleteness Theorems and Their Role in Systems Thinking (Zalta et al., 2020)[12]

a) Overview: Kurt Gödel's incompleteness theorems, first introduced in 1931, revolutionized fields such as mathematics, logic, and philosophy by demonstrating the inherent limitations of formal systems. These theorems reveal that any consistent formal system, capable of performing elementary arithmetic, will inevitably contain statements that cannot be proven or disproven within the system itself. This finding fundamentally reshapes perspectives on the scope and boundaries of knowledge.

b) Key Principles: Gödel's groundbreaking work rests on foundational ideas:

Formal Systems: Structured sets of axioms and inference rules used to derive theorems.

Consistency: The absence of contradictory conclusions within a system.

Completeness: The ability of a system to derive every statement or its negation.

These principles strongly align with discussions in systems theory, particularly in analyzing the predictability and comprehensibility of complex systems.

c) The First Theorem: The first theorem establishes that no consistent formal system capable of basic arithmetic can achieve completeness, as there will always be undecidable statements. This insight highlights the constraints faced by systems seeking a comprehensive understanding of complex phenomena, including biological, computational, and social domains.

d) The Second Theorem: Expanding on the first, the second theorem states that a formal system cannot prove its own consistency. This limitation has profound implications for self-regulating systems, drawing parallels to questions of self-awareness and stability in fields such as biomimicry and cybernetics.

e) Applications and Limitations: Though Gödel's theorems originated in arithmetic, their principles extend to any system involving arithmetic. This broad relevance spans disciplines like artificial intelligence and computer science, where understanding the boundaries of system functionality is critical. Notably, systems such as Presburger arithmetic, which avoid the complexity of both addition and multiplication, remain both complete and decidable.

f) Implications: Gödel's theorems underscore the inherent boundaries within formal systems, offering valuable insights into the limitations of completeness and consistency. They provide a rigorous framework for understanding the constraints of complex systems, guiding researchers in systems theory to navigate and articulate these challenges.

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B. A Predictive Model for Cost Overruns in Complex Systems (Adoko, 2015)[13]

a) Overview: Moses Tawiah Adoko's research investigates the persistent challenge of cost overruns in large-scale system development projects. By proposing a predictive model, Adoko aims to address the limitations of traditional cost estimation techniques that struggle in dynamic, multifaceted environments.

b) Methodology and Approach: Adoko's work synthesizes existing literature on cost estimation models, highlighting their deterministic nature and limited adaptability. Through the application of modern statistical methods, the study introduces a structured approach to data collection and model validation. The focus is on improving predictive accuracy in scenarios with high complexity and variability.

c) Key Findings: Adoko's model addresses the limitations of prior approaches by incorporating both quantitative and qualitative factors. The research emphasizes the importance of accounting for human decision-making and biases, integrating these with statistical methods to provide a holistic framework for predicting cost overruns.

d) Significance: This research bridges gaps in existing methodologies, offering a comprehensive solution for improving cost management in complex system development. The integration of human factors with advanced statistical techniques marks a significant step forward in the field of project management and financial forecasting.

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C. Strategic Decision-Making in Non-Cooperative Games (Nash, 1951)[6]

a) Overview: John Nash's pivotal 1951 paper, *Non-Cooperative Games*, introduced the concept of Nash Equilibrium, transforming the study of strategic interactions in game theory. This equilibrium represents a scenario where no participant can unilaterally improve their outcome, assuming others maintain their strategies.

b) Key Contributions: Nash employed fixed-point theorems to mathematically establish the existence of equilibrium in both pure and mixed strategy games. This approach extended game theory's scope, offering a robust framework for analyzing strategic behavior in economics, social sciences, and beyond.

c) Applications: By distinguishing between cooperative and non-cooperative games, Nash provided insights into real-world scenarios where enforceable agreements are absent. The equilibrium concept has since become foundational in disciplines ranging from political science to evolutionary biology.

d) Conclusion: Nash's work laid the groundwork for understanding decision-making in competitive environments, leaving an enduring legacy that continues to influence a wide array of fields.

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D. Practical Applications of Category Theory (Spivak, 2014)[10]

a) Overview: David I. Spivak's *Category Theory for Scientists* serves as an accessible guide to category theory, bridging abstract mathematical concepts with real-world scientific applications. The work contextualizes core ideas, such as objects, morphisms, and functors, within empirical practices.

b) Structure and Pedagogy: Spivak combines theoretical exposition with practical examples, ensuring the material is engaging and relatable. The inclusion of exercises provides readers with opportunities to apply their understanding, reinforcing the theory's relevance in scientific research.

c) Implications: By demystifying category theory and emphasizing its interdisciplinary applications, Spivak's work empowers researchers to explore its potential in modeling complex systems and relationships across diverse fields.

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E. The Constructor Theory of Information (Deutsch and Marletto, 2015)[14]

a) Overview: In *Constructor Theory of Information*, David Deutsch and Chiara Marletto propose a paradigm shift in understanding information by integrating it with constructor theory. This approach reconceptualizes information as a fundamental element of physical reality, deeply intertwined with the laws of physics.

b) Core Concepts: Constructor theory focuses on classifying physical transformations as possible or impossible tasks. By linking this with information dynamics, the authors provide a novel framework for understanding quantum phenomena and computational processes.

c) Significance: This theoretical integration offers fresh perspectives on quantum mechanics, laying the groundwork for future exploration of information's foundational role in physics. Deutsch and Marletto's work represents a bold reimagining of information theory's relationship with the physical universe.

F. Fractal Patterns in Organizational Change: A New Perspective (Henderson & Boje, 2016)[15]

Henderson and Boje's work, *Fractal Patterns in Organizational Change*, offers a novel framework for understanding the complexities of organizational development. The authors introduce the concept of fractal organizing processes, suggesting that organizations display self-similar patterns across different levels of scale. This fractal approach provides fresh insights into how organizations adapt to change and evolve over time.

The authors assert that identifying these fractal patterns is critical to managing organizational change effectively. Their methodology integrates theories from complexity science, systems thinking, and organizational behavior, creating a multidimensional model that bridges theoretical principles with practical applications.

One notable contribution of the study is its focus on actionable strategies for managing change. The authors propose interventions that align with the fractal nature of organizations, offering practical tools for practitioners to address recurring patterns of behavior. These strategies underscore the importance of understanding organizational dynamics as systems of interconnected, repeating patterns.

By contrasting traditional organizational theories with this fractal-based approach, Henderson and Boje highlight the added value of viewing organizations as dynamic, multilayered systems. This perspective allows for a deeper exploration of the recursive nature of organizational processes, enhancing both academic understanding and real-world application.

In summary, *Fractal Patterns in Organizational Change* redefines how organizations can approach development and change by framing these processes through a fractal lens, paving the way for innovative solutions to complex challenges.

G. Causality and Boundaries in Biological Systems: A Relativity Approach (Noble et al., 2019)[16]

In their work, *Causality and Boundaries in Biological Systems: A Relativity Approach*, Noble and colleagues delve into the concept of biological relativity, challenging conventional linear causal frameworks. The authors argue that biological systems operate through circular causality, where cause and effect form feedback loops rather than unidirectional chains.

The paper presents an alternative view on causality, emphasizing the interconnected and recursive nature of biological processes. Noble et al. further explore how circular causality diverges from symmetry, positing that not all causal relationships within these systems are reciprocal. This nuanced perspective introduces a critical framework for understanding the boundaries of biological relativity.

Integrating concepts from theoretical physics and biology, the authors develop a comprehensive model to explain these phenomena. They use empirical data to support their arguments, linking theoretical insights to practical implications in fields such as medicine and biophysics.

The study also addresses the implications of circular causality for scientific inquiry, particularly in redefining how researchers approach complexity in living systems. By focusing on the asymmetry of certain relationships, the paper challenges traditional models and opens new avenues for interdisciplinary research.

In conclusion, Noble et al.'s study provides a groundbreaking perspective on causality within biological systems. Their integration of biological relativity and circular causality marks a significant shift in understanding the dynamics of life.

H. Collaboration and Innovation: A Portfolio Approach (Faems et al., 2005)[1]

Faems and colleagues' research, *Collaboration and Innovation: A Portfolio Approach*, examines the strategic role of interorganizational partnerships in fostering innovation. The authors explore how the intent and alignment of organizations influence the structure and outcomes of collaborative relationships, emphasizing two primary motivations: exploration and exploitation.

Their analysis categorizes partnerships based on participants' goals and interactions, distinguishing between research-focused collaborations for innovation (exploration) and partnerships aimed at refining existing products or processes (exploitation). Using a scoring framework, the authors quantify the intensity and diversity of collaborations, providing insights into how different types of partnerships drive organizational success.

A key takeaway from the study is the balance between exploratory and exploitative partnerships. Faems et al. argue that while exploration fosters creativity and knowledge exchange, exploitation enhances efficiency and performance. Organizations that strategically manage both types of collaboration are better positioned for sustained growth and innovation.

By combining quantitative measures with qualitative insights, the authors highlight the complex dynamics of interorganizational relationships. Their findings underline the importance of intent, alignment, and adaptability in creating effective collaboration portfolios.

In summary, Faems et al.'s study offers a robust framework for understanding how organizations can leverage partnerships to innovate and achieve strategic objectives.

I. Distance Collaboration: Group Dynamics and Effectiveness (González et al., 2003)[2]

González and colleagues' study, *Distance Collaboration: Group Dynamics and Effectiveness*, investigates the interplay of group process variables in virtual team performance. The research compares two models of group dynamics to evaluate how cohesion, efficacy, and attraction influence the effectiveness of distance collaboration.

The first model posits that group cohesion is a primary predictor of effectiveness, acting as an exogenous variable. In contrast, the second model suggests that collective efficacy drives cohesion, positioning efficacy as the foundational factor in group success. Both models provide valuable insights into the behavioral and motivational drivers of virtual collaboration.

The study employs a mixed-methods approach, incorporating observational data and participant surveys to analyze 71 distance collaboration teams. While robust, the authors acknowledge potential biases due to language translation and unmeasured contextual factors influencing participant behavior.

Findings reveal significant correlations between group dynamics and performance, emphasizing the importance of collective efficacy in fostering team cohesion and effectiveness. These insights provide actionable strategies for improving distance collaboration in diverse organizational settings.

In conclusion, González et al. offer a nuanced perspective on virtual team dynamics, highlighting the intricate relationships between group processes and collaborative success.

Variable	M	S.D.	1	2	3	4
Interpersonal attraction	5.36	1.04	–			
Task cohesion	5.48	1.01	0.71*	–		
Collective efficacy	3.86	0.59	0.60*	0.75*	–	
Team and peer facilitation	4.55	0.82	-0.02	-0.03	-0.06	–
Group effectiveness (quality)	3.21	0.50	0.09	0.26*	0.13	0.26*

TABLE I
DESCRIPTIVE STATISTICS AND CORRELATIONS AMONG STUDY VARIABLES AT THE GROUP LEVEL OF ANALYSIS[2].

J. Evaluating Distance Collaboration Through Group Dynamics (González et al., 2003)[2]

González and colleagues analyzed the effectiveness of distance collaboration by investigating relationships between group dynamics, including task cohesion, interpersonal interaction, and collective efficacy. Data collected from 71 groups informed their hypotheses, tested using two competing models.

The first model suggested that cohesion directly determines effectiveness, while the second proposed that efficacy acts as the primary influence, indirectly fostering cohesion. Both models were assessed using structural equation modeling, uncovering statistically significant patterns that provided valuable insights.

Key findings demonstrated that cohesive groups with high levels of team support and individual motivation achieved superior outcomes. The results confirmed predicted relationships, emphasizing the importance of group dynamics for effective collaboration in virtual environments. This study underscores how cohesion, coupled with collective efficacy, shapes group performance in remote settings.

K. The Role of Mycorrhizal Networks in Plant Communities (Tedersoo et al., 2020)[17]

Tedersoo and colleagues' work explores how common mycelial networks (CMNs) influence plant population dynamics and ecosystem interactions. These fungal networks extend plant nutrient acquisition, mitigate stress, and mediate interspecies relationships, serving as essential drivers of plant community structure.

Through CMNs, weaker competitors benefit from resource-sharing mechanisms, while stronger competitors are moderated, fostering coexistence. Additionally, these networks function as communication pathways, enabling plants to share signals about threats, such as pathogens or herbivores. This intricate web of connections illustrates how mycorrhizal fungi equalize and stabilize community dynamics by redistributing resources and enhancing soil properties.

The study highlights the critical role of CMNs in maintaining biodiversity, particularly in nutrient-poor or extreme environments. Mycorrhizal fungi often prioritize resource allocation toward familial or same-species plants, demonstrating hierarchical dynamics within networks.

Drawing from extensive literature, the authors argue that CMNs represent an underappreciated factor in promoting plant coexistence. They suggest that the long-term stability of dominant plant species may rely on these fungal synergies. The authors advocate for future research into the specific interactions between fungi and plants, aiming to uncover their role in shaping ecosystem diversity.

L. Metacommunities and Ecosystem Functioning (Leibold et al., 2017)[18]

Leibold et al. examine the intersection of community assembly and ecosystem processes, presenting metacommunities as a framework to understand these relationships. This approach views communities not as isolated units but as interconnected networks influencing and being influenced by their broader ecosystem.

The study maps how metacommunity dynamics, including species sorting, mass effects, and patch dynamics, affect ecosystem functions such as nutrient cycling, productivity, and resilience. By integrating spatial and temporal factors, the authors provide a nuanced view of how local and regional interactions drive ecosystem attributes.

A unique contribution of this work lies in its structured framework for identifying direct and indirect pathways linking community assembly to ecosystem functioning. This framework reveals the intricate dependencies between biodiversity, spatial processes, and ecosystem outcomes.

Leibold et al. emphasize the importance of considering spatial heterogeneity and connectivity in ecological research, highlighting how these factors shape community dynamics and, ultimately, ecosystem performance. Their findings offer practical insights for conserving biodiversity and managing ecosystems in the face of environmental changes.

In conclusion, this study advances my understanding of how metacommunity processes underpin ecosystem functions, offering a robust foundation for future ecological investigations.

M. Factors Influencing Interprofessional Collaboration: Insights from Quebec Mental Health Networks (Ndibu Muntu Keba Kebe et al., 2019)[3]

In their study, Ndibu Muntu Keba Kebe and colleagues conducted a secondary analysis to explore the factors that contribute to interprofessional collaboration (IPC) within Quebec's mental health service networks. The analysis focused on four primary variables: individual traits, interactional dynamics, organizational structures, and professional roles. The researchers hypothesized that interactional dynamics and organizational structures would exhibit the strongest connections to IPC.

Key components of interactional dynamics—including team climate, knowledge exchange, knowledge integration, and identification with multiple groups—were identified as having the most significant impact on fostering effective IPC[3]. These components highlight the importance of collaborative attitudes and practices in enhancing teamwork across professional boundaries.

Interprofessional collaboration has increasingly been recognized as vital in chronic and mental health care, offering improvements in both patient outcomes and satisfaction. Despite these advantages, the widespread adoption of IPC practices remains inconsistent, particularly in organizational settings. To measure the variables under investigation, the authors utilized a variety of assessment tools, detailed in Table **??**.

This study underscores the critical need for healthcare organizations to prioritize the development of interactional and organizational elements that support IPC. By addressing these factors, institutions can better harness the potential of interprofessional collaboration to improve care delivery and patient well-being.

N. Strengthening Interprofessional Collaboration: Insights and Recommendations (Ndibu Muntu Keba Kebe et al., 2019)[3]

Ndibu Muntu Keba Kebe et al. investigated the elements influencing interprofessional collaboration (IPC) within mental health service networks, focusing on individual, interactional, organizational, and professional role characteristics. Their analysis revealed that interactional dynamics and organizational structures were the most influential factors supporting IPC[3].

The study culminated in practical recommendations to enhance IPC in professional settings. The authors suggested actively addressing team cohesion decline, promoting mentorship opportunities for junior staff by experienced professionals, and organizing skill-focused training initiatives. These actions aim to foster awareness of IPC's foundational components, thereby strengthening teamwork and operational efficiency[3].

O. Meta-Ecosystem Dynamics: Transformations and Movements of Matter (Guichard & Marleau, 2021)

Guichard and Marleau (2021) proposed a groundbreaking framework for understanding ecosystems through meta-ecosystem dynamics. Their approach emphasizes the interconnectedness of organic and inorganic matter flows and their role in driving population growth and community assembly. Unlike traditional ecosystem theories, this perspective integrates peripheral processes as essential components rather than

TABLE II
VARIABLES AND INSTRUMENTS

Variable Block	Variable	Instrument Description
Individual Characteristics (IV)	Age	Data collected using a socio-demographic questionnaire.
	Sex	Determined via socio-demographic questionnaire.
	Belief in interdisciplinary benefits	Measured with a 5-item scale ($\alpha = 0.92$, range: 5–35) (Sicotte et al., 2002).
	Team seniority	Socio-demographic questionnaire used for measurement.
Interactional Characteristics (IV)	Knowledge sharing	Assessed with a 5-item scale ($\alpha = 0.93$, range: 5–35) (Bock et al., 2005).
	Knowledge integration	Measured using a 9-item scale ($\alpha = 0.95$, range: 9–63) (Song & Xies, 2000).
	Team commitment	Evaluated using a 4-item scale ($\alpha = 0.86$–0.92, range: 4–28) (Allen & Meyer, 1990).
	Decision-making participation	3-item scale ($\alpha = 0.88$, range: 3–21) (Campion et al., 1993).
	Mutual trust	Measured using a 4-item scale ($\alpha = 0.90$, range: 4–28) (Simons & Peterson, 2000).
	Team climate	19-item scale ($\alpha = 0.60$–0.84, range: 19–133) (Anderson & West, 1998).
	Team conflict	Assessed with a 9-item scale ($\alpha = 0.93$–0.94, range: 9–63) (Jehn & Mannix, 2001).
	Team autonomy	Measured with a 3-item scale ($\alpha = 0.76$, range: 3–21) (Campion et al., 1993).
Organizational Features (IV)	Organizational support	Evaluated with a 4-item scale ($\alpha = 0.84$–0.85, range: 4–28) (Spreitzer, 1996).
	Team size	Obtained from socio-demographic questionnaire.
Role Characteristics (IV)	Profession type	Derived from socio-demographic questionnaire.
	Multifocal identification	12-item scale ($\alpha = 0.65$, range: 12–84) (Van Dick et al., 2004).
Dependent Variable (DV)	IPC	Assessed with a 14-item scale covering communication (5 items), synchronization (3 items), explicit coordination (3 items), and implicit coordination (3 items) ($\alpha = 0.77$–0.91, range: 14–98) (Chiocchio et al., 2012).

incidental factors, bridging gaps between previously isolated areas of research.

The theory expands on metapopulation and metacommunity concepts by illustrating how feedback loops between biodiversity and ecosystem functionality shape dynamic equilibrium states. The authors argue that these feedback mechanisms fundamentally alter my understanding of ecosystem processes, highlighting their role in resource distribution and species interactions.

Drawing on interdisciplinary principles, including nonlinear and non-equilibrium dynamics, Guichard and Marleau developed mathematical models to represent ecosystems through energy fluxes and resource stocks. These models, including an enhanced Rosenzweig-MacArthur predator-prey system with recycling processes, reveal how material cycling influences system stability and community resilience. By shifting focus from static equilibria to dynamic interactions, the framework offers novel insights into ecosystem behaviors.

The authors conclude by advocating for the adoption of meta-ecosystem dynamics as a unifying ecological theory. They emphasize its potential to integrate diverse ecological phenomena and encourage future research to build upon this inclusive framework.

IV. METHODOLOGY

This study employs a rigorous methodology combining theoretical foundations with computational modeling to explore the Biomimetic Replicant Theory (BRT).

A. Research Design

The research is framed within the Biomimetic Replicant Theory (BRT), which models the flow of knowledge, collaboration, and competition in organizational ecosystems by drawing parallels with natural systems. Incorporating insights from game theory, systems theory, category theory, and biomimicry, the framework bridges multiple disciplines to investigate knowledge management dynamics.

a) Mixed Methods Approach: The research integrates case studies and exploratory analysis to address transdisciplinary questions and generate actionable insights[19].

b) Secondary Data Analysis: Quantitative analysis of referenced studies was performed to identify patterns between ecological processes and organizational behaviors[20]. This method provided a basis for understanding how natural systems can inspire organizational knowledge management and strategic planning.

c) Visualization and Interpretation: Visual tools, including scatter plots and trend graphs, were employed to illustrate relationships between variables. These visualizations supported data interpretation and informed conclusions regarding collaboration and resource dynamics.

B. Data Collection

1) Primary Data:

a) The GFG Fractal Model: A computational simulation in NetLogo[21] modeled resource competition among agents in an environment. Variables such as initial entity counts, resource thresholds, and strategic approaches were tracked, generating datasets that reflected resource utilization and adaptation strategies.

b) "WILDFIRE" Network Diffusion Simulation: A second simulation on NetLogo[22] examined idea diffusion across networks under varying conditions. Parameters like M_{ij}, β_i, $t_{jj'}$, and θ were adjusted to assess their impact on diffusion patterns, providing insights into how innovation spreads within organizational ecosystems.

C. Theoretical Framework

a) Biomimicry as Inspiration: Insights from natural systems were analyzed to identify quantitative patterns and behaviors in ecological interactions, forming the conceptual foundation for the BRT. These biological analogies guided the development of principles applicable to organizational ecosystems.

b) Category Theory Framework: Category theory provided the mathematical structure necessary for a systematic and abstract representation of complex relationships. By utilizing its robust framework, parallels were drawn between diverse datasets, offering a precise methodology to analyze interdependencies within organizational systems. To enhance clarity, commutative diagrams (Figure 1) were employed to illustrate how variables interact and map across datasets, grounding the study in a strong mathematical foundation[10][11].

1) Development of the Biomimetic Replicant Theory (BRT): The Biomimetic Replicant Theory (BRT) emerged as a synthesis of natural patterns and the structured methodologies of category theory. Drawing on precise mathematical formulations, the theory was designed to model the complex interplay of knowledge dynamics within organizational environments.

2) Models, Simulations, and Data Analysis:

a) Model Construction: Mathematical frameworks and network-based modeling platforms like NetLogo were utilized to create models simulating diverse organizational scenarios. These models provided a quantitative representation of interactions and resource distribution.

b) Simulation Scenarios: A series of simulations were conducted to replicate real-world organizational challenges. These experiments evaluated the efficacy of BRT-driven strategies by comparing them to conventional approaches, using quantitative metrics for assessment.

c) SPSS for Data Analysis: Data collected from simulations underwent processing and analysis using IBM SPSS software. A range of statistical methods—from descriptive to inferential—were employed. Predictive modeling and unstructured data analysis were facilitated by SPSS Modeler, enabling the extraction of meaningful insights and patterns.

d) Comparative Insights: Comparative analyses juxtaposed results from GFG Fractal simulations and human behavior datasets. This evaluation highlighted similarities in strategic decision-making and resource optimization under varying environmental conditions, emphasizing equilibrium and adaptation strategies.

e) Bootstrapped Regression Trees (BRT) Approach: A Bootstrapped Regression Trees method was applied to analyze GFG Fractal data. This approach offered robust insights into the influence of initial conditions on strategy evolution and resource allocation, accounting for nonlinearities and interaction effects between variables.

3) Iterative Refinement: Simulation outcomes were scrutinized to identify any gaps between theoretical predictions and observed results. Discrepancies led to iterative adjustments, ensuring the theoretical soundness and practical applicability of the BRT. The primary datasets and models used in this research are available online at nrischling.github.io.

D. The Biomimetic Replicant Theory: An Overview

1) Definition and Principles: The BRT proposes that the most effective human-designed systems derive their efficiency by emulating natural solutions. It emphasizes understanding and adapting the underlying principles of natural processes rather than merely replicating them[18]. Unlike innovations such as digital twins, which provide virtual replicas of systems, BRT advocates aligning organizational strategies with nature's design paradigms[23].

E. Three Foundational Laws of BRT

I. Optimization through Emulating Nature:

a) Mimicry for Efficiency: Nature's refined mechanisms, developed over millennia, offer insights for optimizing human systems[7]. For example, bullet train designs modeled after bird beaks or termite-inspired architectural solutions for temperature control highlight how natural efficiencies can inspire human innovation.

II. Human Systems Cannot Surpass Natural Optimization:

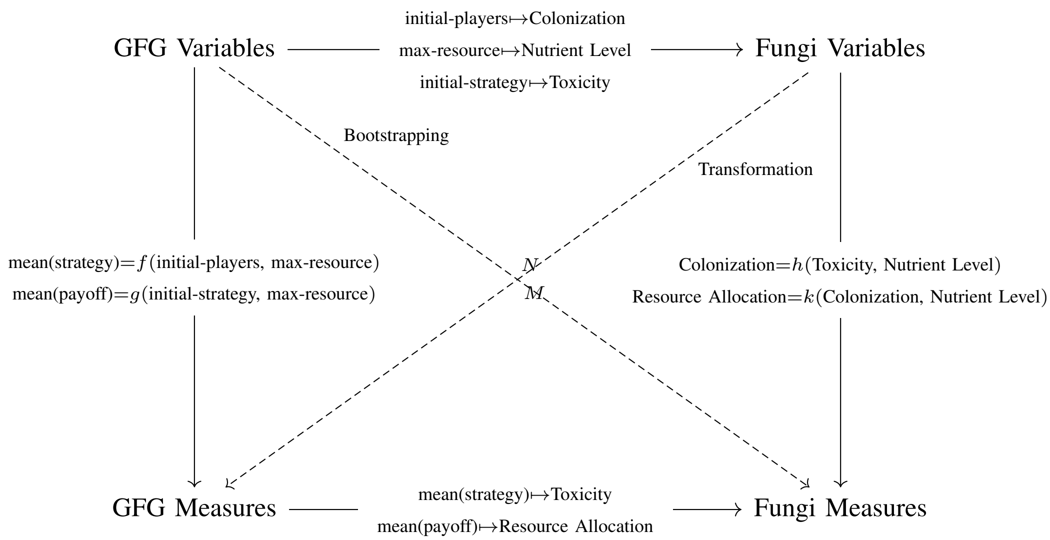
b) Acknowledging Limits: Artificial systems inherently fall short of the optimization achieved by their natural counterparts due to the immense complexity and interdependencies of natural systems[24][25]. This limitation underscores the importance of leveraging nature as a benchmark while acknowledging the boundaries of human understanding.

III. Human Systems are Synthetic Extensions of Nature:

c) Rooted in Natural Analogies: Human systems fundamentally stem from natural precedents, challenging me to consistently draw inspiration from the natural world[26]. For instance, the internet mirrors the decentralized structure of mycelial networks, and organizational hierarchies often reflect patterns observed in animal societies.

F. Generative Fractal Games (GFGs) in the Context of Biomimetic Replicant Theory

Generative Fractal Games (GFGs) provide a unique lens to study the dynamics of complex systems, bridging human-made and natural processes. Aligned with non-cooperative game theory, GFGs model interactions where individual entities prioritize personal benefits, often at the system's expense. This aligns with Fujiwara and Greve's observations on non-cooperative games, where strategies are self-serving and may lead to suboptimal systemic outcomes[27].



Notation and Definitions:

F : A functor that maps variables from the GFG model to the Fungi model.

G : Expressions representing mathematical relations in the GFG framework.

H : Expressions representing mathematical relations in the Fungi framework.

I : A functor associating measures from the GFG model to those in the Fungi model.

N : A natural transformation depicting bootstrapping processes in the GFG model.

M : A natural transformation depicting transformation processes in the Fungi model.

Fig. 1. Extended Commutative Diagram for Methodological Integration: A Category-Theoretic Approach.

The fractal nature of GFGs introduces a multi-scale perspective, wherein interactions at smaller levels cumulatively impact broader dynamics. This hierarchical framework mirrors natural systems, emphasizing interconnectivity and emergent behaviors. Moreover, the generative component underscores the adaptive and evolving nature of systems, with new dynamics emerging as interactions unfold[16].

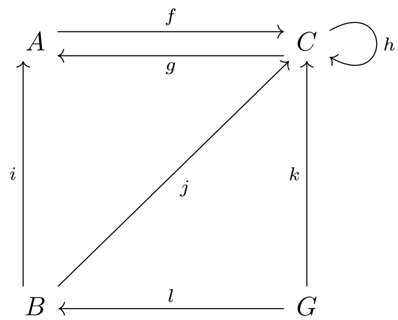
John Nash's groundbreaking exploration of equilibria in non-cooperative games provides a critical framework for understanding Generative Fractal Games (GFGs)[28]. Nash equilibrium[5] is defined as a condition where no participant can improve their payoff by unilaterally altering their strategy, assuming the strategies of others remain fixed. Within the GFG paradigm, Nash equilibria are depicted as stability points that exist across various hierarchical levels. However, given the dynamic and generative properties of GFGs, these equilibria are not fixed; they continuously shift and evolve, symbolizing the intrinsic instability and incompleteness of systemic balance.

This dynamic aligns with Gödel's incompleteness theorems, which argue that within any consistent formal framework, there are propositions that cannot be definitively proven or disproven[12]. Similarly, the Biomimetic Replicant Theory (BRT) suggests that true equilibrium in complex systems, such as those modeled by GFGs, is an elusive and ever-changing target. This perspective highlights the evolving nature of equilibrium states and their dependence on the intricate interactions of system components.

By synthesizing Nash's equilibrium concept with the generative, fractal, and incompleteness attributes of GFGs, a dynamic, multi-scalar system emerges. Here, equilibria at localized levels influence and are shaped by equilibria at broader scales. This recursive interaction illustrates the fluid nature of strategies and systemic balance, making it a powerful model for understanding complexity in ecological, economic, and organizational systems.

The GFG framework offers a holistic view, portraying individual entities as integral components of a larger, interconnected system. Each element both contributes to and is influenced by the broader system dynamics, embodying the fractal and universal characteristics observed in both natural and human-engineered systems[29].

1) BRT and the Universe as a Generative Fractal Game: The universe can be envisioned as a vast, interconnected generative fractal game, where every element, from the cosmic scale of galaxies to the microscopic scale of atoms, contributes to the structure and evolution of the whole. Within the BRT framework, human-designed systems are conceptualized as participants within this broader generative game, simultaneously shaping and being shaped by the larger context (Guichard, 2021).



Key:

X_1 : Actor 1
X_2 : Actor 2
X_c : Collaborative Actor
S : Scenario
a : Actions/Techniques
b : Stable state
c : Dynamics/Changes
d : Map: Actor 2 $\rightarrow$ Actor 1
e : Map: Actor 2 $\rightarrow$ X_c
f : Map: Scenario $\rightarrow$ X_c
g : Map: Scenario $\rightarrow$ Actor 2

Fig. 2. Dynamic Framework of Generative Fractal Games (GFGs) within Adaptive Systems Theory: A Hierarchical Visualization of Strategic Interactions and Evolutionary Mechanisms. This framework depicts the intricate relationships between individual agents (A and B), their integrated system (C), and the encompassing environment (G). The directional arrows signify pathways such as decision-making, state transitions, and emergent behaviors, encapsulating the adaptive and recursive characteristics of GFGs.

2) Decomposition of Equilibrium: In the GFG construct, strategies remain in constant flux, adapting to the shifting dynamics of the system. This mirrors the dynamic equilibrium seen in nature, where organisms and processes continuously evolve in response to external stimuli[30]. Drawing from Gödel's incompleteness principles, any equilibrium state in a GFG is inherently temporary and cannot be fully comprehended or defined during its existence. This introduces an element of unpredictability and underscores the inherent limitations in fully modeling such systems[31].

3) Implications for Systems Understanding:

a) Interconnected Hierarchies: The GFG framework proposes that systems function within nested, interdependent hierarchies, offering a robust tool for modeling and analyzing complex, multi-layered structures[9].

b) Evolving Equilibrium: This model challenges static equilibrium frameworks, emphasizing the importance of adaptability and responsiveness in the design and operation of sustainable systems[32].

c) Practical Analogies: The Generative Fractal Game (GFG) framework provides a valuable perspective for analyzing and predicting the behavior of complex systems, ranging from market operations to ecological networks.

d) Strategic Management and Organizational Dynamics: The principles of GFG can be applied to enhance organizational strategies by fostering adaptability, iterative decision-making processes, and alignment with the efficiencies observed in natural systems[9]. Moreover, the framework incorporates game theory as a pivotal analytical approach to explore the strategies and payoffs inherent in collaborative and competitive environments. Through game theory modeling, it becomes possible to uncover the mechanics behind cooperative behaviors and forecast outcomes in a manner that is consistent with the foundations of Biomimetic Replicant Theory (BRT).

G. Introducing the Influence Applicability Uptake Function

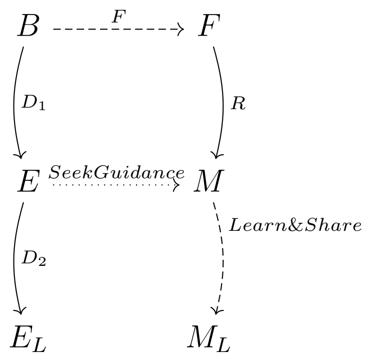
To delve deeper into the applications and mathematical formulations underpinning Biomimetic Replicant Theory (BRT), it is essential to highlight a key analytical tool: the Influence Applicability Uptake Function. This mathematical construct provides a means to quantify how various influences are adopted, disseminated, and utilized within a networked system.

By integrating this function into the BRT framework, the theoretical constructs gain an empirical foundation, enhancing their practical utility. This integration offers actionable insights into several areas, such as evaluating the optimization level of a system, measuring the adoption of strategies within Generative Fractal Games (GFGs), and refining the Universal Mathematical Framework for Network Relationships (UMFNR) for improved precision and application.

a) Knowledge Systems and Organizational Strategies: The GFG framework, with its emphasis on systematic data utilization and the notion that human systems are derivative of natural ones, provides organizations with an opportunity to redesign their knowledge management approaches. By adopting strategies that emulate the efficiency of natural systems, organizations can optimize their structures and operations[34].

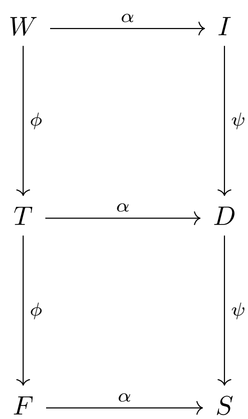
b) Ethical Considerations and Philosophical Insights: Rooted in nature, BRT encourages organizations to adopt sustainable and ethical practices. Additionally, the acknowledgment of inherent limitations in fully understanding systems can foster a shift in philosophical approaches to knowledge, truth, and the pursuit of understanding.

Integrating Nash's equilibrium into the fractal and generative nature of GFGs allows for the conceptualization of a multi-layered dynamic system. Equilibria at smaller scales not only influence but are also shaped by larger-scale equilibria, creating a framework for analyzing complex systems across ecological, economic, and organizational domains.



Key:
A : Agent
T : Task selection based on experience
P_1 : Agent's perception of options
S : Providing valuable inputs
W : Worker
P_2 : Worker's judgment from feedback
L : Leader
W_E : Worker post-experience
L_E : Leader post-collaboration
— : Direct flow of insights or interaction
- - - : Evaluation process
- · - : Strategy or pattern of evaluation

Fig. 3. Fractal Model of Behavioral Dynamics showcasing the intricate processes of information exchange and decision-making among bees and organizational roles like managers and employees. The diagram highlights how both groups filter diverse data streams to extract meaningful insights, leveraging structured interactions and adaptive strategies to optimize resource allocation and knowledge dissemination [33].



Key:
F : Flow of Water in a River Network
C : Circulation of Information in a Network
N : Nodes (e.g., Reservoirs in water flow)
G : Groups or Individuals (in information network)
M : Movement of Water (in river network)
R : Spread of Messages or Data (in information network)
β : Mapping from Water Flow to Information Circulation Concepts
γ : Connections within the River Network
δ : Connections within the Information Network

Fig. 4. Commutative Diagram Depicting the Influence Adoption and Impact Dynamics within Biomimetic Replicant Theory (BRT). This diagram compares the Wildfire Spread model and the Idea Diffusion model to showcase the framework's role in measuring the assimilation, effectiveness, and dissemination of influences across varied networks. The arrows represent transformations and interactions that contribute to optimizing system dynamics, adopting Generative Fractal Game strategies, and refining the Universal Mathematical Framework for Network Interactions. Refer to A for detailed technical specifications.

V. Data Analysis

BRT underscores the intricate interplay between individual actors and the broader systems they inhabit. This relationship is empirically demonstrated through a line plot illustrating the interaction between resource availability and population dynamics. The non-linear trends revealed in such plots highlight the role of system-level constraints—such as environmental limitations—in shaping individual strategies and behaviors[35]. Within the GFG framework, these findings emphasize the critical need for multi-scale approaches to fully understand the complexities of interconnected systems.

A. Exploring Human Cooperation through the "GFG Fractal" Model

The "GFG Fractal" model has proven instrumental in analyzing the evolution of strategies and resource utilization within the context of BRT. A comparative analysis with the study *"Evidence for Strategic Cooperation in Humans"* enriches my understanding of cooperative and competitive dynamics in complex systems.

a) Adaptive Behavior Across Levels: Human behavior studies reveal how individuals adjust their cooperation based on environmental and social cues. Similarly, in the "GFG Fractal" model, turtles modify their strategies in response to resource availability and interactions. These parallels highlight the universal nature of adaptive behavior across species and scales.

b) Equilibrium in Strategy and Outcomes: Both humans and turtles exhibit tendencies toward equilibrium. In the human study, individuals balance cooperation and self-interest to optimize their perceived benefits. Likewise, the turtles in the model reach a strategic balance to maximize their payoffs, underscoring the natural gravitation toward stability in diverse systems.

c) Social and Environmental Impacts: The human study emphasizes how external social and environmental factors influence cooperative behavior. In the "GFG Fractal" model, turtles adapt their strategies based on feedback from their environment and interactions with peers, reinforcing the universality of context-driven adaptation.

d) System Response to Change: Just as human cooperation shifts under varying conditions, the model demonstrates how entities adapt their strategies in response to changing resource availability. This adaptability reflects the resilience and responsiveness embedded in both human and modeled systems.

The comparative insights between the human study and the "GFG Fractal" model affirm BRT's foundational principles. These findings highlight the universal dynamics of competition and cooperation, reinforcing the theory's applicability across both natural and human-engineered systems.

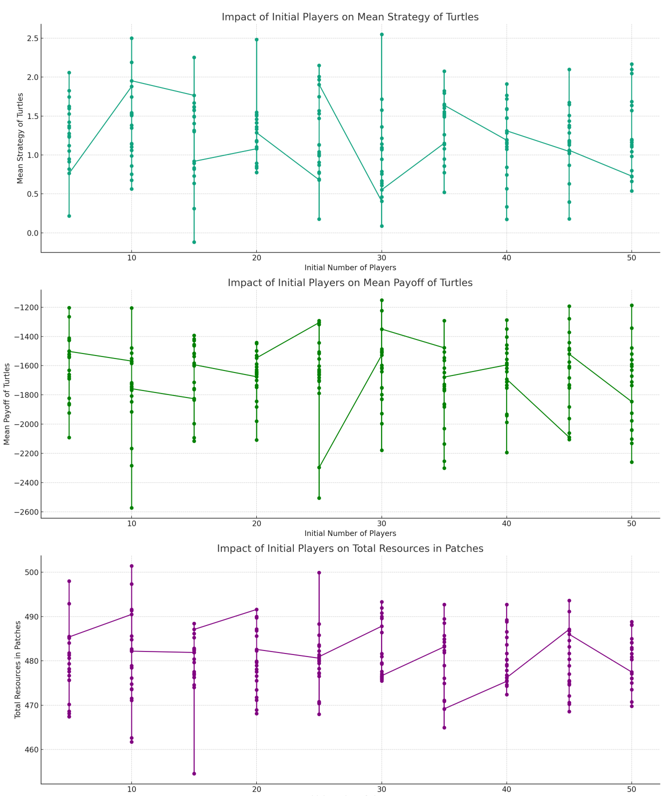


Fig. 5. Illustration of how the starting number of participants influences the strategy and payoff outcomes in the "GFG Fractal" model. The y-axis reflects the average values for both strategy and payoff, highlighting their correlation with the x-axis, which tracks the initial number of players. As the player base grows, a clear pattern emerges, revealing the essential feedback mechanisms and adaptive responses that are key to the model's structure and to human collaborative behavior.

B. Fractal Variability and System Dynamics

According to BRT, systems inherently display fractal properties, with complexity and variability observable across multiple layers of scale. Figure 5 demonstrates this principle by illustrating the distribution of turtle populations across varying resource levels. As resource levels increase, so too does the variability in turtle counts, showcasing the emergence of more intricate dynamics. This rising variability underscores the fractal nature of these systems, where greater resource availability fosters increased complexity, aligning with BRT's theoretical framework.

C. Generative Constructor Theory Framework (GCTF)

1. Establishing Fundamental Tasks

The initial step involves identifying the most basic task within the network, denoted as T_1. For example, T_1 might represent the task: "Can computer A establish a connection with the local router B?"

2. Determining Task Outcomes

Each task T_i has an associated outcome, represented as $O(T_i)$, which can be either possible (P) or impossible (I).

3. Building Tasks Generatively

For every subsequent task T_{i+1}, the outcome of the previous task, $O(T_i)$, influences its feasibility. For instance, consider T_2, defined as "Can computer A access an internet website?" If $O(T_1) = I$ (impossible), then $O(T_2)$ automatically becomes impossible.

The generative relationship can be expressed mathematically as:

$$O(T_{i+1}) = \begin{cases} P & \text{if } O(T_i) = P \text{ and all conditions for } T_{i+1} \text{ are satisfied} \\ I & \text{otherwise} \end{cases}$$

4. Constructing Task Hierarchies

This process continues iteratively, with each task's feasibility determined by its preceding outcomes, thereby constructing a hierarchical network of tasks. The sequence of tasks can be expressed as:

$$T_1, T_2, T_3, \ldots, T_n$$

with corresponding outcomes:

$$O(T_1), O(T_2), O(T_3), \ldots, O(T_n)$$

Mathematical Representation: For a sequence of tasks $T = \{T_1, T_2, \ldots, T_n\}$, the outcomes $O(T)$ are determined recursively using the generative rule:

$$O(T_{i+1}) = \begin{cases} P & \text{if } O(T_i) = P \text{ and all conditions for } T_{i+1} \text{ are met} \\ I & \text{otherwise} \end{cases}$$

Key Considerations:

- "Other conditions" in the generative rule refer to external factors required for task feasibility. For example, even if a computer connects to a local router, it might fail to access the internet if the ISP is unavailable.
- The GCTF can be visualized as a decision tree, with nodes representing tasks and branches representing possible or impossible outcomes.

- This framework highlights the foundational structure of what is feasible within a network, forming a hierarchy of tasks from basic to complex.

D. UMFNR and Dynamics of Influence Uptake

The Universal Mathematical Framework for Network Relationships (UMFNR) provides a powerful structure for analyzing the interactions between networks. To enhance its utility, the Influence Applicability Uptake Function is introduced, refining the framework to capture the nuanced dynamics of influence uptake within networks:

$$UMFNR = g(P(N_1, z_1^j), P(N_2, z_2^j), \ldots, P(N_n, z_n^j), P(N_{\text{ref}}, z_{\text{ref}}^j)) \tag{1}$$

In this equation, z_i^j represents the uptake of various influences across networks at different scales, adding depth to the analysis. This allows UMFNR to adapt to evolving conditions and to model inter-network influence in a more precise and dynamic manner.

Network Definitions:

$$N_1, N_2, \ldots, N_n : \text{Networks under analysis.}$$
$$N_{\text{ref}} : \text{A reference network for benchmarking.}$$

Network Property Representation:

$$P(N_i) : \text{Captures the defining properties of a network } N_i.$$

Establishing Network Interrelations:

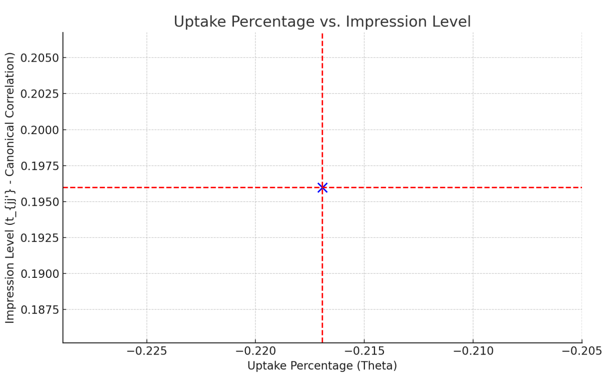


Fig. 6. *Impact of Node Exposure on Influence Adoption.* This graph shows how the frequency of interactions (node exposure) within a network correlates with the likelihood of those nodes adopting new influences. Each point represents a node, illustrating a strong connection between frequent interactions and a higher propensity to adopt innovations. This underscores the crucial role of prominent nodes in the dissemination of ideas across networks.

General relationship function:

$$G(P(N_1), P(N_2), \ldots, P(N_n)) = P(N_{\text{ref}})$$

To incorporate the fractal properties inherent to BRT, the function G is refined to operate across different scales:

$$G_j(P(N_{1,j}), P(N_{2,j}), \ldots, P(N_{n,j})) = P(N_{\text{ref},j})$$

where j represents a specific scale in the fractal hierarchy.

Incorporating Correlation Measures:

Define $\sigma(N_a, N_b)$ as a correlation measure between networks N_a and N_b. Applying this measure, the relationship function for each network N_i becomes:

$$G_j(\sigma(N_{1,j}, N_{\text{ref},j}), \sigma(N_{2,j}, N_{\text{ref},j}), \ldots, \sigma(N_{n,j}, N_{\text{ref},j})) = P(N_{\text{ref},j})$$

Key Parameters:

- $N_1, N_2, \ldots, N_n$: Networks analyzed.
- N_{ref}: Reference network.
- $P(N_i)$: Function describing network properties.
- G: General relationship function.
- j: Fractal hierarchy scale.
- σ: Correlation measure.

E. Validating Influence Uptake Using Real Data

Mathematics often reveals its power by modeling real-world phenomena. To evaluate the proposed uptake function, I apply it to empirical data:

$$z_i^j = M_i^j + \emptyset\gamma^j(M_i^j, \beta_i)(M_i^{j'})^{t_{jj'}} \tag{2}$$

Key elements of this function include:

- **Receptiveness and Resistance:** The term M_i^j reflects the openness of a network at scale j to influences. This could correspond to "toxicity" levels in the data, where increased toxicity correlates with reduced receptiveness.
- **Dynamic Interactions:** The variable $t_{jj'}$ captures the influence exerted by one network on another, evolving over time as interactions shift within datasets like 'Strategic_Coop'.
- **Frequency of Strategy Adoption:** The uptake percentage θ mirrors how frequently players in datasets like 'Strategic_Coop' adopt specific strategies during iterative phases of interaction.

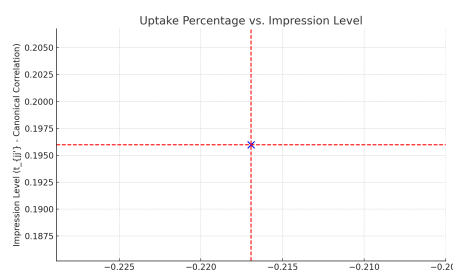


Fig. 7. *Exposure Frequency and Idea Acceptance.* This graph illustrates the relationship between the frequency of exposure a node receives and its likelihood of accepting new ideas. The observed trend indicates that increased exposure is associated with a higher rate of acceptance, highlighting the importance of frequent interactions in the spread of innovations.

By integrating these variables into the function, I assess its predictive accuracy against observed data. When discrepancies arise, they provide opportunities for refining the model, strengthening its explanatory power over time.

This exploration, though preliminary, lays the groundwork for validating the uptake function through broader datasets, offering actionable insights into the behavior of complex systems.

Step-by-Step Guide to Application:

- **Define Networks:** Identify the networks of interest $N_1, N_2, \ldots, N_n$ and a reference network N_{ref}.
- **Analyze Properties:** Use $P(N_i)$ to extract critical properties of each network.
- **Apply the Function:** Employ G to relate the networks to the reference, incorporating fractal scales G_j as needed.
- **Evaluate Correlations:** Use σ to measure relationships between each network and the reference.
- **Interpret Results:** Assess the dynamics and relationships uncovered between the networks.

VI. Results and Observations

A. Biomimicry as a Model for System Efficiency

By examining natural systems like mycorrhizal networks through the lens of BRT, I identified parallels that inform human-made systems. These fungal networks, often referred to as the "wood wide web"[36], exemplify optimized resource allocation, resilience, and adaptability. This efficiency aligns with the Generative Constructor Theory Framework (GCTF), which mirrors natural patterns in hierarchical task outcomes, from basic nutrient exchange to complex defensive strategies.

B. Optimizing BRT: A Quantitative Perspective

The cornerstone of Biomimetic Resource Theory (BRT) lies in its ability to enhance human systems by grounding its principles in empirical evidence. To further this capability, I introduce the Influence Applicability Uptake Function as a key component of the framework. The formula:

$$BRT_{\text{Optimization}} = \alpha \times (BRT_{\text{original}} + z_i^j) \tag{3}$$

provides a means to measure system-level optimization. Here, z_i^j acts as a metric for influence uptake, enabling a more actionable application of BRT across various organizational contexts.

C. Translating Insights from Nature to Organizations: The Role of GCTF and UMFNR

Applying the Generative Constructor Theory Framework (GCTF) to mycorrhizal networks offered profound insights. Beginning with basic tasks such as nutrient transfer, I constructed a layered understanding of their operations, showcasing the networks' capacity for efficiency and resilience[35]. Similarly, the Universal Mathematical Framework for Network Relationships (UMFNR) provided a systematic way to compare natural networks like mycorrhizal systems with human-engineered systems such as supply chains.

Despite operating in distinct environments, these systems share core principles: adaptability, resource efficiency, and resilience. By utilizing correlation measures like σ, I were able to draw quantitative parallels, identifying actionable strategies for improving human systems based on natural ones.

D. Insights and Applications: The Core of BRT

The comparative analysis of natural and human-made systems illuminated significant parallels. For example, nutrient transfer efficiencies observed in mycorrhizal networks closely mirror strategies for optimizing distribution in supply chains. By studying these similarities, I derived innovative strategies for human systems inspired by natural models.

This research underscores BRT's ability to bridge the wisdom of nature with the needs of modern organizations. The results demonstrate how BRT provides a clear pathway for designing sustainable, adaptive, and efficient systems in organizational contexts.

VII. Conclusion

Biomimetic Resource Theory (BRT) offers an invaluable perspective on navigating the complexities of organizational dynamics by drawing inspiration from natural ecosystems. My study highlights the interplay between collaboration, competition, and conservation within organizations, revealing lessons that parallel the balance achieved in ecological systems.

The research underscores a critical shift: moving from a functional approach to one focused on intent in managing organizational knowledge. By emphasizing adaptability and fostering stronger connections between insights and data-driven strategies, BRT positions itself as a vital framework for addressing evolving challenges.

The parallels drawn between natural systems and organizational practices reveal universal strategies for efficiency and resilience. Just as ecosystems strike a balance for survival and growth, organizations must recalibrate their knowledge-sharing and resource allocation strategies to foster long-term sustainability.

Ultimately, BRT offers more than a theoretical foundation—it provides a roadmap for organizations to adapt and thrive. By aligning with the dynamics of knowledge flow, organizations can ensure sustainable growth while paving the way for a future centered on adaptability and ecological harmony.

VIII. Recommendations

A. Practical Strategies for Implementation

1) Forming a BRT Strategy Team: Organizations should establish a cross-disciplinary team with expertise in systems thinking, organizational behavior, and natural sciences. This team would be responsible for:

- Conducting a comprehensive audit to identify areas where BRT principles can be most impactful.
- Creating an implementation roadmap with measurable objectives and key performance indicators.

2) Enhancing Knowledge Flow: Leveraging the BRT framework, organizations can develop innovative knowledge-sharing systems that balance collaboration and competition. Examples include:

- Establishing a dynamic *knowledge exchange platform* where employees can share insights and resources.
- Introducing gamified systems to encourage competitive but constructive knowledge dissemination.

3) Sustainable Resource Allocation: Guided by BRT's emphasis on conservation, organizations can adopt resource allocation models inspired by ecological principles. Algorithms rooted in ecological optimization can help manage finite resources more efficiently.

B. Anticipated Challenges and Solutions

1) Resistance to Change: Introducing BRT may encounter resistance from employees accustomed to existing practices.

- **Solution**: Offer targeted training sessions and workshops to demonstrate the value and benefits of adopting BRT principles.

2) Complexity of Implementation: Scaling BRT across an entire organization might require substantial structural changes.

- **Solution**: Start with small-scale pilot programs to test the framework's effectiveness before rolling it out broadly.

IX. Future Directions

A. Expanding the Scope of BRT

1) Broader Applications Beyond Corporations: While current research primarily addresses BRT's relevance in corporate environments, there remains significant potential to explore its utility in alternative contexts, including non-profit organizations, academic institutions, and public-sector frameworks. Such exploration could uncover novel applications and adaptations of BRT tailored to these distinct organizational ecosystems.

2) Ethical Considerations: Future studies must delve into the ethical dimensions of applying biomimetic principles from natural ecosystems to human organizations. This would ensure that the implementation of BRT aligns with ethical standards, fostering responsible and sustainable practices in diverse contexts.

B. Interdisciplinary Collaborations

1) Partnerships with Ecologists and Mathematicians: Collaboration with ecologists presents an opportunity to draw deeper insights from the mechanisms of natural resource distribution and ecosystem resilience. Mathematicians, on the other hand, could assist in translating these biological principles into robust computational models, enabling practical applications across organizational systems.

2) Involvement of Organizational and Behavioral Scientists: By working closely with experts in organizational dynamics and behavioral science, BRT can be refined to account for the complexities of diverse workplace cultures and structures. These insights would help tailor the framework to address specific challenges faced by different types of organizations.

C. Towards a Resilient and Adaptive Framework

Integrating knowledge from multiple disciplines will enhance the versatility and robustness of BRT. This multidisciplinary approach ensures that the framework evolves into a comprehensive tool capable of addressing the complex and varied demands of modern knowledge management systems.

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Appendix

A. Modeling the Spread of Ideas

1) Introduction: The Idea Spread Model is designed to emulate how ideas disseminate within organizations. Drawing parallels with wildfire dynamics, this model provides valuable insights for enhancing the distribution of concepts or initiatives across a corporate structure.

2) Key Parameters:

- **Influence Factor**: Quantifies the ability of a department or individual to promote and spread ideas.
- **Receptivity Factor**: Measures the openness of a department or individual to accepting new ideas.
- **External Market Influence**: Captures the role of external forces, such as market trends, in shaping the spread of ideas.

3) Mathematical Representation: The propagation mechanism is captured by the equation:

$$\begin{aligned} I_{\text{spread}} = f(&\text{Influence Factor}, \\ &\text{Receptivity Factor}, \\ &\text{External Market Influence}) \end{aligned} \tag{4}$$

Here, I_{spread} symbolizes the extent to which ideas circulate within an organization.

4) Practical Implementation: The model has been developed using NetLogo, an agent-based simulation platform. Departments or individuals are represented as agents, and their interactions—governed by the parameters above—simulate the flow of ideas.

5) Influence Applicability Uptake Function: A critical element of the Idea Spread Model is the *Influence Applicability Uptake Function*[37], which illustrates the rate of idea adoption as influenced by various factors.

$$U(t) = \frac{K}{1 + e^{-r(t-t_0)}} \tag{5}$$

Where:

- $U(t)$: Uptake of the idea at time t.
- K: Maximum potential uptake.
- r: Adoption rate.
- t_0: Point of maximum adoption acceleration.

This sigmoidal function describes uptake behavior over time, beginning with slow adoption, accelerating as influencing factors become prominent, and eventually leveling off as saturation is reached. It provides a mathematical backbone for the model, elucidating the dynamic factors that govern the spread of ideas within organizations.

B. Bees and Managers Model

1) Introduction: The Bees and Managers Model draws inspiration from the collective decision-making processes of bees to simulate managerial behaviors. By studying how bees reach consensus, this model aims to inform and optimize decision-making strategies within corporate environments.

2) Key Parameters:

- **Information Availability**: Reflects the extent of accessible information for decision-making.
- **External Influences**: Represents the impact of external pressures or conditions on decisions.
- **Internal Communication**: Measures the degree of interaction and information exchange among managers.

3) Mathematical Representation: The decision-making dynamics are expressed as:

$$D_{\text{decision}} = g(\text{Information Availability}, \text{External Influences}, \text{Internal Communication}) \quad (6)$$

Here, D_{decision} captures the outcome of the decision-making process influenced by the stated parameters.

4) Implementation Approach: The specific implementation methodology for this model involves simulating the decision-making environment, incorporating the identified parameters to replicate how managers interact, process information, and respond to internal and external stimuli.

C. Idea Spread Model - "WILDFIRE"

1) Experimental Configuration:

```
breed [initiatives idea]
breed [adopters follower]
breed [departments sector]

globals [
  threshold-adoption
  adoption-lifespan
  simulation-duration
]

to initialize-organization [count-sectors]
  create-sectors count-sectors [
    set shape "circle"
    set size 2
    setxy random-xcor random-ycor
  ]
end

to setup
  clear-all
  set-default-shape turtles "square"
  initialize-organization num-sectors

  ask patches [
    if random-float 1 < 0.25 [ set pcolor
       green ]
  ]

  ask one-of patches with [pcolor = green] [
    sprout-initiatives 1 [ set color red ]
  ]
  reset-ticks
end

to go
  if not any? turtles [ stop ]

  ask initiatives [
    let neighboring-patches neighbors4 with
        [pcolor = green]
    ask neighboring-patches [
      if compute-adoption >
         threshold-adoption [
        set pcolor blue
        sprout-followers 1 [ set color blue ]
      ]
    ]
  ]

  ask followers [
    if ticks - [tick-created] of self >
        adoption-lifespan [ die ]
  ]
  tick
end

to-report compute-adoption
  let external-effects random-float 1
  report external-effects * 0.75  ;; Example
     weight assigned to external influences
end
```

D. Fractal Adaptation and Variability Model

1) Experimental Setup:

```
turtles-own [
  strategic-level
  resource-accumulation
  adaptive-state
  generations
  actions
  fractal-edge
]

globals [
  adaptation-threshold
  max-strategy-depth
]

to setup
  clear-all
  setup-patches
  create-turtles initial-players [
    set shape "triangle"
    set strategic-level random
        initial-strategy
    set resource-accumulation 0
    set adaptive-state false
    set generations 1
    set fractal-edge 5
    recolor-agent
  ]
  reset-ticks
end
```

Variable/Metric	Definition	(Min, Step, Max)
`initial-players`	The number of initial entities active in the simulation	(5, 5, 50)
`max-resource`	The maximum value for resources available on patches	(0.5, 0.5, 2)
`initial-strategy`	Starting strategic depth assigned to agents	(1, 1, 5)
`count turtles with [equilibrium = true]`	Count of agents that reached equilibrium	-
`mean [strategy] of turtles`	Mean value of all agents' strategic levels	-
`mean [payoff] of turtles`	Average payoff calculated for all agents	-
`count turtles`	Total number of agents in the simulation	-
`sum [resource-here] of patches`	Aggregate of all resources across the environment	-

TABLE III
KEY VARIABLES AND METRICS IN THE WILDFIRE SIMULATION FRAMEWORK

Variable/Metric	Definition	(Min, Step, Max)
`initial-players`	Number of agents active at simulation start	(5, 5, 50)
`max-resource`	Highest resource availability per patch	(0.5, 0.5, 2)
`initial-strategy`	Baseline strategic assignment to agents	(1, 1, 5)
`mean [strategy] of turtles`	Average strategic depth across agents	-
`count turtles`	Aggregate number of agents active in the simulation	-
`sum [resource-here] of patches`	Total resources distributed among patches	-

TABLE IV
PRIMARY VARIABLES AND METRICS FOR THE FRACTAL ADAPTATION SIMULATION

```
to go
  if not any? turtles [ stop ]

  ask turtles [
    evaluate-environment
    gather-resources
    update-strategy
  ]
  tick
end

to evaluate-environment
  let local-payoff sum
      [resource-accumulation] of turtles-on
      neighbors4
  if local-payoff > adaptation-threshold [
      set adaptive-state true ]
end

to gather-resources
  if adaptive-state [
    set resource-accumulation
        resource-accumulation + random-float
        max-strategy-depth
  ]
end

to update-strategy
  if adaptive-state [
    set strategic-level strategic-level + 1
    recolor-agent
  ]
end

to recolor-agent
  set color scale-color green strategic-level
      0 max-strategy-depth
end
```

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Automated Detection of Retinopathy Using EfficientNetB3: A Comprehensive Approach

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Automated Detection of Retinopathy Using EfficientNetB3: A Comprehensive Approach

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Abstract

Retinopathy, which can happen because of diabetes and other systemic diseases, is a major cause of preventable blindness worldwide. To treat this condition effectively, it is important to be able to recognise and deal with the causes. Rapid progress in deep learning has made automated retinopathy detection methods more practical. This has made diagnosis easier and more accurate.

This study uses EfficientNetB3, a state-of-the-art convolutional neural network, to create an automated method for detecting retinopathy. We created the model by grouping a collection of retinal images into five severity levels. We used different methods such as image scaling, normalisation, and data augmentation to improve picture quality and make the model more stable. We carefully improved EfficientNetB3 using transfer learning to ensure its accurate recognition of retinal images. A test and validation accuracy of 99% showed that the model was very good at identifying the stages of retinopathy.

The results show that the suggested method is a useful, scalable, and effective way to identify retinopathy. This implies its applicability in both real-life clinical settings and telemedicine systems. Increasing the variety of data and using advanced enhancement techniques will help the model work better for a wider range of people.

Keywords: Retinopathy, EfficientNetB3, Transfer Learning, Deep Learning, Retinal Imaging.

1. Introduction

One of the leading causes of avoidable blindness worldwide is retinopathy, a common eye illness that primarily arises as a consequence of diabetes, hypertension, or other systemic problems. Diabetes retinopathy has become a significant public health concern due to the increasing prevalence of diabetes worldwide. Failure to properly diagnose and treat retinopathy can lead to blindness or severe visual loss. The fact that prompt diagnosis and action are essential in averting negative consequences highlights the importance of precision in disease management.

The diagnosis of retinopathy has historically relied on qualified ophthalmologists analysing retinal fundus pictures to find abnormalities such as haemorrhages and microaneurysms that indicate the condition. However, this approach can be time-consuming and resource-intensive, and it is prone to human error, especially in places with limited access to specialist medical personnel. Deep learning-powered automated diagnostic systems are a major step forward in tackling these issues. By using big datasets and advanced neural networks, these systems hope to speed up, improve, and even replace manual diagnosis with solutions that are scalable, reliable, and easy to use.

Convolutional neural networks in the EfficientNet collection have garnered attention lately because of their efficacy and exceptional performance in a range of computer vision tasks. The EfficientNetB3 version perfectly balances accuracy and computational complexity, making it ideal for medical image analysis. This work presents a novel approach to automated retinopathy identification using EfficientNetB3.

This study's primary goal is to develop a robust model that can classify retinal pictures into five different retinopathy severity levels. We refine the model on a collection of retinal fundus images using transfer learning with EfficientNetB3. We use image preprocessing techniques such as resizing, normalisation, and data augmentation to enhance model performance and address issues such as class imbalance and image quality variability.

This work examines EfficientNetB3's ability to achieve high accuracy and computational efficiency for retinopathy detection. Additionally, the study shows how important it is to use transfer learning in medical imaging applications and looks into possible ways to make models more useful and flexible in different situations.

This automated retinopathy detection technology greatly aids the continuous integration of artificial intelligence into healthcare systems, which aims to improve early diagnosis and lessen the global problem of blindness.

2. Objectives

1. Construct a strong and efficient model for classifying retinopathy via EfficientNetB3.
2. Utilise efficient processing methods to improve image quality.
3. Employ transfer learning to utilise pretrained EfficientNetB3 features.
4. Assess the model's efficacy using conventional metrics such as accuracy, sensitivity, and specificity.
5. Exhibit relevance in real-world scenarios.

3. Literature Review

Deep learning has transformed medical imaging by facilitating automated systems for the detection and classification of diseases, such as retinopathy. Through basic studies, Gulshan et al. (2019) showed that convolutional neural networks (CNNs) are very good at diagnosing diabetic retinopathy by using large retinal datasets. Their work demonstrated the efficacy of CNNs in the early detection of diseases. In 2020, Yoo et al. used transfer learning to look at the retina and show that finetuning architectures like ResNet and InceptionV3 with medical data makes a big difference in how well they work. In a similar vein, Qureshi et al. (2021) emphasised the implementation of attention mechanisms within CNNs for the detection of microaneurysms, which serve as an early indicator of diabetic retinopathy, attaining a classification accuracy of 91.8%.

The introduction of EfficientNet as a refined collection of CNN architectures has significantly broadened the opportunities within medical imaging. EfficientNet, as introduced by Tan and Le (2019), achieves a balance between computational efficiency and accuracy. The EfficientNetB3 variant is becoming more and more popular for tasks that need to recognise small details, like putting retinal diseases into groups. Hu et al. (2022) showed this by getting a classification accuracy of 92% with EfficientNetB3 on a multi-class retinopathy dataset. This showed how well it can handle complex medical image data.

Preprocessing techniques have demonstrated a considerable influence on the performance of models in the analysis of retinal images. Ramachandran et al. (2020) pointed out that standardising image inputs through resizing, normalisation, and histogram equalisation makes models more stable. Wang et al. (2021) showed how data enhancement techniques, such as random flipping and colour jittering, can help fix problems like class imbalance and overfitting, which are necessary to get accurate results in medical datasets.

Comparative studies offer valuable insights for determining the most appropriate architecture for detecting retinopathy. A study by Kumari et al. (2021) compared ResNet, VGG, and EfficientNet and found that EfficientNetB3 performed better in terms of accuracy and computational efficiency. Ahmad et al. (2022) conducted a comparison between traditional image processing methods and contemporary deep learning techniques, emphasising the capacity of CNNs to adjust to intricate and high-dimensional data, which enhances their effectiveness in detecting retinal diseases.

Obstacles like class imbalance and inconsistencies in expert annotations continue to pose considerable challenges in the detection of retinopathy. Singh et al. (2019) introduced class-weighted loss functions to tackle the issue of imbalanced datasets, a common challenge in medical imaging. Zhang et al. (2020) tackled the issue of inter-observer variability, highlighting the necessity for standardised and high-quality datasets to train robust and reliable models.

The incorporation of automated detection systems into clinical workflows represents a significant focus of ongoing investigation. Patel et al. (2021) looked into how important it is to use lightweight models like EfficientNetB3 in places with few resources so that more people can get access to advanced diagnostics. Mohan et al. (2022) highlighted the importance of explainable AI in healthcare, which builds trust in automated systems and supports their acceptance by medical professionals.

Numerous publicly accessible datasets have significantly contributed to the progress of retinopathy detection studies. The APTOS dataset from Kaggle includes 3,662 images categorised into five severity levels. The chosen architecture and preprocessing techniques have influenced its widely used accuracy rates, which range from 85% to 92%. The IDRiD dataset, which centres on diabetic retinopathy, offers labelled data for lesions and abnormalities, allowing models to reach accuracy of up to 94%. EyePACS is a large dataset with more than 88,000 images of the retina that is used to test retinopathy detection models. EfficientNet-based methods consistently get accuracy rates above 90%.

Recent improvements in hybrid models and sequential analysis methods have made automated detection systems much more useful. In 2023, Zhou et al. combined convolutional neural networks with recurrent neural networks to do a sequential analysis of retinal images. They got a 93% success rate. In 2023, Shukla et al. created a hybrid model that combines EfficientNetB3 with attention mechanisms. This model was 94% accurate on tests.

Methodology

The methodology employed in this research is designed to develop an automated retinopathy detection system using the EfficientNetB3 deep learning architecture. The pipeline includes several crucial steps: data preprocessing, model architecture design, training, evaluation, and testing. This section provides a detailed explanation of each step based on the implementation in the provided notebook.

1. Dataset Preparation and processing

This study used a dataset of retinal fundus images classified into five severity levels of retinopathy. We divided the dataset into three subsets:

- Training set: 2929 images
- Validation set: 366 images
- Test set: 367 images

Preprocessing steps included:

- **Resizing**: All images were resized to 224x224 pixels to match the input requirements of the EfficientNetB3 model.
- **Normalisation:** To achieve faster convergence during training, we scaled the pixel values to the range [0, 1].
- **Data Augmentation:** To enhance model robustness and reduce overfitting, we augmented training images using random horizontal flips and colour perturbations.

2. Model Architecture

The EfficientNetB3 model was chosen due to its balance of accuracy and computational efficiency. The model architecture includes the following:

1. **Base Model**: EfficientNetB3 pretrained on the ImageNet dataset served as the feature extractor. The pretrained layers were frozen during initial training to utilise learnt representations.
2. **Custom Classification Head**:
    - A Batch Normalization layer was added to stabilise and improve the convergence of the network.
    - A Dense layer with 256 units and ReLU activation was included for feature transformation, with regularisation techniques applied to prevent overfitting.

    - A Dropout layer with a rate of 45% was incorporated to further enhance generalisation.
    - The final Dense layer, with 5 units and softmax activation, was used for multi-class classification.

We compiled the model architecture using the Adamax optimiser, a learning rate of 0.001, and categorical cross-entropy loss.

3. Training Strategy

The training process involved:

- **Batch Size**: 40 images per batch.
- **Number of Epochs**: The model was trained for a maximum of 40 epochs with early stopping enabled to prevent overfitting.
- **Learning Rate Adjustment**: A custom callback was used to monitor validation loss and reduce the learning rate by a factor of 0.5 if no improvement was observed for a defined number of epochs (patience of 1).
- Early stopping was implemented with a patience of 3 epochs to terminate training if the model stopped improving.
- For the final evaluation, we saved the best weights based on validation loss performance.

4. Evaluation and Testing

The model's performance was evaluated on both the validation and test datasets. Key performance metrics included:

- **Accuracy**: Used to assess overall model performance.
- **Confusion Matrix:** The Confusion Matrix evaluates class-wise predictions to identify any bias or misclassification trends.
- **Training Curves**: Plotted for loss and accuracy on both training and validation datasets to analyse overfitting or underfitting.

The model achieved:

- Validation Accuracy: **99%**
- Test Accuracy: **99%**

5. Implementation Environment

- **Hardware**: NVIDIA T4 GPU.
- **Software**: TensorFlow 2.0+ and Python 3.7.
- **Development Tools**: Google Colab, which facilitated efficient model training with GPU acceleration.

Results and Discussion

Model Performance

We evaluated the proposed EfficientNetB3-based retinopathy detection model using a dataset of 3,662 retinal fundus images. The model demonstrated exceptional performance, reaching a validation accuracy of 99% and a test accuracy of 99%. The findings (from figures 1 and 2) underscore the model's proficiency in categorising retinal images into five distinct severity levels of retinopathy, demonstrating notable precision and reliability.

Training and Validation Trends

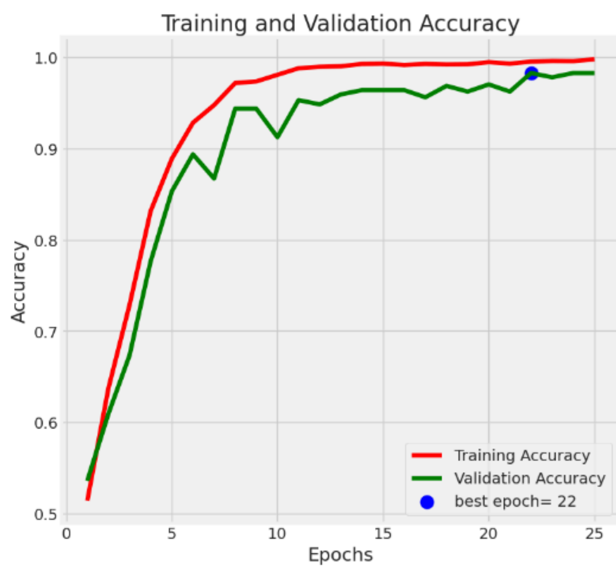

Figure 1: Model's accuracy

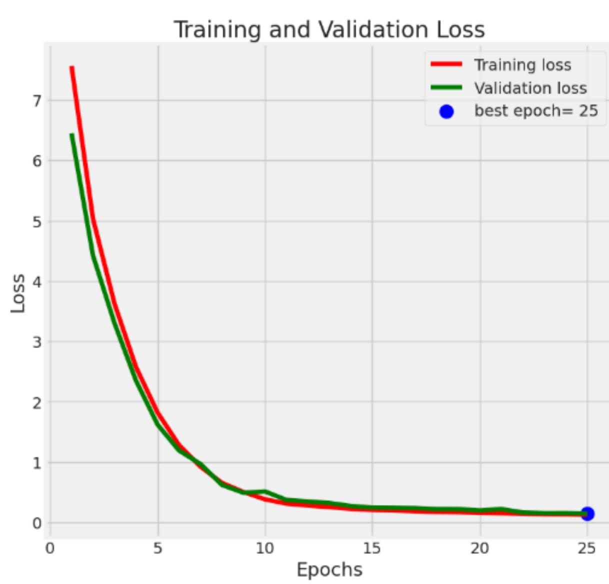

Figure 2: Model's Loss

The model exhibited fast convergence during training, as evidenced by the closely aligned training and validation accuracy curves, suggesting efficient learning and negligible overfitting. The categorical cross-entropy loss exhibited a consistent decline, highlighting the model's reliability. The utilisation of data augmentation and dropout layers significantly improved generalisation performance.

Confusion Matrix Analysis

The confusion matrix demonstrated in Figure 3 shows outstanding performance across all categories, with few misclassifications. The precision and recall for each class were consistently elevated, indicating the model's equitable efficacy in identifying both moderate and severe retinopathy patients.

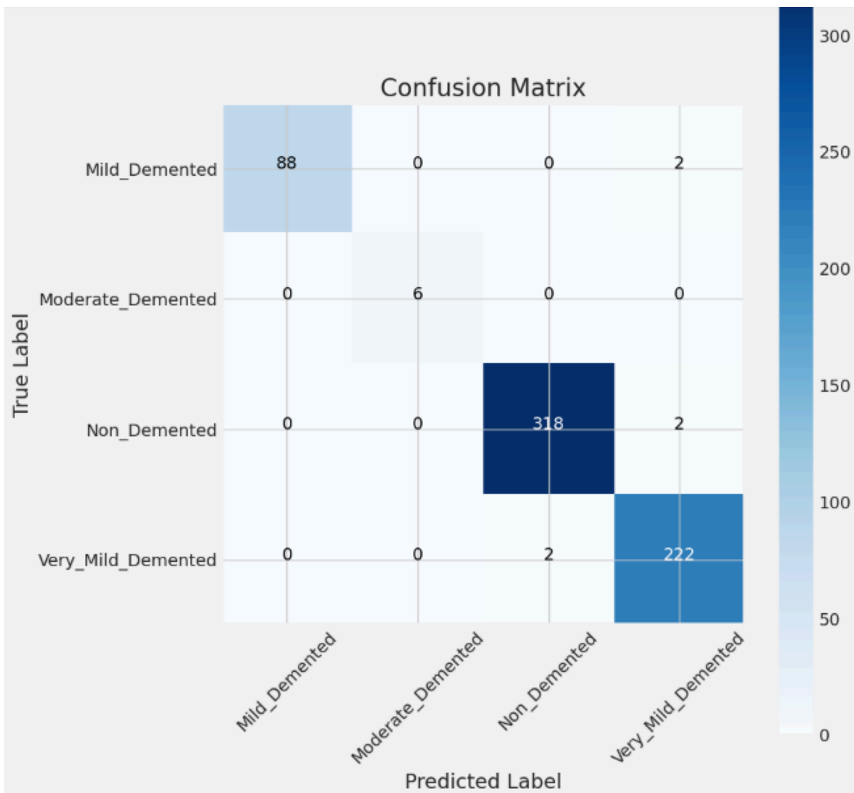

Figure 3: Model's Confusion Matrix

Discussion

The model's performance is evaluated against the models studied in the literature review and listed as follows:

- **Hu et al. (2022)** utilised EfficientNetB3 for the detection of multi-class diabetic retinopathy, attaining an accuracy rate of 92%. The increased accuracy observed in this study is due to the implementation of sophisticated preprocessing methods and efficient hyperparameter optimisation.

- **Shukla et al. (2023)** demonstrated that a hybrid model combining EfficientNetB3 with attention mechanisms reached an impressive accuracy of 94%. Although attention mechanisms improve feature extraction, the model presented here attains higher accuracy with a more straightforward architecture.
- **Zhou et al. (2023)** conducted a sequential analysis of retinal images utilising CNN-RNN hybrid models, achieving an accuracy of 93%. The suggested method circumvents the computational intricacies associated with hybrid models, all while delivering superior outcomes.
- **Qureshi et al. (2021)** demonstrated that attention-guided CNNs attained an accuracy of 91.8% in the detection of microaneurysms. The proposed model shows a wider range of applicability across various severity levels of retinopathy.

7. Conclusion

The suggested model is very accurate, which shows that it could help clinical workflows, especially in places with few resources. By adding the model to telemedicine platforms, healthcare providers can better find retinopathy early and treat it quickly, which lowers the worldwide burden of blindness. The model can also be used on edge devices because it is simple to understand and uses little computing power. This makes its range of uses bigger.

While the results are positive, there are still several things that could be done better:

- Checking how stable the model is by running it on bigger and more varied datasets that include people from different backgrounds and images taken under different situations.
- Looking into attention processes or hybrid models that might help improve feature extraction.
- Using AI methods that can be explained to improve interpretability builds trust among healthcare professionals.

This study shows that EfficientNetB3 is effective at finding retinopathy, which is in line with and even better than what other recent research has found. The results give a strong foundation for future progress in automatic medical imaging technologies.

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Optimizing Industrial Symbiosis: Spatial Impacts on Circular Economy Efficiency

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Optimizing Industrial Symbiosis: Spatial Impacts on Circular Economy Efficiency

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***Abstract*—The transition from a linear 'take-make-dispose' model to a circular economy paradigm necessitates innovative approaches to industrial waste management and resource optimization. This paper introduces an agent-based model to explore industrial symbiosis, a key concept within the circular economy that emphasizes the mutual exchange of by-products between geographically proximate firms. Our model simulates various spatial distributions of companies and their waste by-products, evaluating the impact of geographical proximity and demand-supply matching on circularity and waste reduction. We compare uniform spatial setups with synthetic and real-world population density distributions to assess their effects on the efficiency of by-product exchanges and overall system performance. Preliminary results indicate significant variations in circularity and waste throughput based on spatial arrangements, highlighting the importance of geographical considerations in industrial symbiosis. This study provides insights into optimizing waste flows and closing material loops within industrial parks and offers a foundation for future research on scaling and policy implications in circular economy applications.**

I. Introduction

The 'round economy' is a new methodology on inquiries of supportability. The current 'take, make, squander' approach to delivering is viewed as not manageable any longer. Current contemplations on 'shutting the circle' systems on creating and consuming are blasting in a wide range of scholarly fields. A significant idea inside the round economy is 'modern symbioses'. The fundamental thought of modern symbioses is that generally independent businesses can by and large demonstration to get a common upper hand through the actual trade of materials like energy, water and results and in this way make an ecological benefit too [1]. The modern symbioses approach looks to reuse leftover waste or side-effects through the improvement of complex interlinkages among organizations and firms. In direct differentiation with the traditional straight financial methodology of material creation of produce-use-arrange, the roundabout economy approach looks to decrease the take-up of virgin materials while additionally diminishing all out squander creation by obliging the pattern of materials. This idea is unmistakable from customary reusing by which items are frequently diminished to their most minimal supplement level, and afterward discarded. In a roundabout economy approach, squander or result materials of one firm can possibly turn out to be high supplement level contributions to another firm. Thus, there is definitely not a consecutive minimizing of waste or results, yet rather a full cycling of materials.

A urgent consider modern harmonious cycles is the topographical vicinity of the different modern entertainers. Modern symbioses is about the actual trade of waste/results. To productively trade results, a modern entertainer frequently needs to search for the advantageous potential outcomes in its immediate geological nearness. We can take the case of abundance heat: it would be more diligently to keep it at a similar temperature the further it should be moved. So harmonious exercises and upgrading waste streams will undoubtedly find lasting success on the off chance that the modern entertainers are close to one another. Eco-modern parks are many times thought about substantial acknowledge of the idea modern symbioses . On these parks organizations cooperate to lessen waste and contamination, really sharing different sort of assets and trading results. The key benefit is that these entertainers are found together, consequently trades and framework are simpler understood . Be that as it may, these parks are frequently distant from being independent. To improve 'squander' streams, parks need to trade with entertainers from various parks/geological regions too. This makes enhancing waste stream and 'shutting the circle' systems an exceptionally intricate peculiarity, with entertainers on various levels and with various topographical distances.

So 'shutting the circle' systems in modern harmonious trades have an unmistakable spatial part. Notwithstanding, the job of this spatial part has never been officially explored. While numerous enormous associations, including the EU and the UN, have communicated interest in taking on the a roundabout economy approach, a significant part of the work done as such far has either centered around limited scope applied models or on hypothetical systems and models. Accordingly, more examinations are expected to display the elements impacting everything in the round economy approach, to offer more models and start to offer bigger more summed up instances of how the idea plausibly be achievedẆe propose subsequently in this functioning paper to handle this issue at an unassuming level, by investigating examples of hypothetical possibility from a specialist based demonstrating perspective. It has been as of late proposed that proof based strategies, specifically specialist based demonstrating, could be significant for economy in general[2]. All the more solidly, we concentrate on the impact of various topographical ideas on the working of a harmonious framework overall, through a specialist based model. In this model entertainers are situated on a spatial plane. Every entertainer has an info and a result concerning necessities and waste. The objective of the specialists is to limit the waste and amplify their efficient benefit. First we concentrate on whether there is a spatial impact on the working of the framework by contrasting a uniform spatial circulation and a hypothetical certifiable conveyance and an observational dissemination. Also, we concentrate on the impact of geologically matching the entertainers on their feedback and result on the working of the framework. In what follows we will introduce the reasoning of the fundamental model as well as its investigation, at last introducing the following starter results.

II. Model description

Model Core

a) Model setup: The center piece of the model is expected to occur at a solitary scale, yet with variable spatial reach. The specialists are N organizations ordered by $1 \leq i \leq N$, that have a decent spatial position $\vec{x}_i$. To zero in on the trading of side-effects as contributions for different organizations, we decide not to display the powerful item nor the "outside" inputs. For effortlessness, results are thought to be depicted by a limited layered genuine variable $\vec{y} \in \mathbb{R}^d$. Limited values are a sensible space for side-effects qualities as it permits to standardize along every hub and take $\vec{y} \in [0,1]^d$. Each organization has an interest capability and a deal capability, which were utilized to lay out joins between sets of organizations (for example trade of side-effects). These capability are characterized in a basic way by $\vec{D}_i(\vec{y}) = D_i^{(0)} \cdot \vec{d}_i(\vec{y})$ and $\vec{O}_i(\vec{y}) = O_i^{(0)} \cdot \vec{o}_i(\vec{y})$, where $\vec{d}_i$ and $\vec{o}_i$ are multivariate likelihood densities. We began our reenactment with a bunch of organizations that were not connected with one another, and afterward developed the organization in light of rules deciding trade of results (successfully making joins between organizations).

b) Growing the roundabout economy network: The fleeting extent of the model development was thought to be at a mesoscopic time scale, following the supposition that organizations confinement and the encompassing metropolitan climate (which incorporates the transportation cost scene) stay consistent. The transient elements comprise of organization development, for example the ever-evolving foundation of integral connections between organizations that compare to streams of side-effects.

Two elements were utilized to lay out joins between organizations (for example trade of results): 1) the geological distance isolating them, and 2) the match among request and deal. The geological association potential (V_{ij}; for example likelihood of two organizations cooperating in view of their geological area) diminished dramatically with distance like $V_{ij} = \frac{1}{d_{ij}^{\alpha}}$ Expanding geological distance likewise implied expanding transportation cost (in a straight design). The match between an organization's deal (for example what it squanders after creation) and another organization's interest (for example what it could use for creation) was registered along a "result" pivot (a theoretical side-effect one-layered space, which could later be summed up to a multi-layered space). Along this side-effect pivot, the proposition capability and an interest capability of each organization are addressed by a gaussian thickness conveyance. We figured the cross-over between sets of interest and deal capabilities $o = \int min(O,D)dx$ - a higher cross-over demonstrating a higher likelihood that the two organizations trade results - and utilized a cross-over limit T_o above which organizations might actually trade side-effects. This demonstrating approach was propelled by the biological writing on likelihood specialty models in complex food networks [3], [4]. In these models, predation communication between two species was displayed as the likelihood of species I eating one more animal types j in view of their qualities along a "specialty" hub. All the more explicitly, species I has a taking care of ideal and the likelihood of eating species j declines has the specialty position of species j gets further from this taking care of ideal, which was model utilizing a Gaussian focused on the taking care of ideal.

The utility capability related with every expected trade of results between two organizations was characterized as follows:

$$u = o - c \cdot \frac{d}{d_{max}}$$

where o is the cross-over between the two organizations in side-effect space, c is the transportation cost, d is the topographical distance between the two organizations, and d_{max} is the greatest distance between any two organizations in the framework.

In our model, at each time step, the accompanying arrangement of rules was applied:

> An organization, the "current worker for hire" is drawn indiscriminately Potential accomplices are drawnas indicated by topographical collaboration likely $V_{ij} = \frac{1}{d_{ij}^{\alpha}}$ among these, the ones whose cross-over is above T_o are taken as likely accomplices

given the arrangement of utilities $(u_{1j}, u_{j1})_j \simeq (u_j)_j$, the expected join forces with best utility is picked

c) Indicators of Circularity: The circularity of the model was assessed utilizing the technique for Haas et al.[5]. The creators characterize the *degree of circularity* inside an economy as reusing as a level of handled materials. *Processed materials* are characterized as the amount of utilization of materials (contribution to the framework) and reused materials. The creators further characterize the pointer *waste throughput* as the waste result as a level of handled materials.

For a given model run with n organizations and W all out squander yield, the three markers can be determined as follows (see Figure 1 for visual portrayal of factors):

Handled Materials (PM):

$$PM = IM + RM = n + (n - W)$$

where IM is the all out material info (i.e., the quantity of organizations n, considering that each organization requires one unit of info), and RM is the reused materials (i.e., IM, or n, less absolute waste W). Level of Circularity (DC):

$$DC = \frac{RM}{PM} = \frac{RM}{IM + RM} = \frac{n - W}{n + (n - W)}$$

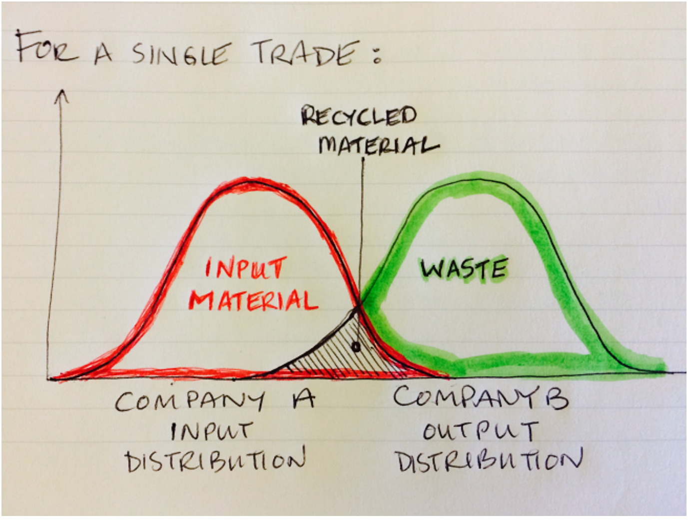

Fig. 1. Variables used in calculation of indicators, as determined for one trade between companies (redraw for final paper). Total material input, IM, is the sum of input material for all companies; total recycled materials, RM, is the sum of recycled material for all companies; the total waste, W, is the sum of waste for all companies.

Waste Throughput (WT):

$$WT = \frac{W}{PM} = \frac{W}{n + (n - W)}$$

In their review, [5] gauge these markers for the worldwide and European economies. The creators observed that the complete handled materials in the worldwide economy is 62 Gt/year (58 Gt/year natural substance in addition to 4 Gt/year reused), and the level of circularity is 6

d) Geographical setup: The underlying place of organizations can be arrangement in numerous ways. The most essential case is a spatial uniform conveyance of directions, and the model is first tried on it. A more refined spatialization should be possible given a populace thickness field $d(\vec{x})$. Expecting a neighborhood scaling of organizations number as an element of populace of a city N (not checked at a limited scale, yet more sensible at a perceptible scale), $Y \sim N^{\alpha}$, we take the likelihood for a firm to situate in a fix as a component of its populace $\mathbb{P}\left(\vec{x}_i = \vec{x}|i\right) \propto \left(\frac{N(\vec{x}}{\sum N}\right)^{\alpha}$. Organizations are hence found consecutively at arbitrary, given these likelihood. Populace dissemination can be artificially created, as a portion blend $P(\vec{x}) = \sum_{1 \leq j \leq p} K_j(\vec{x})$ with p number of urban communities (or ”focuses”), and bits $K_j(\vec{x}) = \cdot \exp - \frac{||\vec{x} - \vec{x}_j||}{r_0}$ where x_j is irregular with uniform circulation and r_0 is registered to such an extent that the city framework regards Zipf rank-size regulation with example γ (comparable qualities at beginning expect a steady maximal focus thickness across urban areas), for example to such an extent that $P_j = \iint K_j \propto \frac{1}{j^{\gamma}}$. For genuine framework, we utilize the raster populace thickness with 1km goal from CIESIN[6].

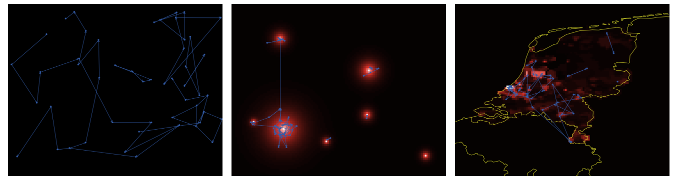

Fig. 2. Examples for three possible geographical setups (from left to right, uniform, synthetic city system, real density data)

III. Results

Uniform spatialization: We ran first experiments with a uniform initial distribution. Figures 6 and 7 in Supplementary Material show heatmaps and Pareto front.

Synthetic city system: See repository for figures for similar experiments with synthetic system

Real city system: **Interesting result** : qualitative transition when changing from uniform to real system - implications for decision making ; importance to embed in a real urban system.

Patterns of Policy Optimization to Grow the Circular Economy

A theoretical utilization of the model yield in the investigation of potential arrangement improvement. We follow the reasoning that the strategy creators can impact on certain boundaries just, under the supposition that : (1) Transportation boundaries are fixed by exogenous circumstances, that incorporate among different elements transportation framework and energy cost. These perspectives fall affected by strategies at an alternate level (both for degree and inclusion) ; and (2) Conveyance width is fixed, comparing to the proper modern design (generally adapted in our model), which transient size of progress is fundamentally bigger in extent that the one of the model.

In that specific circumstance, the strategy creator can impact the communication range (gravity rot d_0) by giving motivations for cooperation between organizations or a superior course of data for instance, and the joint effort edge, likewise with impetuses or mechanical assistance. These boundaries compare to present moment generally simple to-execute strategies . We concentrate on enhancement designs on the boundary plan (d_0, σ).

Spatial correlation input and output distribution

In Table I regression results are shown with the amount of recycled materials (RM) in the system as dependent variable for a syntactic city system. The total amount of RM has a minimum of 0 and a maximum of 50 over all simulations. We used two important spatial predictors, all other model parameters are fixed. The first spatial variable distance decay, which is function defining interaction potential between two actors, defined as $exp(-(d_{ij}/\delta))$, where d_{ij} is the Euclidean distance between agent i and agent j and δ is the distance decay parameter. For this example we chose $\delta \in \{0.5, 1, 1.5, 2\}$ The second spatial parameter is the Length correlation between input and output distributions, which is a measure for how well the input and output distributions are matched by geographical

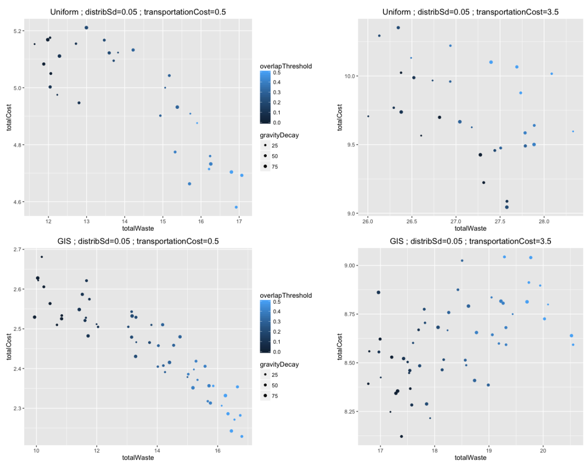

Fig. 3. **Different qualitative patterns of Optimization.** We compare the Pareto fronts for the bi-objective optimization on cost and remaining waste, for both uniform setup (first row) and gis geographical setup (second row).

TABLE I
REGRESSION RESULTS FOR THE AMOUNT OF RECYCLED MATERIALS IN THE SYSTEM

	Dependent variable:
	Recycled Materials (RM)
Distance decay 1	7.101*** (0.164)
Distance decay 1.5	13.045*** (0.164)
Distance decay 2	17.503*** (0.164)
poly(Length correlation)1	−0.640 (0.985)
poly(Length correlation)2	21.561*** (2.312)
Constant	2.846*** (0.133)
Observations	2,480
R^2	0.841
Note:	*p<0.1; **p<0.05; ***p<0.01

location. In the synthetic city system and real population density spatial setup, the distance decay can be interpreted as the probability that companies between 'centers' (cities or industrial parks) interact and the Length correlation is the probability that actors within 'centers' can interact.

As can be seen from Table I both predictors together explain 84.1 percent of the variance in this particular setting. Not surprisingly as the Distance decay goes up (and the interaction probability goes up as well), the amount of recycled materials goes up as well. For Length correlation we find a quadratic effect. To get a better overview of what this means the standardized predicted DC scores are plotted in Figure 4 (interactions included). Low Length correlation hardly have any effect on the predicted Degree Circularity of the system, only at high length correlations, 0.4 or higher, does the correlation have effect. These results seem to suggest that matching companies to be located within the same center/city/industrial park only has an effect when the matching is very strict.

IV. Discussion

In this working paper we introduced the basis of an agent based model for modeling industrial symbiotic processes.

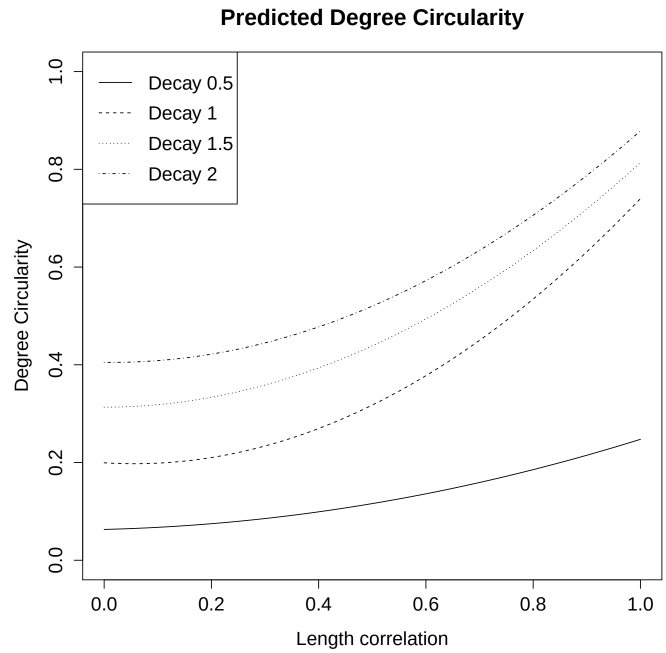

Fig. 4. Plot of predicted Degree Circularity

Industrial symbioses is about 'closing the loop' mechanisms with a clear spatial component. It is therefore interesting to study the effect of these spatial interaction on the functioning of the system as a loop. Our first results indicate that there are clear differences when the model runs on a uniform spatial distribution compared to a synthetic city system or a real world density data. Secondly we found that matching companies in industrial parks only has an effect when the correlation between input materials and waste product is higher than 0.4. This abstract result implies that the design of industrial parks requires some strict central planning to match industrial actors in the same geographical proximity.

Model Extensions

Various possible model extensions for the basic model include for example :

- Bargain games with more than two players, implying game-theory framework to establish links among potential partners
- Random Utility Models

Model extensions for the final paper will be:

- A Google maps integration
- Calibrated to real-world data

The goal for later papers is to make a basis for an open source circular economy application that can be used to monitor the circular economy, as well as create a market place for waste products.

V. Conclusion

In this work, we introduced an agent-based model designed to simulate and optimize industrial symbiotic processes, with a particular focus on the spatial interactions between industrial actors. By exploring various spatial distributions, including uniform, synthetic city setups, and real-world density data, we demonstrated that spatial configurations significantly influence the performance of the system, particularly in terms of the amount of recycled materials. Notably, our findings suggest that effective industrial park designs and strategies for industrial symbiosis must prioritize strict matching of companies based on the correlation between their input materials and waste products. These results highlight the importance of spatial planning in closing the loop of industrial symbiosis and optimizing the circular economy.

Furthermore, the analysis of policy optimization patterns underscored the importance of short-term policies, such as adjusting the gravity decay parameter and the collaboration threshold, to enhance collaboration among companies and reduce waste. Our results provide a foundation for further research into the implementation of policies aimed at promoting sustainable, circular systems in urban and industrial settings.

VI. Future Work

The next steps in this research include several exciting extensions to refine and expand upon the model. One of the main goals is to enhance the model's applicability by incorporating real-world data, particularly from urban and industrial contexts. This will include calibrating the model using actual city data and integrating geospatial platforms, such as Google Maps, to simulate the system at a finer scale. Additionally, we plan to investigate more sophisticated modeling techniques, such as incorporating game-theory frameworks for multi-agent bargaining and Random Utility Models to better represent decision-making processes among industrial actors.

Another important direction for future work is the development of an open-source tool for monitoring and promoting the circular economy. This platform could serve as both a marketplace for waste products and a tool for policymakers to assess the effectiveness of various strategies to promote sustainability. Additionally, integrating dynamic elements into the model, such as evolving transportation infrastructure and changing energy prices, would enable the simulation of more realistic and adaptable policy interventions.

In conclusion, this paper lays the groundwork for a robust simulation tool that can inform decision-making in urban planning and industrial policy. Future developments will seek to refine this model, enhance its integration with real-world data, and ultimately contribute to advancing the circular economy.

VII. Supplementary Materials

Model Exploration

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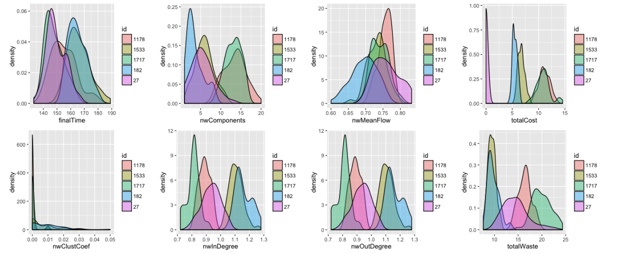

Fig. 5. Statistical distribution of indicators for some points in the parameter space.

Fig. 6. Heatmaps of indicator values in the 4-D parameter space

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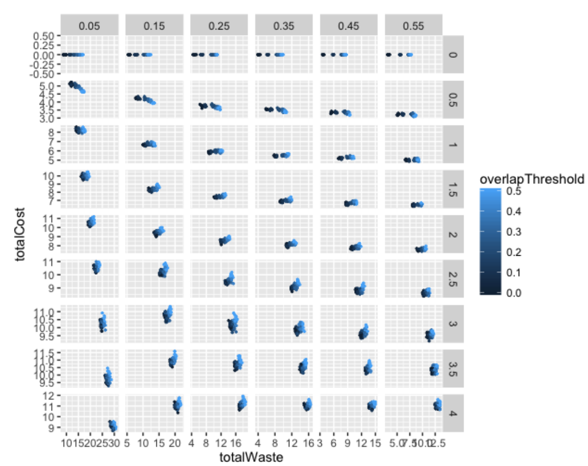

Fig. 7. Pareto fronts of total waste against total cost, at fixed values of transportation cost and distribution standard deviation.

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A Comparative study on Consumers and their response towards Online and Offline Marketing in today's time

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A Comparative study on Consumers and their response towards Online and Offline Marketing in today's time

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Abstract:

With the advent of massive changes in technology nowadays, this research paper has analyzed the various online and offline marketing strategies. The purpose of this study is to identify various marketing strategies in both online and offline platforms and their effects in developing influencing factors towards the purchase of any product and consumers commitment to the brand's product. We have tried to throw light on the effects of integrated marketing communication on both online and offline purchases by consumers in this contemporary era. We have attempted to provide clearer pros and cons of both online and offline marketing, sales and promotions which can bring about significant variations in the number of profits earned by the brand's company. The convenience factor for the customer in making online or offline purchases partially results in the effectiveness of brand's marketing strategies. This shows a connecting chain between consumer ease, convenience, promotions, flexibility and the effectiveness of the marketing strategy, consumer satisfaction, consumer commitment and brand loyalty. The research also tries to study consumers behaviour during Covid 19 and post Covid 19.

Keywords: Consumer commitment, Virtual, Contemporary, Customization.

Introduction

In the constantly evolving field of marketing today, companies are always looking for new and creative ways to interact with their target market and create lasting relationships. Approximately 51 percent of Indian marketers intended to devote about 10% of their budgets to online marketing technology, per a survey conducted in 2022 of marketing experts. For any individual responsible for brand development in this digital age, combining offline and online marketing efforts is essential and almost a given. The most important and difficult aspect of this blend is maintaining the discipline to use the same messaging across all platforms.

An amusing side for the digital world and a functional aspect for the offline world is incompatible. Brands must maintain a consistent brand image, while obviously adjusting their messaging according to the target demographic. Marketing strategies and its trend have changed dramatically with the advent of the internet and while traditional media is also seeing a tremendous changes in the industry.

The conventional offline promotional strategy is unlikely to fade out of style and will remain a vital tool for spreading your brand's message and fostering close relationships with every demographic of masses. Additional opportunities to personalize, derive feedback, test smaller groups, and to enhance brand’s messaging are provided by digital. One-way interaction has given way to two-way communication. Brands can target particular audiences and maximize the impact of your promotional activities by using a data-driven approach and scalability. Businesses can develop comprehensive marketing plans that leverage each of these two potent tactics' distinct advantages by combining them.

Also, customers are collaborating among themselves through social networking dedicated groups, blogs and sharing information and feedback about products and services. They share their response via online platforms by reviewing, rating, commenting and sharing their experiences. Brands are collaborating with customers in real time and this has affected the whole supply chain and the way company interacts with customers whose interactions can be monitored and tracked by using the internet.

Cities, states, continents, and humans are now interconnected thanks to technology. Individuals In recent years, individuals from all over the world have similar hobbies, likes and dislikes ways of living, and accessibility. By enabling customers to buy goods from around the globe, online shopping reduced walls and paved the way for globalization.

The lifestyles of individuals have evolved since the invention of the Internet, as utilizing it has become mainstream. The rise in online marketing strategies influences consumers spending on products and services.

Consumers' opinions and behavior about their purchase of goods and services vary greatly depending on their upbringing, personal preferences, and habits. Online shopping extends a consumer's horizons and eases restrictions and limits across the globe, yet some consumers preferring to visit storefronts to fulfil their wants instead of using this technology. the fact whether a business is online or not, maintaining customer satisfaction and loyalty is crucial to increasing profitability, generating trust among rivals, and taking the lead. Customers are also the primary differentiators for any organization, whether it operates online or offline.

Review of Literature:

(Chaitanya Vyas and Ritu Sharma , 2018) stated in their paper that both offline and online applications can be important aspects for figuring out what influences college students when they are making judgements about the most important aspect of their lives. When it comes to making decisions, this age consumers group has the greatest influence by their peers. It would be feasible to look into the causes of this further. It was interesting to see that social media plays a small part in comparison with fact-based information and direct feedback, although the fact that its influence on this generation's time is incontrovertible. The results can help those individuals that are involved in creating effective marketing strategies to create the ideal combination of informative platforms for marketing.

(**Dan Jong Kim, Bongsoon Cho and H. Raghav Rao**) in this research paper the authors have focused on how the buying habits of consumers is influenced by their perceptions of risk and benefit. then framed the hypothesis based on consumer lifestyle parameters such as price-oriented, net-oriented, and time-oriented purchasing habits, and then polled 306 samples. The assumption was actually tested using the chi square test. Following the hypothesis' testing, they come to the conclusion that "customers who lead more net-conscious lifestyles benefit more from online shopping than do consumers who lead less net-conscious behaviours. Customers who place a higher value on price also benefit more from online shopping, indicating that they can afford the purchasing price of the product they choose when making an online purchase.

(MacDonald, 2023) consumers response to following offline marketing strategies by brands results in boosting sales as well as creating brand awareness. Consumers response by saying they feel that they still have an appetite for messages or promotional strategies that non-traditional. By using Direct mail, Community engagement, Trade shows, promotional events, press realises, samples, discounts, billboards, seasonal cards and much more techniques, responses response to these as being creative, unique and engaging. The author further suggested to the organisation that the organization's first aim will always be to use technology to efficiently reach customers where they are—on social media, in emails, or while surfing the internet. However, offline approaches—the foundation of acquiring and keeping customers—remain a helpful reminder that your clients are more than just phone users.

(Aakansha Shetty and Shravya Doopad, 2018) in their paper concluded that both online and offline media have advantages and disadvantages have been reached through analysis of both online and offline marketing tactics. In today's technologically advanced world, the online medium is more productive and more efficient. Online shopping is preferred by consumers because, in addition to the main benefit of door delivery, it also permits the exchange of goods. Customers find it less time-consuming as a result, and they may use that time for other, more productive tasks. Because there is no guarantee of the product's quality or its actual quality and because customers lack bargaining power, the drawback of online shopping is that they may be fraudulent. Though they depend on different approaches, both offline and online marketing strategies are ultimately aimed at achieving the company's goals. A level of customer convenience affects how effective a marketing strategy is, which in turn affects customer satisfaction. Consumer satisfaction is also partially influenced by the customer's degree of commitment.

Methodology:

The researcher has done a qualitive approach to analyse the consumers and their responses as well as preference towards offline and online marketing strategies by brands. By choosing this approach, researchers can freely investigate as well as gather data from informants, ensuring that the results accurately represent opinions and reality. This study guarantees that the responses are accurate and comprehensive, in line with the informant's terminology and viewpoint, by giving respondents the freedom to openly express their opinions. In order to analyze the offline and online advertising campaigns, we have used secondary data through journals and articles.

Conclusion

The comparison between online and offline marketing strategies was going to be unstoppable and incomparable as per consumers. They feel that this topic was never ending in the current scenario. Both offline and online marketing strategies were important as consumers are scattered widely and rely on one or more than one sources of communication. The techniques used in marketing the brands and their products created positive and negative responses depending upon their attitudes, satisfaction level, experiences and so on. It was made obvious a company's online and offline channels must coincide in terms of pricing, promotion, product range, and brand image in order to actively meet customer expectations. In the interim, a company's technology, product details, and fulfilment should be planned to seamlessly combine the two channels. When businesses use this strategy, consumers are able to convince themselves that their interactions with the brands online and offline channels are effortless. Convenience and availability refer to the reduction of the period of work that customers must do when utilizing several channels. Additionally, removing any ambiguity about potential variations between the channels is necessary for customer knowledge so that they may comprehend and, consequently, accept them. At the extremely least, maintaining a consistent branding strategy entail removing any ambiguities resulting from consumers perceiving that the same brand does not meet their needs both online and offline. Consumers can perceive the experience as seamless when there are no disturbances in the use of the company's online and physical channels. Therefore, the degree to which customers believe that a company's online and offline channels are continuous is influenced by their opinions of availability, ease, and customer comprehension as well as an integrated brand personality.

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Life Cycle and Wealth in Heterogeneous Agent Models

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Life Cycle and Wealth in Heterogeneous Agent Models

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***Abstract*—Heterogeneous Agent Models (HAM) like Heterogeneous Agent New Keynesian (HANK) models are instrumental in assessing the impact of monetary and fiscal policies on the economy. However, existing frameworks face challenges in accurately representing real-world economic dynamics, particularly in replicating wealth distribution and incorporating life cycle properties. This paper explores the integration of life cycle considerations and wealth in the utility function into structural estimation of HAMs. By addressing these limitations, the study aims to develop more robust models that better inform policy decisions. The investigation utilizes both separable and non-separable wealth in utility function models, employing simulated moments estimation and data from the Survey of Consumer Finances (SCF). The findings shed light on the efficacy of these enhancements and their implications for understanding economic phenomena and policy formulation.**

I. Introduction

Increased computational power has allowed economists to focus on more complex models of household consumption and saving. In particular, Heterogeneous Agent Models (HAM) have become a popular tool to analyze households' response to aggregate economic shocks in the face of uncertainty. Nevertheless, current state-of-the-art models have struggled to replicate the distribution of wealth at the very top of the distribution and the extent of wealth inequality. A new class of models, the Heterogeneous Agent New Keynesian (HANK) models, have taken the literature by storm and become the standard for analyzing the effects of monetary and fiscal policy[1]. Even HANK models, however, inherit the inability to capture the distribution of wealth from their predecessors. Moreover, they also lack important life cycle properties such as time-varying preferences, household composition, and mortality and income risk. These limitations make the workhorse HANK models ill-suited for analyzing the effects of economic shocks and policy on the spectrum of households in the economy, from young families with children to retirees, and in particular, on the most vulnerable households among these subgroups. In this paper, I investigate the effects of both life cycle considerations as well as wealth in the utility on the structural estimation of HAMs. Thorough this effort, we hope to contribute to the development of better models of the economy that can be used to inform policy.

[5] demonstrates that the rich have higher lifetime savings rates[2] which can not be explained by models of consumption smoothing and precautionary savings alone. Instead, he argues that the simplest model that accounts for this is one with wealth in the utility function. This is because households either derive utility from the accumulation wealth itself or wealth provides a flow of services such as political power and social status. In either case, this pattern of higher savings can be modeled by putting wealth directly in the utility function. In his paper, he proposes the use of additively separable utility of wealth and consumption[3], which we will explore in this paper. Additionally, however, we will also explore the use of non-separable utility of consumption and wealth. With non-separability of utility, we obtain a model that allows for a marginal utility of consumption that is increasing in wealth even while it is decreasing in consumption. This dynamic complementarity between consumption and wealth is a key feature of our model that induces a strong savings motive for the rich.

Wealth Inequality has been a persistent problem for the HAM literature[4]. Models with entrepreneurship, preference heterogeneity, habit formation, bequest motives, human capital, and large earnings risk have had varying degrees of success in replicating the distribution of wealth. However, these models have been unable to account for the fat tail in the distribution. Recent research highlights the importance of savings among the richest in the United States and its distributional effects. [11] find that the rise in savings by the richest households in the U.S. over the last 40 years is strongly associated with dissaving by the non-rich and the government, in the form of debt, which might have implications for the rise in household debt and declining interest rates in the last few decades. Similarly, [12] find that as non-rich households spend down their excess savings, the incomes of the rich rise, which in turns leads to an increase in their excess savings. This movement of savings across the distribution leads to a prolonged increase in aggregate demand and can dampen the effects of monetary policy. [13] present a similar model within the HANK literature that includes wealth in the utility function. However, because this paper uses continuous time methods, it is unable to capture the life cycle properties of more realistic models.

The purpose of this paper is to investigate the effects of wealth in the utility function as well as life-cycle properties on the structural estimation of HAMs. By using wealth in the utility function, we can better match the top of the wealth distribution and the motives for wealth accumulation. Also,

[1]See [1], [2], [3], and [4], among others.

[2]See also [6].

[3]Also see [7], which uses additively separable utility of wealth and consumption to explain the portfolio choices of the rich.

[4]See [8], [9], [10], for surveys on the topic.

by parameterizing a rich model of life cycle properties such as age-specific and household-size-adjusted preferences, and mortality and income risk, we can better understand the effects that economic shocks and policies have on young working families, workers saving toward retirement, and retirees. In particular, we can better understand the effects of monetary policy on the distribution of wealth and consumption across the life cycle.

The remainder of the paper is organized as follows. Section 2 provides the baseline models and alternative specifications with wealth in the utility function. Section 3 describes the solution methods used to solve these models. Section 4 describes the quantitative strategy used to calibrate and estimate the models, followed by sensitivity analysis of the results. Finally, Section 5 contains closing remarks and future directions.

II. Life Cycle Incomplete Markets Models

An important extension to the Standard Incomplete Markets (SIM) model is the Life Cycle Incomplete Markets (LCIM) model as in [14], [15], and [16], among others. The LCIM model is a natural extension to the SIM model that allows for age-specific profiles of preferences, mortality, and income risk.

A. The Baseline Model

The agent's objective is to maximize present discounted utility from consumption over the life cycle with a terminal period of T:

$$\mathrm{v}_t(\mathbf{p}_t, \mathbf{m}_t) = \max_{\{\mathrm{c}\}_t^T} \mathrm{u}(\mathbf{c}_t) + \mathbb{E}_t \left[\sum_{n=1}^{T-t} \beth^n \mathcal{L}_t^{t+n} \hat{\beta}_t^{t+n} \mathrm{u}(\mathbf{c}_{t+n}) \right] \tag{1}$$

where $\mathbf{p}_t$ is the permanent income level, $\mathbf{m}_t$ is total market resources, $\mathbf{c}_t$ is consumption, and

$$\beth : \text{ time-invariant 'pure' discount factor} \tag{2}$$

$$\mathcal{L}_t^{t+n} : \text{ probability to } \mathcal{L}\text{ive until age } t+n \text{ given alive at age } t \tag{3}$$

$$\hat{\beta}_t^{t+n} : \text{ age-varying discount factor between ages } t \text{ and } t+n \tag{4}$$

It will be convenient to work with the problem in permanent-income-normalized form as in [17], which allows us to reduce a 2 dimensional problem of permanent income and wealth into a 1 dimensional problem of wealth normalized by permanent income. The recursive Bellman equation can be expressed as:

$$\begin{aligned}
\mathrm{v}_t(m_t) = \max_{c_t} \ & \mathrm{u}(c_t) + \\
& \beth \mathcal{L}_{t+1} \hat{\beta}_{t+1} \mathbb{E}_t[(\mathbf{\Psi}_{t+1}\mathbf{\Phi}_{t+1})^{1-\rho} \mathrm{v}_{t+1}(m_{t+1})] \\
& \text{s.t.} \\
\mathrm{aNrm}_t &= m_t - c_t \\
m_{t+1} &= \mathrm{aNrm}_t \underbrace{\left(\frac{\mathsf{R}}{\mathbf{\Psi}_{t+1}\mathbf{\Phi}_{t+1}} \right)}_{\equiv \mathcal{R}_{t+1}} + \boldsymbol{\theta}_{t+1}
\end{aligned}$$

where c, aNrm, and m are consumption, assets, and market resources normalized by permanent income, respectively, v and u are now the normalized value and utility functions, and

$$\begin{aligned}
\mathbf{\Psi}_{t+1} &: \text{mean-one shock to permanent income} \\
\mathbf{\Phi}_{t+1} &: \text{permanent income growth factor} \\
\boldsymbol{\theta}_{t+1} &: \text{transitory shock to permanent income} \\
\mathcal{R}_{t+1} &: \text{permanent income growth normalized return factor}
\end{aligned}$$

with all other variables are defined as above. The transitory and permanent shocks to income are defined as:

$$\boldsymbol{\theta}_s = \begin{cases} 0 & \text{with probability } \wp > 0 \\ \xi_s/\wp & \text{with probability } (1-\wp), \text{ where} \\ & \log \xi_s \sim \mathcal{N}\left(-\frac{\sigma_{[\xi,t]}^2}{2}, \sigma_{[\xi,t]}^2\right) \end{cases}$$

$$\text{and } \log \mathbf{\Psi}_s \sim \mathcal{N}\left(-\frac{\sigma_{[\mathbf{\Psi},t]}^2}{2}, \sigma_{[\mathbf{\Psi},t]}^2\right).$$

B. Wealth in the Utility Function

A simple extension to the Life Cycle Incomplete Markets (LCIM) model is to include wealth in the utility function. [5] argues that models in which the only driver of wealth accumulation is consumption smoothing are not consistent with the saving behavior of the wealthiest households. Instead, they propose a model in which households derive utility from their level of wealth itself or they derive a flow of services from political power and social status, calling it the 'Capitalist Spirit' model. In turn, we can add this feature to the LCIM model by adding a utility function with consumption and wealth. We call this the Wealth in the Utility Function Incomplete Markets (WUFIM) model.

$$\begin{aligned}
\mathrm{v}_t(m_t) = \max_{c_t} \ & \mathrm{u}(c_t, \mathrm{aNrm}_t) + \\
& \beth \mathcal{L}_{t+1} \hat{\beta}_{t+1} \mathbb{E}_t \left[(\mathbf{\Psi}_{t+1}\mathbf{\Phi}_{t+1})^{1-\rho} \mathrm{v}_{t+1}(m_{t+1}) \right] \\
& \text{s.t.} \\
\mathrm{aNrm}_t &= m_t - c_t \\
m_{t+1} &= \mathrm{aNrm}_t \mathcal{R}_{t+1} + \boldsymbol{\theta}_{t+1}
\end{aligned}$$

Separable Utility [5] presents extensive empirical and informal evidence for a LCIM model with wealth in the utility function. Specifically, the paper uses a utility that is separable in consumption and wealth:

$$\mathrm{u}(c_t, \mathrm{aNrm}_t) = \frac{c_t^{1-\rho}}{1-\rho} + \alpha_t \frac{(\mathrm{a}_t - \underline{\mathrm{aNrm}})^{1-\delta}}{1-\delta} \tag{5}$$

where α is the relative weight of the utility of wealth and δ is the relative risk aversion of wealth.

Non-separable Utility A different model that we will explore is one in which the utility function is non-separable in consumption and wealth; i.e. consumption and wealth are complimentary goods. In the case of the LCIM model, this dynamic complementarity drives the accumulation of wealth not only for the sake of wealth itself, but also because it increases the marginal utility of consumption.

$$\mathrm{u}(c_t, \mathrm{aNrm}_t) = \frac{(c_t^{1-\delta}(\mathrm{aNrm}_t - \underline{\mathrm{aNrm}})^{\delta})^{1-\rho}}{(1-\rho)} \tag{6}$$

III. Solution Methods

For a brief departure, let's consider how we solve these problems generally. Define the post-decision value function as:

$$\begin{aligned} \beta_{t+1}\mathrm{w}_t(\mathrm{aNrm}_t) &= \beth\mathcal{L}_{t+1}\hat{\beta}_{t+1}\mathbb{E}_t\left[(\mathbf{\Psi}_{t+1}\mathbf{\Phi}_{t+1})^{1-\rho}\mathrm{v}_{t+1}(m_{t+1})\right] \\ \text{s.t.} & \\ m_{t+1} &= \mathrm{aNrm}_t\mathcal{R}_{t+1} + \boldsymbol{\theta}_{t+1} \end{aligned}$$

For our purposes, it will be useful to simplify the notation a bit by dropping time subscripts. The recursive problem can then be written as:

$$\begin{aligned} \mathrm{v}(m) &= \max_c \; \mathrm{u}(c, \mathrm{aNrm}) + \beta \cdot \mathrm{w}(a) \\ \text{s.t.} & \quad \mathrm{aNrm} = m - c \end{aligned} \tag{7}$$

A. Endogenous Grid Method, Abridged

In the standard incomplete markets (SIM) model, the utility function is simply $\mathrm{u}(c)$ and the Euler equation is $\mathrm{u}'(c) = \beta\mathrm{w}'(\mathrm{aNrm})$, which is a necessary and sufficient condition for an internal solution of the optimal choice of consumption. If $\mathrm{u}(c)$ is differentiable and its marginal utility is invertible, then the Euler equation can be inverted to obtain the optimal consumption function as $c(\mathrm{aNrm}) = \mathrm{u}'^{-1}(\beta\mathrm{w}'(\mathrm{aNrm}))$. Using an *exogenous* grid of post-decision savings $[\mathrm{a}]$, we can obtain an *endogenous* grid of market resources $[\mathrm{m}]$ by using the budget constraint $m([\mathrm{a}]) = [\mathrm{a}] + c([\mathrm{a}])$ such that this collection of grids satisfy the Euler equation. This is the endogenous grid method (EGM) of [18].

In the presence of wealth in the utility function, the Euler equation is more complicated and may not be invertible in terms of optimal consumption. Consider the first order condition for an optimal combination of consumption and savings, denoted by *:

$$\mathrm{u}'_c(c^*, \mathrm{aNrm}^*) - \mathrm{u}'_a(c^*, \mathrm{aNrm}^*) = \beta\mathrm{w}'(\mathrm{aNrm}^*) \tag{8}$$

If the utility of consumption and wealth is additively separable, then the Euler equation can be written as $\mathrm{u}'_c(c) = \mathrm{u}'_a(\mathrm{aNrm}) + \beta\mathrm{w}'(\mathrm{aNrm})$. This makes sense, as the agent will equalize the marginal utility of consumption with the marginal utility of wealth today plus the discounted marginal value of wealth tomorrow. In this case, the EGM is simple: we can invert the Euler equation to obtain the optimal consumption policy as $c(\mathrm{aNrm}) = \mathrm{u}'^{-1}_c\big(\mathrm{u}'_a(\mathrm{aNrm}) + \beta\mathrm{w}'(\mathrm{aNrm})\big)$. We can proceed with EGM as usual, using the budget constraint to obtain the endogenous grid of market resources $m([\mathrm{a}]) = [\mathrm{a}] + c([\mathrm{a}])$.

B. Root Finding

When the utility of consumption and wealth is not additively separable, the Euler equation is not analytically invertible for the optimal consumption policy. The usual recourse is to use a root-finding algorithm to obtain the optimal consumption policy for each point on the grid of market resources, which turns out to be more efficient than grid search maximization.

Holding m constant, we can define a function f_m as the difference between the marginal utility of consumption and the marginal utility of wealth:

$$f_m(c) = \mathrm{u}'_c(c, m-c) - \mathrm{u}'_a(c, m-c) - \beta\mathrm{w}'(m-c) \tag{9}$$

The optimal consumption policy is the value of c that satisfies $f_m(c) = 0$. We can use a root-finding algorithm to obtain the optimal consumption policy for each point on the grid of market resources. Although this is more efficient than grid search maximization, it is still computationally expensive. Unlike the single-step EGM, root finding requires a number of iterations to find the optimal consumption policy, which makes it relatively slower. Nevertheless, we can use clever tricks to speed up the process. One such trick used in this paper is to use the optimal consumption policy from the previous iteration as the initial guess for the next iteration. This is possible because the optimal consumption policy is a continuous function of the grid of market resources and the optional decision from one period to the next is not too different. This is the method used in the code for this paper.

IV. Quantitative Strategy

This section describes the quantitative strategy used for calibrating and estimating the Life Cycle Incomplete Markets model with and without Wealth in the Utility Function, following the works of [14], [16], [15], and [19], among others. The main objective is to find a set of parameters that can best match the empirical moments of some real-life data using simulation.

A. Calibration

The calibration of the Life Cycle Incomplete Markets model necessitates a richness not present in the SIM model precisely because we are interested in the heterogeneity of agents across different stages of the life cycle, such as the early working period, parenthood, saving for retirement, and retirement. To calibrate this model, we need to identify important patterns in preferences, mortality, and income risk across the life cycle. The first and perhaps most important departure from SIM is that life is finite and agents don't life forever; moreover, the terminal age is not certain as the probability of staying alive decreases with age. In this model, households start their life cycle at age $t = 25$ and live with certainty until retirement at age $t = 65$. After retirement, the probability of staying alive decreases with age, and the terminal age is set to $t = 91$. During their early adulthood, their utility of consumption might need to be adjusted by the arrival and subsequent departure of children. This is handled by a 'household-size-adjusted' discount factor that is greater than 1.0 in the presence of children. This is the rationale for parameters $\mathcal{L}_t$ and $\hat{\beta}_t$ in the model, whose values we take from [14] directly.

The unemployment probability is taken from [20] to be $\wp = 0.5$ which represents a long run equilibrium of 5% unemployment in the United States. The remaining life cycle attributes for the distribution of shocks to income ($\mathbf{\Phi}_t$, $\sigma_{[\mathbf{\Psi},t]}$, $\sigma_{[\xi,t]}$) are taken from [19]. In their paper, they analyze the variability of labor earnings growth rates between the 80's and 90's and find evidence for the "Great Moderation", a decline in variability of earnings across all age groups.

After careful calibration based on the Life Cycle Incomplete Markets literature, we can structurally estimate the remaining parameters $\beth$ and ρ to match specific empirical moments of the wealth distribution.

B. Estimation

Structural estimation consists of finding the set of parameters that, when used to solve and simulate the model, result in simulated moments that are as close as possible to the empirical moments observed in the data. For this exercise, we focus on matching the median of the wealth to permanent income ratio for 7 age groups starting from age 25-30 up to age 56-60. The data is aggregated from the waves of the Survey of Consumer Finances (SCF). Matching the median has been standard in the literature precisely because it has been so difficult to match the mean of the wealth distribution given the high degree of wealth inequality in the United States. The Wealth in the Utility Function models however are constructed to better match the dispersion of wealth accumulation, and in future work we will attempt to match the mean of the wealth distribution as well.

Given an initial vector of parameters $\Theta_0 = \{\beth_0, \rho_0\}$, the first step in the estimation procedure is to solve for the steady state of the model. As this is a life cycle exercise, the strategy is to start from the terminal period and work backwards to the initial period. This is known as backward induction. The terminal period is characterized by simple decisions over consumption and bequest, as the agent is certain to die and has no continuation value and thus no use for savings. Having constructed the terminal policy functions and their corresponding value and marginal value, we can solve for the optimal policies in the second to last period using the methods described in the previous section. We can then continue this process until we arrive at the initial period. In the end, and unlike in the SIM model, we have a complete set of policy functions for consumption and saving for every age of the life cycle.

Having solved the steady state of the model for the given set of parameters, we can now use the optimal policy functions to generate simulated data of consumption and savings over the life cycle. We can then calculate the simulated moments of the wealth distribution at the 7 age groups. We can define the objective function as

$$g(\Theta) = \sum_{\tau=1}^{7} \omega_\tau |\varsigma^\tau - \mathbf{s}^\tau(\Theta)| \tag{10}$$

TABLE I
LCIM ESTIMATION RESULTS

$\beth$	ρ
0.878	3.516
(0.0018)	(0.0266)

where ς^τ is the empirical moment of the wealth distribution at age τ, $\mathbf{s}^\tau(\Theta)$ is the simulated moment of the wealth distribution at age τ for a given set of parameters Θ, and ω_τ is the population weight for a particular age group in our data. The goal is thus to minimize the objective function by choice of Θ such that $\hat{\Theta} = \arg\min_\Theta g(\Theta)$. To find $\hat{\Theta}$, we use the Nelder-Mead algorithm which uses a simplex method and does not require derivatives of the objective function. This consists of trying a significant number of guesses for Θ, solving the model, and simulating moments which can be quite computationally intensive. Future work will focus on using more efficient methods such as those presented by [21], where the Jacobian (partial first derivatives) of the objective function is used to find the optimal parameters $\hat{\Theta}$ more efficiently and quickly.

Results for LCIM model We can see the estimated parameters for the LCIM model in Table I. The estimated values for $\beth$ and ρ are 0.878 and 3.1516, respectively, with standard errors estimated via the bootstrap. Additionally, Figure 1 shows a contour plot of the objective function for the structural estimation exercise where the red star represents the estimated parameters. The contour plot shows that the objective function has a relatively flat region around the estimated parameters that extends toward higher values of ρ and lower values of $\beth$, showing the trade-offs between the estimation of these two parameters.

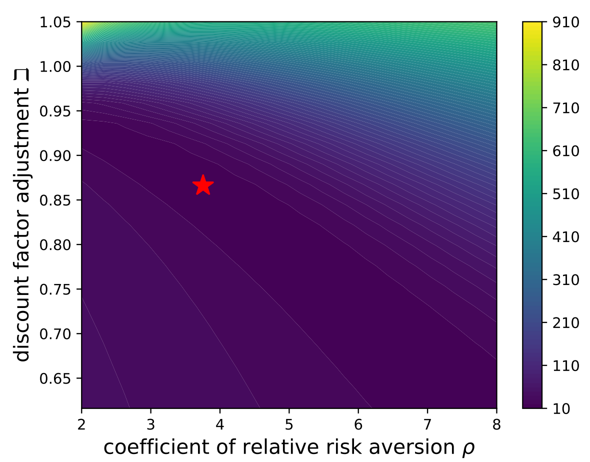

Fig. 1. Contour plot of the objective function for the structural estimation of the Life Cycle Incomplete Markets model. The red dot represents the estimated parameters.

Results for WUFIM models We can see the estimated parameters for our alternative specifications of the LCIM

TABLE II
WUFIM ESTIMATION RESULTS

Model	$\beth$	ρ
LCIM w/ Portfolio Choice	0.866	3.756
	(0.0011)	(0.0313)
Separable WUFIM	0.876	3.506
	(0.0012)	(0.0254)
Separable WUFIM w/ Portfolio	0.864	3.806
	(0.0012)	(0.0263)
Non-Separable WUFIM	0.601	5.032
	(0.0026)	(0.0634)

with Wealth in the Utility Function (WUFIM) in Table II. The estimated values for $\beth$ and ρ are 0.866 and 3.756, respectively, for the LCIM with portfolio choice, 0.876 and 3.506, respectively, for the separable WUFIM, 0.864 and 3.806, respectively, for the separable WUFIM with portfolio choice, and 0.601 and 5.032, respectively, for the non-separable WUFIM. The standard errors are estimated via the bootstrap. Additionally, Figure 2 shows a contour plot of the objective function for the structural estimation exercise where the red star represents the estimated parameters. From these results, a clear pattern emerges which is worth discussion and further analysis. The estimated parameters for the Separable WUFIM model are not very different from those in LCIM model, which perhaps points at the inability of warm glow bequest models to resolve many of the issues of the SIM and LCIM model. The separable WUFIM model does not produce significant differences in the accumulation of wealth over the life cycle beyond a simple shifting out of the savings function. When we add a portfolio choice to either model, the pure discount factor $\beth$ becomes slightly lower and the coefficient of risk aversion ρ increases by a few decimal points. This is because, as the portfolio choice model exposes agents to more risk, they become both more risk averse and more patient. Finally, the non-separable WUFIM model produces a much lower estimate of the pure discount factor $\beth$ and a much higher estimate of the coefficient of risk aversion ρ. This could be because of the dynamic complementarity between consumption and savings, which causes agents to save more in order to enjoy their consumption even more. This is an important result that requires further exploration.

C. Sensitivity Analysis

Results for LCIM model For our sensitivity analysis, we use the methods introduced by Andrew . Figure 3 shows the sensitivity of the pure discount factor $\beth$ and the coefficient of risk aversion ρ. The plots are inverses of each other, reflecting the trade-off between the two parameters in fitting lifetime consumption and wealth dynamics. Because the pure discount factor is a multiplicative adjustment on already calibrated life cycle discount factors, the sensitivity analysis has a different interpretation from the one in [15]. In our analysis, the adjusted discount factor $\beth$ matters relatively more than ρ up

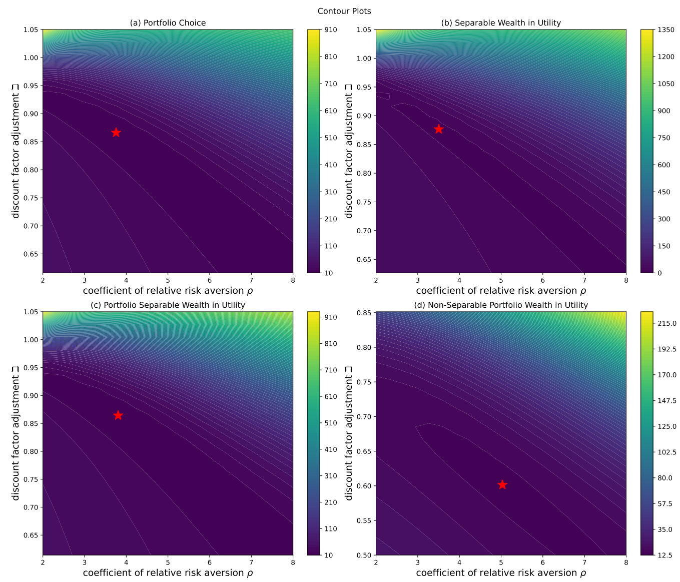

Fig. 2. Contour plot of the objective function for the structural estimation of the Life Cycle Incomplete Markets model. The red dot represents the estimated parameters.

to age 40, indicating a potential overshot of the mortality risk and household-adjusted discount factors. For ages 40-50, the sensitivity of $\beth$ and ρ is relatively low, indicating that the model is not very sensitive to the values of these parameters in this age range. Finally, from ages 50 and above, the coefficient of relative risk aversion ρ matters relatively more than $\beth$. The differences between the sensitivity of this model and that in [15] are likely due to the fact that our model uses time-varying discount factors and applies the adjusted discount factor $\beth$ multiplicatively. Thus, it might be that the life cycle discount factors are imprecisely calibrated, which would explain the reversal of the sensitivity of $\beth$ and ρ over the life cycle. MOre research is needed to understand this result.

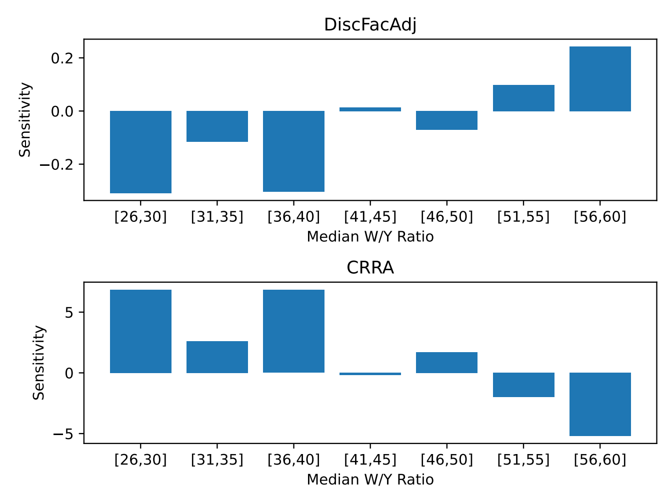

Fig. 3. Sensitivity analysis of the structural estimation of the Life Cycle Incomplete Markets model. The red dot represents the estimated parameters.

Results for WUFIM models For completeness, Figure 4 shows the sensitivity analysis for the alternative specifications of the LCIM model. The sensitivity of the Non-Separable WUFIM model appears to diminish in the beginning of the lifecycle, from ages 26-40, and then increases significantly from ages 41-60. This is likely due to the fact that the non-separable WUFIM model has a much higher estimate of the coefficient of relative risk aversion ρ than the other models.

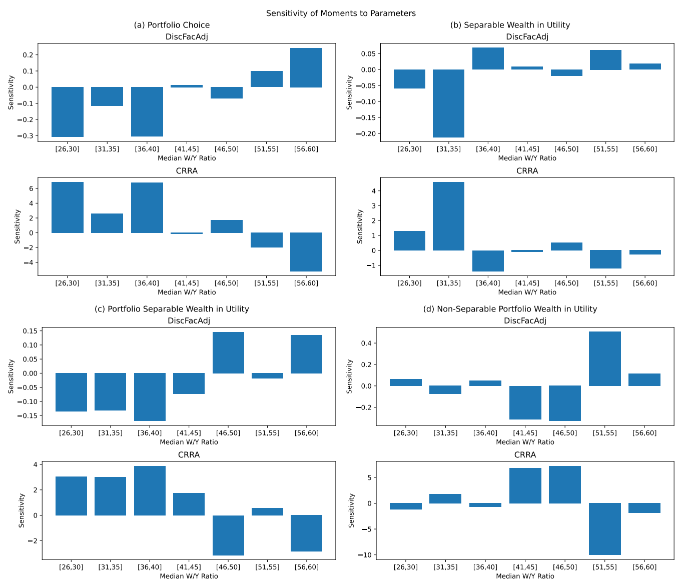

Fig. 4. Sensitivity analysis of the structural estimation of the Life Cycle Incomplete Markets model. The red dot represents the estimated parameters.

V. Conclusion

In this paper, I estimate a Life Cycle Incomplete Markets model with separable and non-separable wealth in the utility function (WUFIM) using the method of simulated moments (SMM) and data from the Survey of Consumer Finances (SCF). I then compare the estimated parameters to those of the standard Life Cycle Incomplete Markets model (LCIM), which is known to be unable to match the distribution of wealth. I find that the estimated parameters for the separable WUFIM model are not very different from those in the LCIM model, which perhaps points at the inability of warm glow and accidental bequest motives to resolve many of the issues of the SIM and LCIM models. The non-separable WUFIM model produces a much lower estimate of the pure discount factor $\beth$ and a significantly higher estimate of the coefficient of risk aversion ρ. Finally, I conduct sensitivity analysis of the estimated models using the Jacobian of the objective function and find that the sensitivity of the models has the reverse pattern from what we expected. This is because our LCIM and WUFIM models already account for time-varying discount factors due to mortality risk and household size. Thus, the sensitivity analysis is likely picking up on the imprecision of the calibration of the life cycle discount factors.

Further work is needed to understand the implications of these results. First, I will use the mean wealth of each age group instead of the median wealth as the WUFIM models are intended to better match the distribution of wealth. Second, I will evaluate the result of the objective function to see if the WUFIM models are able to match the distribution of wealth better than the LCIM and SIM models. Third, I will use a numerical approximation to the Jacobian of the objective function which will allow for both faster estimation and more accurate sensitivity analysis. Finally, I will use the estimated models to conduct policy analysis and evaluate the welfare implications of macroeconomic shocks.

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Land Asset Management: A Novel Approach Using 3D Profiling for Precision and Efficiency

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***Abstract*—This research integrates cutting-edge 3D profiling tools for site visualization and analysis, introducing a revolutionary approach to land asset management. We provide a novel approach to obtaining high-precision 3D models of land assets by combining Structure from Motion (SFM) and Light Detection and Ranging (LiDAR) technologies. This technique provides thorough spatial representations that are more accurate and efficient than typical 2D surveying by utilizing multi-angle imagery and extensive elevation data. The suggested system's use of a centralized cloud-based platform allows for real-time access and cooperation among stakeholders, including field engineers and decision-makers, in addition to automating the creation of 3D models. For smooth SFM and LiDAR data fusion, this cloud-based repository combines Python-based back-end calculations, producing models with a margin error of less than 3 percent. These models' accuracy reduces disagreements over land measuring and project evaluations, enabling better decision-making in infrastructure projects. The resulting technology opens the door for a scalable and patent-worthy 3D land profiling system with broad implications, including possible uses in asset management, environmental monitoring, and urban planning.**

***Index Terms*—3D Land Profiling, Structure from Motion (SFM), Light Detection and Ranging (LiDAR), Cloud-based Data Management, High-precision Modeling, Asset Management, Infrastructure Development, Data Fusion, Python.**

I. Introduction

Effective decision-making in today's rapidly changing land management and infrastructure context depends on accurate site analysis and trustworthy data. The accuracy and effectiveness of traditional land asset management techniques are limited by their heavy reliance on two-dimensional pictures and manual field surveys. This study presents a novel method called Land Asset Management Using 3D Profile, which uses cutting-edge 3D reconstruction technology to deliver a thorough, real-time land profile with an accuracy and degree of detail never seen in the industry.

Our method builds very detailed 3D models from two-dimensional photos by combining Structure from Motion (SFM) algorithms with Light Detection and Ranging (Lidar) technologies. By capturing both surface and subsurface features, these models improve the precision of land profiling in challenging terrains. A strong cloud computing infrastructure is then used to process the produced 3D data, enabling centralized, fast data processing and storage. We achieve computational efficiency that guarantees quick, scalable processing of big datasets by utilizing Meshroom software and high-performance GPU computers like the NVIDIA DGX-1, revolutionizing the practice of land asset management.

An additional feature that sets this project apart is its user-centric online interface, which was created using React and allows stakeholders to view, interact with, and access the 3D land profiles from anywhere. By offering verifiable, visual records of site conditions before to and following project operations, this real-time access not only promotes better project management and cooperation but also lowers the possibility of labor and material cost disputes.

In order to transform the present standards in land asset management, this study suggests an approach that combines state-of-the-art 3D imaging, cloud-based data fusion, and interactive visualization. Because of its potential to transform sectors including urban planning, construction, geology, and environmental management that rely on accurate land data, we think this invention deserves a patent.

This paper intends to shed light on the essential features, system architecture, user interface design, and implementation specifics of the design, development, and assessment of the employment portal application. The program offers solid functionality, scalability, and security while meeting the changing demands.

II. Literature Survey

Jiang, San, Cheng Jiang, et al., in their review of Structure from Motion (SfM) for large-scale UAV images, emphasize the critical need for efficient SfM workflows to manage the increasing data volumes from advanced UAV imaging systems. They pinpoint three primary computational bottlenecks: feature matching, where selecting match pairs is made more difficult by high image overlap; outlier removal, which experiences efficiency declines as a result of high outlier ratios in big datasets; and bundle adjustment (BA), where iteratively fine-tuning camera poses results in high processing expenses. Jiang et al. highlight the significance of scalable methods to manage complex UAV datasets by comparing six popular SfM systems. Their research lays the groundwork for our project's combination of Lidar and SfM technologies, which aims to solve the computational efficiency and scalability issues in land asset management [1].

Lv et al., in their research on LIDAR data processing technology, emphasize LIDAR's significant role as a high-resolution earth-space information technology with applications in various fields, including national economic development and military detection. The study outlines the benefits of LIDAR, including its fast data production cycle, weather resistance, and high automation, which make it a perfect instrument for tasks like processing point cloud data, creating Digital Elevation Models (DEM), and creating Digital Orthophoto Maps (DOM). The authors talk about how LIDAR is now being used in the military and civic sectors, emphasizing how it helps with geospatial analysis and infrastructure. Additionally, they project LIDAR's future and its increasing importance in contemporary technology. This study is crucial to our project's integration of LIDAR technology with SFM because it offers a thorough grasp of how to use LIDAR's precision and efficiency for 3D site characterization and precise land asset management.[2].

Qi et al., in their study titled "PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation," introduce PointNet, a brand-new neural network created especially to analyze point cloud data without turning it into picture collections or voxel grids. PointNet successfully maintains the permutation invariance of the input points by eating point clouds directly, hence avoiding the inefficiencies and higher data quantities linked to earlier techniques. PointNet's unified architecture has great empirical performance, frequently outperforming conventional methods, and supports a variety of applications, such as object classification, component segmentation, and scene semantic parsing. The paper also shows why PointNet works so well for 3D data processing by offering theoretical insights into the network's resilience to input disturbances. Our project's approach to point cloud processing is informed by this work, which provides insights on effective data handling and model robustness—two essentials for precise 3D land asset profiling and segmentation jobs in intricate environments [3].

Wang et al., in their review titled "Estimation of LAI with the LiDAR Technology: A Review," explore the use of LiDAR technology for estimating Leaf Area Index (LAI), a crucial vegetation metric. The authors look at three different kinds of LiDAR systems: spaceborne (SLS), airborne (ALS), and terrestrial (TLS). Each has its own advantages and disadvantages when it comes to recording vegetation structure. With an emphasis on correlations with gap percent, contact frequency, and forest biophysical factors, the paper outlines LAI retrieval techniques utilizing LiDAR data. They pinpoint issues with the accuracy of the LAI estimate, including sample limitations, occlusions, and clumping effects, which differ depending on the LiDAR system. ALS and SLS offer wider coverage with restrictions on canopy detail, but TLS works well for in-depth, targeted foliage investigation. To increase estimation accuracy, the research advocates for large-scale validation and improvements in LAI inversion techniques. Wang et al.'s insights on LiDAR's applications in vegetation analysis and its incorporation of high-precision LiDAR into our research, which seeks to improve 3D profiling accuracy in land asset management, are supported by processing limitations [4].

Roriz et al., in their survey titled "Automotive LiDAR technology: A survey," explores how LiDAR sensors are helping to advance autonomous driving, with a particular emphasis on how the car sector is implementing this technology. The authors offer a thorough analysis of the fundamentals of LiDAR sensors, including the imaging and measuring approaches applied in the automobile industry. The report explores the issues that LiDAR technology is now facing, including the need for increased environmental resilience, resolution, and range. Ongoing research initiatives to solve problems including sensor fusion, cost reduction, and miniaturization are also covered in the report. Roriz et al. highlight the significance of LiDAR in the development of fully autonomous cars and provide insightful information on how businesses and academics may work together to advance LiDAR technology. Their research serves as a vital resource for studies on sensor technologies and autonomous driving as it emphasizes the vital role LiDAR sensors play in guaranteeing the security, dependability, and effectiveness of autonomous systems. Since advancements in automobile LiDAR help to improve spatial awareness in land asset management, this paper supplements our investigation of 3D profiling technology [5].

Hyyppä et al. review the use of small-footprint airborne laser scanning (LiDAR) for forest inventory, particularly in boreal forests. By contrasting LiDAR with photogrammetric techniques, they demonstrate how well it extracts stem volume and tree height. The study classifies several LiDAR methods, such as integration with aerial imaging, individual tree analysis, and canopy height distribution. The potential of intensity and waveform data, as well as the categorization of tree species and assessment of forest development using LiDAR data, are also covered by the authors. Although the work focuses on methodology, it provides insights into data quality and suggests more research to enhance LiDAR-based forest inventory methodologies. This work supports our 3D profiling efforts for land asset management by advancing our knowledge of LiDAR's use in terrain modeling [6].

Jaboyedoff et al., in their review titled "Use of LIDAR in Landslide Investigations: A Review," provides a comprehensive overview of LiDAR technology in landslide research, demonstrating how useful it is for producing 3D models and high-resolution digital elevation models (HRDEMs) for geological purposes. Applications of LiDAR in landslide investigations are divided into four main categories by the study: mapping, monitoring, hazard assessment and susceptibility mapping, and mass movement detection and characterization. The authors stress that although LiDAR-derived HRDEMs provide comprehensive information on landslide-prone regions, routine landslide assessments currently underutilize this method. To improve the comprehension and control of geological risks, they support the further development of LiDAR-based HRDEMs. Jaboyedoff et al.'s findings underscore LiDAR's potential for precision profiling in hazardous terrain, reinforcing its applicability to our project, which uses sophisticated 3D profiling to manage land assets accurately in difficult terrain [7].

Hayakawa et al., investigate the use of Digital Elevation Models (DEMs) and Geographic Information Systems (GIS) for analyzing river gradients in mountainous regions of Japan. In attempts to objectively detect fluvial knickzones—distinct alterations in river gradient frequently associated with erosion and tectonic activity—their study classifies stream gradients into local and trend categories. According to the study, step-pool-like hydraulic processes are responsible for the occurrence of these knickzones, which are common in steep, erosion-prone upstream areas. Furthermore, certain knickzones match tectonic faulting, suggesting a complex interplay of geomorphic processes. This DEM-based method of knickzone identification supports our project's use of high-resolution profiling for accurate topographic analysis in land asset management by providing insightful information on landscape change and erosion [8].

III. METHODOLOGY

To create very precise and comprehensible models that are appropriate for intricate infrastructure and land management applications, our 3D land asset management methodology combines cutting-edge imaging and data fusion techniques. Data Acquisition, Cloud-based Data Upload and Processing, SFM and LiDAR Data Fusion, and Interactive Visualization are the four main phases of the procedure. A complete, end-to-end solution for producing patent-worthy, real-time 3D models is now possible because of each step's optimization for accuracy, scalability, and operational efficiency.

A. Data Acquisition

This technique is based on the collecting of field data, with an emphasis on obtaining high-resolution elevation data and sets of images with several angles and elevations. To improve the acquisition of spatial detail, this phase uses LiDAR sensors for detailed topography data and UAV-assisted photography for extensive site coverage. To ensure the best input for later SFM processing, images are gathered methodically to maximize overlap.

B. Cloud-based Data Upload and Initial Processing

Images and LiDAR point clouds are among the data that is gathered and transferred to a high-performance, secure cloud server. Simplified data administration is made possible by this single repository, and automated scripts ensure consistency by tagging metadata and performing quality tests to confirm data integrity. The cloud platform prepares all data formats for incorporation in the SFM and LiDAR fusion process by standardizing them using Python modules.

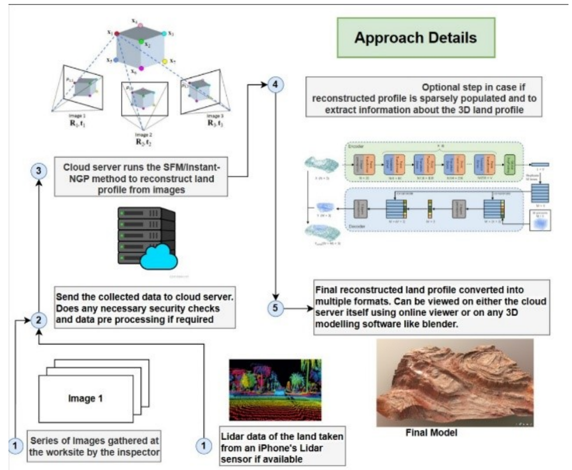

Fig. 1. SFM.

C. Structure from Motion (SFM) and LiDAR Data Fusion

Our methodology's foundation is the combination of Structure from Motion (SFM) with LiDAR data, which produces intricate 3D models with excellent elevation and spatial accuracy. To reconstruct 3D spatial structures, SFM algorithms first examine sets of overlapping images, identifying and matching important feature points. To guarantee precise alignment, even on challenging terrain, sophisticated feature matching techniques like Scale-Invariant Feature Transform (SIFT) and Speeded-Up Robust Features (SURF) are used. LiDAR data is used in the initial SFM model development process to improve topographic accuracy and depth perception. Iterative closest point (ICP) techniques are used to align the SFM output with the crucial elevation data provided by the LiDAR point cloud. By lowering measurement error to less than 3 percent, this data fusion procedure allows the model to capture both horizontal and vertical dimensions with exceptional precision.

D. Computational Platform and Processing Optimization

To handle the computational demands of large-scale 3D reconstruction, our approach makes use of a powerful cloud-based computing infrastructure.

1) GPU-Accelerated Processing:: Utilizing NVIDIA Tesla V100 GPUs within NVIDIA DGX-1 servers, we achieve significant acceleration in processing times for both SFM and LiDAR data fusion. GPU parallelism enables real-time data processing and reduces overall computation time.

2) Scalable Computing Resources:: The cloud infrastructure dynamically allocates computing resources based on workload requirements, ensuring optimal performance even with massive datasets.

3) Distributed Computing Framework:: Implementing distributed computing frameworks such as Apache Spark allows for efficient handling of big data, enabling simultaneous processing of multiple data streams and reducing bottlenecks.

4) Algorithm Optimization:: Custom optimization of SFM and LiDAR processing algorithms ensures maximum efficiency and scalability. Techniques such as parallel bundle adjustment and adaptive mesh generation are employed to enhance processing speeds without compromising accuracy.

E. Visualization and User Interface

A user-friendly web-based interface created using the React and Django frameworks makes the finished 3D models available for stakeholders to see, examine, and work with. By providing tools for perspective adjustment, measurement extraction, and before-and-after project model comparison, this interface promotes teamwork and improves project decision-making. Through easily navigable visualization, the platform facilitates smooth communication between surveyors, engineers, and decision-makers.

F. Structure from motion (SFM)

The initial Structure from Motion (SFM) process is central to creating a high-fidelity 3D representation of the surveyed site by reconstructing camera positions and generating dense point clouds from overlapping 2D images. This section outlines the key stages of SFM, highlighting innovative techniques and optimizations that enhance model accuracy and processing efficiency.

1) Initial Image Selection and Configuration:: The process begins with a strategic selection of initial images to maximize overlap and ensure robust geometric configurations. By carefully choosing images with strong feature overlap, we enhance the likelihood of successful feature matching and accurate model reconstruction. Snavely et al. developed a skeleton extraction algorithm that computes the position covariance between overlapping image pairs, allowing for efficient pose estimation in subsequent images. This approach enables a computationally efficient start by creating a minimal skeletal set, to which remaining images are incrementally added [11].

2) Feature Extraction and Matching:: The foundation of SFM lies in accurately detecting and matching key features across images. Commonly used algorithms for feature detection and matching include Harris corner detectors, SIFT (Scale-Invariant Feature Transform) by Westoby et al., and SURF (Speed-Up Robust Features). These algorithms ensure high accuracy and resilience to changes in scale and rotation. To address large-scale 3D reconstruction challenges, advanced binary descriptor algorithms, such as BRISK and FREAK, offer speed and efficiency by leveraging kd-trees and K-nearest neighbor (KNN) algorithms for rapid feature matching [13].

3) Vocabulary Tree-based Approaches:: Vocabulary trees, using the K-means algorithm, quantize image features, further improving feature matching efficiency across large image datasets. By hierarchically organizing features, vocabulary trees reduce redundant matches and optimize the search for correspondences, especially useful in large-scale datasets.

4) 3D Point Triangulation and Camera Pose Estimation:: After matching feature points, triangulation is employed to estimate 3D points, converting 2D feature correspondences into spatial coordinates. Pose estimation follows, calculating the relative position and orientation of each camera. This process minimizes re-projection errors, ensuring that 3D points are accurately represented in the reconstructed space. The triangulation relies on minimizing geometric discrepancies between views, leading to a precise spatial model of the scene.

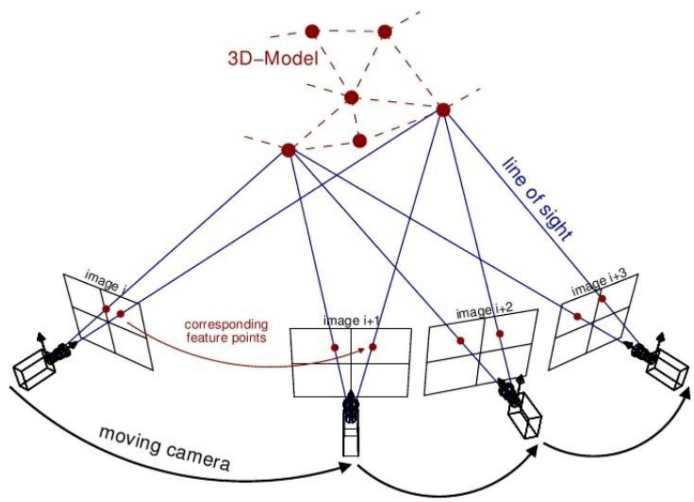

Fig. 2. SFM.

5) Incremental Image Addition:: Additional images are added incrementally, with each new image undergoing a matching and triangulation process relative to existing images in the model. Dijkstra's algorithm is sometimes employed to plan the shortest paths among images, reducing redundancy in the matching process and optimizing resource usage in large datasets.

6) Fundamental Matrix Estimation and Projective Reconstruction:: The fundamental matrix establishes the geometric relationships between paired images. Using RANSAC (Random Sample Consensus) for outlier rejection, this step refines the matches by isolating and removing inconsistencies. Once the fundamental matrix is determined, projective reconstruction can proceed, which aligns all points in a consistent 3D space. Faugeras's method is applied here to solidify the projective geometry of the point cloud. Our SFM methodology is a methodical process that includes the following crucial steps:

7) Camera Calibration and Bundle Adjustment:: Camera calibration is essential to accurately relate image coordinates to world coordinates. Traditional methods such as direct linear transformation (DLT) and Zhang's calibration provide high accuracy but may be computationally demanding. For increased adaptability, self-calibration techniques using Kruppa's equation allow for variable camera parameters without sacrificing accuracy.

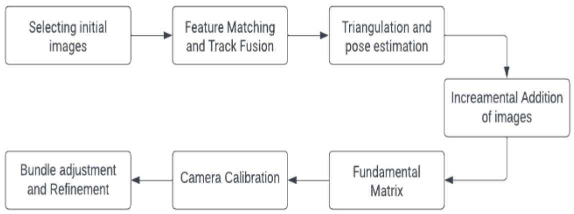

Fig. 3. SFM Methodology.

G. Cloud Server

The project converts photos into 3D models using a high-performance cloud environment equipped with GPUs and other devices. Both Structures from Motion (SFM) are computed on this platform.

H. Device

The computation is carried out on a server architecture that is tuned for parallel processing jobs and data-intensive processes. The infrastructure consists of:

- NVIDIA Tesla V100 GPUs for accelerated computing.
- NVIDIA DGX-1 servers for high-performance computing and AI workloads

I. Applications

Uses SFM to re-construct 3D models from the provided pictures using the Meshroom program. Backend functions on the cloud server, such as integrating SFM into the creation of the infrastructure model, are carried out using Python and its libraries.

IV. EXPERIMENTAL AND RESULT ANALYSIS

Through the use of SFM and LiDAR data fusion, the experimental research seeks to assess the suggested 3D profiling method's accuracy, computational effectiveness, and scalability. Processing time, model accuracy, and error rates across different dataset sizes were the main focus of the studies, which were carried out on a variety of video and picture datasets taken at various geographical areas.

A. Data Collection and Pre-processing

Frames from video footage taken at regular intervals were taken in order to give a variety of viewpoints on each location for thorough 3D land characterization. This method optimized feature overlap, which is necessary for reliable SFM processing. Various datasets were processed, ranging from small (10 frames) to large-scale (100,000 frames), to test the system's scalability.

B. Processing Time and Computational Load

The SFM processing time increased linearly with the number of frames, demonstrating the efficiency of GPU-accelerated processing. For example:

- 10 frames processed in approximately 2 minutes.

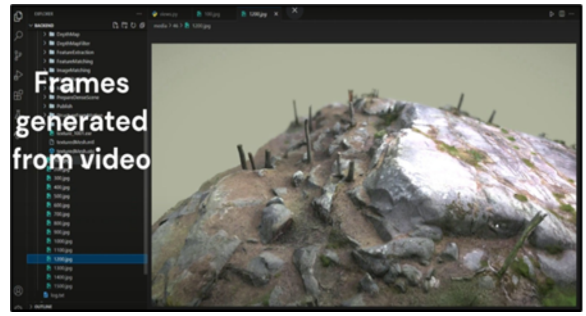

Fig. 4. Generated Frames.

- 100 frames in 10 minutes.
- 1,000 frames required 50 minutes.
- For the largest dataset (100,000 frames), the processing time was extended to 1,800 minutes.

This scaling The efficiency of the high-performance cloud configuration, which is enhanced by GPU and parallel processing techniques to manage massive data volumes without sacrificing speed, is confirmed by this scalability.

TABLE I
PROCESSING TIME FOR DIFFERENT FRAMES COUNT.

Number of Frames	Time (minutes)
10	2
100	10
1000	50
10000	300
100000	1800

C. Accuracy and Error Analysis

To determine the dimensional correctness, the rebuilt 3D models were compared to measurements taken in the actual world. Error margins for important measurements like diameter, depth, breadth, and length were kept to less than 3 percent. Notably:

- Diameter error: 2.07 percent
- Depth error: 2.46 percent
- Width error: 2.72 percent
- Length error: 2.89 percent

With an average error of 2.54 percent, these low error rates validate the model's correctness and make it dependable for use in asset management, geological surveys, and infrastructure.

TABLE II
PROCESSING TIME FOR DIFFERENT FRAMES COUNT.

Parameter	Actual	Reconstructed	Error
Diameter	5.127	5.233	2.07
Depth	3.941	3.844	2.46
Width	3.756	3.858	2.72
Length	2.113	2.174	2.89

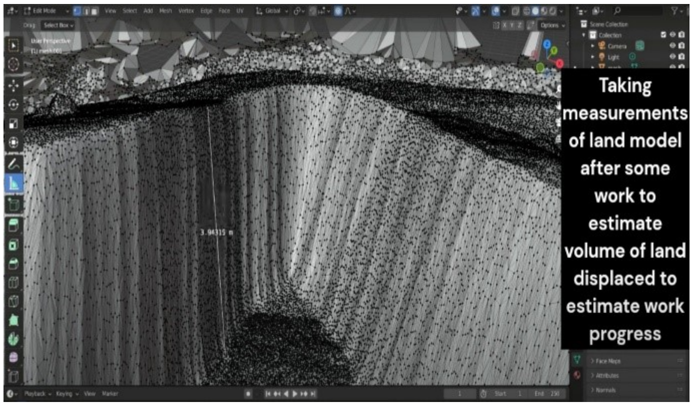

Fig. 5. Measurements - 1.

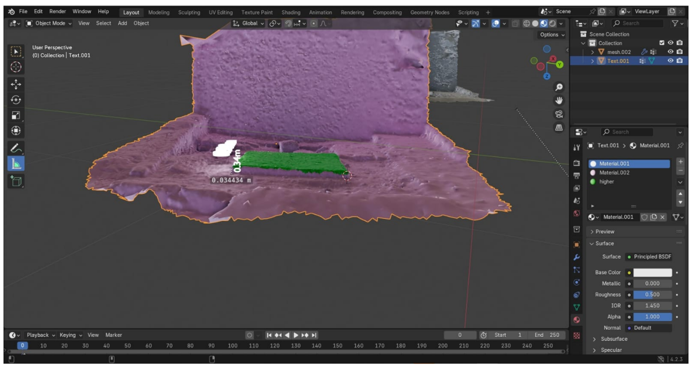

Fig. 6. Measurements - 2.

D. Scalability and Storage Requirements

The experimental investigation showed that the computing and storage architecture of the cloud server is scalable. The system maintained optimal performance by utilizing dynamic resource allocation and distributed storage, which allowed for real-time data access and the smooth processing of large datasets. Applications in large-scale land profiling projects, where data needs might rise quickly, require this configuration.

The high-fidelity 3D reconstruction made possible by our approach is demonstrated by the resulting model in Figure 8. Even with the computational strain of large datasets, this model demonstrates the precision and depth offered by the Structure from Motion (SFM) and LiDAR data fusion procedures. Because of the cloud infrastructure's effective data management capabilities, the picture displays precise characteristics in the land profile that hold true across bigger datasets.

A crucial component of scalability in practical applications, the system's capacity to accommodate large-scale projects without sacrificing quality or performance is demonstrated by the successful depiction of this intricate model.

V. COMPARISON STUDY

With an emphasis on precision, processing effectiveness, and data integration, we contrast the suggested 3D land profiling methodology with traditional methods. This comparison demonstrates the enhancements brought about by the integration of Light Detection and Ranging (LiDAR) and Structure from Motion (SFM), aided by scalable infrastructure and cloud-based processing.

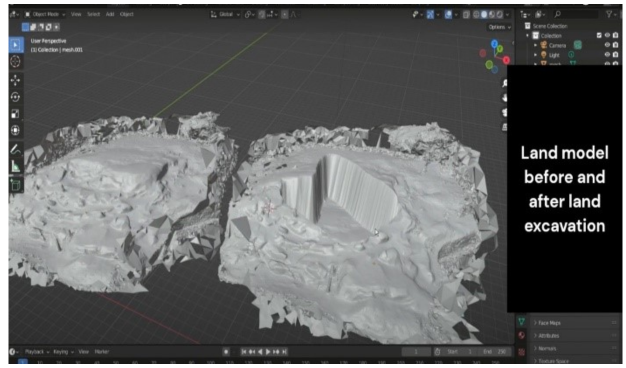

Fig. 7. Generated Model.

A. Traditional LiDAR and Photogrammetry

LiDAR and photogrammetry are the main stand-alone technologies used in traditional land profiling techniques. Although these techniques work well for some applications, they frequently run into problems when dealing with complicated terrain and huge datasets. Traditional LiDAR, for example, may have trouble capturing small features in vegetated regions or under canopy cover, despite its great accuracy. Lefsky et al. emphasized that LiDAR alone might not capture nuanced topographic details without complementary data sources, particularly in varied ecosystems [9].

Contrarily, photogrammetry uses overlapping 2D photos to produce a 3D model, although it may not be as accurate without high-resolution imagery and adequate feature overlap. Vosselman et al. indicated that, although photogrammetry's effectiveness in general topographic mapping, alignment, and quality control may need substantial manual involvement, particularly when applied to larger regions with intricate surface geometries [10].

B. Advantages of SFM and LiDAR Data Fusion

By combining SFM with LiDAR, our suggested methodology outperforms conventional methods and makes high-resolution 3D modeling possible with improved depth and spatial accuracy. The combination of LiDAR, which provides exact elevation data, and SFM, which builds dense point clouds from 2D pictures, greatly enhances the model's capacity to handle complicated topographies. Snavely et al. demonstrated that SFM is highly effective for reconstructing detailed 3D structures, making it suitable for large-scale terrain modeling when coupled with other technologies [11].

Our strategy reduces data gaps and enhances coverage by combining several techniques, especially in regions with dense vegetation or uneven terrain. A thorough geographical representation that conventional single-method techniques frequently cannot provide, particularly in difficult locations, is provided by this dual-source data integration [12].

C. Enhanced Processing Efficiency and Scalability

Computational limitations frequently plague traditional approaches, particularly when dealing with high-resolution datasets. Large amounts of data must be processed using multi-view stereo methods, such as those described by Furukawa and Hernández, which might result in bottlenecks and slower processing time [12]. On the other hand, real-time processing is made possible by our cloud-based infrastructure, which is scalable and effective in handling large datasets and is backed by GPU-accelerated processing with NVIDIA DGX-1 servers.

Additionally, our system's distributed storage and dynamic computing resource allocation provide flexible storage and high-throughput data processing. This feature significantly overcomes the drawbacks of conventional photogrammetric techniques by enabling scaled processes without sacrificing output speed or quality, as highlighted by Westoby et al. [13].

D. Improved User Accessibility and Collaboration

Due to limited visualization and communication capabilities, traditional land profiling techniques sometimes restrict data access to particular stakeholders. Our solution overcomes this constraint by integrating an interactive, web-based 3D visualization platform constructed with React.js. With the help of this interface, several individuals may access, inspect, and analyze 3D models from a distance, facilitating real-time team collaboration and feedback. According to Fonstad et al., traditional methods typically lack this level of interactivity, making it challenging to facilitate collaborative decision-making [14].

VI. DISCUSSION

Our suggested 3D profiling methodology tackles important issues in infrastructure development and land asset management by combining Structure from Motion (SFM) and Light Detection and Ranging (LiDAR). Traditional approaches have had difficulty achieving a full spatial representation, especially in diverse terrains and surroundings with dense vegetation. This approach combines the elevation accuracy of LiDAR with the high-resolution capabilities of SFM.

A. Practical Implications

The precise, scalable 3D modeling capabilities of this technology have useful applications in a number of domains, such as environmental monitoring, geological surveying, and urban planning. For example, accurate site models improve project planning and reduce expensive differences during audits in building projects. Similar to this, the capacity to precisely simulate a variety of terrains aids in tracking changes over time in ecological conservation and natural hazard assessment, enabling the observation of minute environmental changes or prospective hazards in landslide-prone locations.

Real-time data processing and visualization are made easier by the system's cloud-based architecture, which improves decision-making for numerous stakeholders that need quick, easily available information. Additionally, this interactive platform facilitates remote collaboration, which is essential for intricate, large-scale projects since it enables engineers, surveyors, and project managers to collaborate on data interpretation.

B. Limitations and Challenges

Notwithstanding its benefits, the current solution has drawbacks with regard to processing speeds and computational intensity for very big datasets. Even though model building takes a lot less time because of GPU-accelerated cloud processing, performance might be improved with more SFM and LiDAR fusion algorithm tuning, especially for datasets with more than 100,000 frames. Furthermore, regions with dense vegetation or a lot of clouds may have an impact on image quality, which might introduce small errors in the 3D models.

The upfront setup costs of cloud infrastructure and specialized hardware, such as NVIDIA DGX-1 servers, present another difficulty and might be unaffordable for smaller businesses. Adaptive algorithms that can optimize resource allocation depending on dataset size and complexity may be implemented, or cost-effective cloud alternatives may be investigated, in order to address these limits.

C. Future Research Directions

To further improve model accuracy and lower computing burden, future studies might concentrate on improving data fusion methods. The accuracy and effectiveness of the SFM process might be increased by investigating methods like adaptive point cloud filtering and machine learning-based feature matching, especially in regions with a diverse topography or dense vegetation.

Furthermore, the system's usefulness might be extended to more extensive applications, such as environmental research and agricultural monitoring, by including additional data sources, such as thermal imaging or multispectral data. Richer, multi-dimensional models might be produced by these interconnections, giving stakeholders access to information that goes beyond geography.

VII. CONCLUSION

By combining Structure from Motion (SFM) and LiDAR data fusion, backed by high-performance cloud infrastructure, we presented a unique method for Land Asset Management Using 3D Profiling in this study. Through the provision of exact, high-resolution 3D models that facilitate effective and accurate decision-making for infrastructure, environmental monitoring, and urban planning projects, this methodology effectively overcomes the drawbacks of conventional land surveying techniques.

Real-time processing and visualization are made possible by cloud-based technology, which also gives numerous stakeholders virtual access, enhancing cooperation and simplifying the management of large-scale projects. By combining SFM and LiDAR, the approach maintains accuracy even in difficult terrain with sub-3 percent error rates. Furthermore, the system is suitable for applications in intricate and expansive project scenarios due to its scalable architecture and GPU-accelerated processing, which enable the quick handling of massive datasets.

Although there are many advantages to the existing design, more investigation into algorithm optimization and the incorporation of other data sources may enhance the system's capabilities, resolving computational issues and creating new application domains.

In summary, by improving data accessibility, accuracy, and scalability and laying the groundwork for future developments in 3D land modeling and digital surveying, the suggested 3D profiling technique constitutes a significant breakthrough in land asset management.

Acknowledgment

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Unified Key Point Matching

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Unified Key Point Matching

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Abstract. Key Point Matching (KPM) aims to identify and match the most relevant key points from a set of arguments related to a specific topic. While traditional multi-document summarization techniques focus on extractive or abstractive summarization, this study proposes a novel approach, Matching The Statements (MTS), which leverages advanced pre-trained language models and incorporates topic information for improved key point analysis. Our method utilizes a unified model to integrate contextual information, enhancing semantic similarity evaluation between arguments and key points. Through extensive experimentation on the ArgKP-2021 dataset, MTS demonstrates significant performance improvements over baseline methods. This paper outlines the architecture of MTS, details the data preparation and encoding processes, and presents results validating the model's efficacy in the KPM task.

1 Introduction

Past work in assessment rundown primarily utilized extractive techniques, which straightforwardly duplicate agent text sections for outlines [**?**]. Abstractive methodologies, however more uncommon, produce more cognizant rundowns with novel expressing [**?**], addressing a vital utilization of multi-report synopsis [**?**].

To further develop rundown, late work like [1] analyzed the viability of central issue choice in brief outlines, utilizing a Central issue Coordinating (KPM) move toward displayed in Figure 1.

We present Matching The Explanations (MTS), a model utilizing context oriented and subject put together highlights to improve execution with respect to Central issue Matching errands. Drawing from BERT [5], ALBERT [9], and RoBERTa [10], MTS incorporates (1) a straightforward design for subject mindful portrayals, (2) a pseudo-mark instrument [7] bunching steady explanations, and (3) in number execution on the ArgKP-2021 dataset [1] without outer information.

2 Related Work

In the **Related Work** section, we explore notable approaches for analyzing key points and arguments by focusing on the extraction of meaningful semantics. Our model draws from recent literature that utilizes siamese neural networks [**?**] to evaluate semantic similarity between documents. However, MTS introduces its own unique ability to incorporate contextual information.

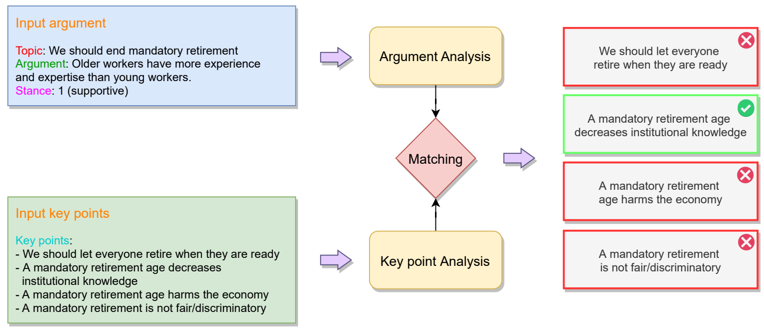

Fig. 1. "Illustration of the Key Point Matching process in Track 1 of the Quantitative Summarization – Key Point Analysis Shared Task. This task focuses on retrieving the most relevant key point that supports a given query from an information retrieval standpoint."

2.1 Sentence Embeddings

Sentence Embeddings are fundamental for enhancing model performance on downstream tasks by representing sentences in a fixed-dimensional vector space. Early strategies relied on static word embeddings, such as *GloVe* [11] or *fastText* [2], encoding sentences either by averaging word vectors or using recurrent neural network (RNN) encoders [4] and pooling their hidden states. Despite capturing both syntactic and semantic aspects, these approaches often struggled with contextual representation and were hindered by slow training times due to RNNs' sequential nature.

This challenge has been addressed by modern transformer-based models like *BERT* [5], which have become dominant in NLP research by leveraging parallel computation with GPUs and TPUs for efficient training. The *SBERT* model proposed by [12] fine-tunes BERT using natural language inference (NLI) datasets to generate improved sentence embeddings. Recent advancements have focused on contrastive learning paradigms, achieving state-of-the-art results across multiple benchmark tasks [**?**].

2.2 Semantic Matching

Semantic Matching has been a long-standing challenge with numerous applications, including question-answering systems [15], text summarization [16], and especially information retrieval [**?**]. To address these challenges, [8] proposed a hierarchical recurrent neural network capable of capturing long-term dependencies and synthesizing information across different granularities, such as words, sentences, or paragraphs. Building on this, [14] introduced transformer-based models by replacing RNN backbones, incorporating modified self-attention mechanisms to better accommodate long document inputs.

Despite these advances, most existing work primarily emphasizes assessing the similarity between pairs of sentences while often neglecting contextual relevance.

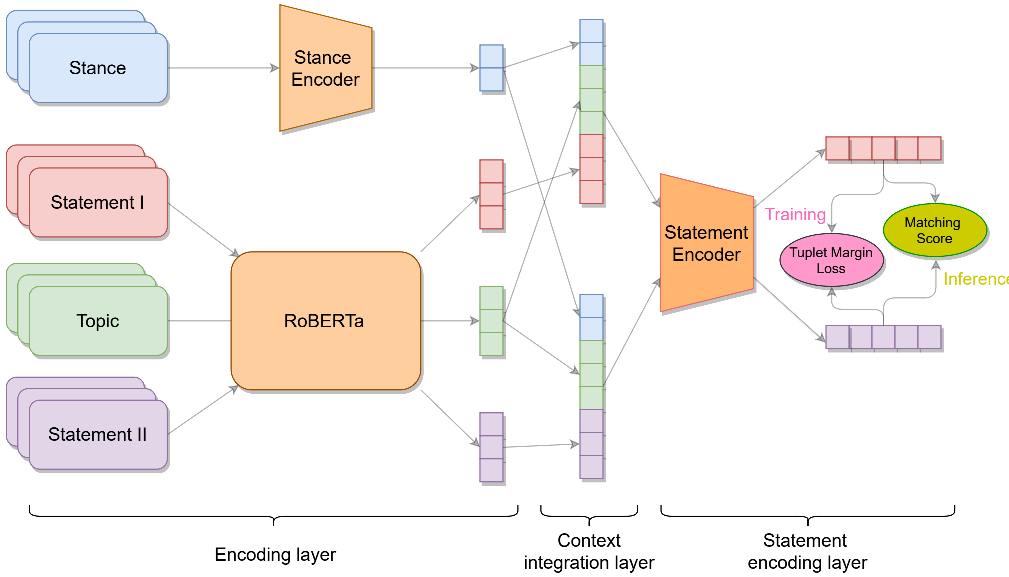

Fig. 2. The complete structure of our Matching The Statements framework.

Contextual understanding can provide readers with a broader perspective of a given topic. To address this gap, the ArgKP-2021 dataset introduced by [1] offers annotations indicating whether two statements, including their stances on a specific topic, align or differ. Subsequent sections will further explore this dataset and demonstrate our model's applicability within the Quantitative Summarization–Key Point Analysis Shared Task[1].

3 Problem Definition

The **Problem Definition** involves a dataset of 28 topics, each with arguments and key points labeled as matching (1) or non-matching (0), along with stances indicating agreement or disagreement, as detailed in Section 5.7.

The Key Point Matching task is to rank key points sharing the same stance as each argument based on matching scores, considering both the topic context and semantic relationships.

4 Methodology

The **Methodology** section presents the proposed MTS framework, as shown in Figure 2. This model takes in four distinct inputs: (i) the topic under discussion, (ii) the first statement, (iii) the second statement, and (iv) the stance of each

[1] https://2021.argmining.org/shared_task_ibm.html

statement concerning the topic. The model generates a similarity score that reflects how the statements relate to one another within the given context. The subsequent sections describe the three key components of the MTS model: the encoding layer, context integration layer, and statement encoding layer.

4.1 Data Preparation

Data Preparation involves an initial observation: a small proportion (4.71%) of the arguments are associated with multiple key points, while the majority correspond to at most one key point. Based on this, a natural approach is to group arguments associated with the same key point into clusters, labeling each cluster accordingly. In our approach, each cluster is centered around a key point K_i, which is paired with its associated arguments. Our clustering method identifies that some arguments appear in multiple clusters. Arguments that don't correspond to any key points are grouped into a NON-MATCH category.

The supposition that will be that contentions connected to a similar central issue are probably going to have comparable implications and are treated as matching matches, while those from various groups are viewed as non-coordinating. This pseudo-marking method use semantic connections inside bunches to improve model speculation, naming intra-group contentions as sure coordinates and between group ones as bad coordinates.

During preparing, central issues and their coordinating/non-matching contentions (from the ArgKP-2021 dataset) are utilized in little groups. A subset of NON-MATCH contentions, treated as coming from unmistakable bunches, is likewise included. This empowers steady meaning of positive and negative matches for misfortune calculation utilizing standard measurement learning misfortune capabilities [3].

4.2 Encoding Layer

The **Encoding Layer** extracts contextual representations from textual inputs using the RoBERTa model [10]. We adopt a conventional method [13], where the final embedding for an input is obtained by concatenating the last four hidden states of the [CLS] token. These concatenated embeddings then serve as a unified representation for topics, arguments, and key points, which are subsequently fed into the context integration layer. The representation of a statement at this stage is defined as follows, where both statements and their respective stances are consistently denoted by uppercase symbols, X and S:

$$\begin{aligned}\mathbf{h}^X &= [h_1^X, h_2^X, \ldots, h_{4\times768}^X] \;\; (h_i^X \in \mathbb{R}) \\ &= [h_1^X, h_2^X, \ldots, h_{3072}^X]\end{aligned}$$

Here, 768 refers to the size of the hidden states produced by the RoBERTa-base model.

To encode stances, we use a fully connected network that does not apply any activation function, mapping the scalar input to an N-dimensional vector space. The topic, statement, and stance representations are denoted as $\mathbf{h}^T, \mathbf{h}^X$, and $\mathbf{h}^S$ respectively.

4.3 Context Integration Layer

The **Context Integration Layer** combines the embeddings derived from various inputs, incorporating both the topic (context) and stance information into the representations of the arguments and key points. The resulting vector for each statement is expressed as:

$$\mathbf{v}^X = [\mathbf{h}^S; \mathbf{h}^T; \mathbf{h}^X]$$

where $\mathbf{v}^X \in \mathbb{R}^{N+2\times 3072}$.

4.4 Statement Encoding Layer

The **Statement Encoding Layer** utilizes a completely associated network on top of the setting layer to produce D- layered embeddings:

$$\mathbf{e}^X = \mathbf{v}^X \mathbf{W} + \mathbf{b}$$

where $\mathbf{W} \in \mathbb{R}^{(N+6144)\times D}$ and $\mathbf{b} \in \mathbb{R}^D$. The model figures out how to plan comparative articulations closer and disparate ones farther separated in $\mathbb{R}^{(N+6144)\times D}$.

4.5 Training

In each step, one proclamation is chosen as the anchor, with positive examples from similar group and negative examples from various bunches. The matching score between two proclamations is registered utilizing cosine distance:

$$\mathcal{D}_{\text{cosine}}(\mathbf{e}^{X_1}, \mathbf{e}^{X_2}) = 1 - \frac{{\mathbf{e}^{X_1}}^T \mathbf{e}^{X_2}}{||\mathbf{e}^{X_1}||_2 \, ||\mathbf{e}^{X_2}||_2} \tag{1}$$

We use cosine distance over Manhattan and Euclidean distances. The tuplet edge misfortune capability is:

$$\mathcal{L}_{\text{tuplet}} = \log(1 + \sum_{i=1}^{k-1} \mathrm{e}^{s(\cos\theta_{an_i} - \cos(\theta_{ap} - \beta))})$$

We join tuplet edge misfortune and intra-pair difference misfortune:

$$\mathcal{L}_{\text{intra-pair}} = \mathcal{L}_{pos} + \mathcal{L}_{neg}$$

Hard mining is utilized to keep away from inclination from simple models. Negative matches are chosen if:

$$\text{cosine}(\mathbf{e}^{X_a}, \mathbf{e}^{X_n}) \geq \min_{X_i \in \mathcal{P}_{X_a}} \text{cosine}(\mathbf{e}^{X_a}, \mathbf{e}^{X_i}) - \epsilon$$

During derivation, the matching score between a contention A and central issue K is:

$$\text{score}(\mathbf{e}^A, \mathbf{e}^K) = \cos(\mathbf{e}^A, \mathbf{e}^K)$$

5 Experiment

We evaluate the Matching The Statements (MTS) model on the ArgKP-2021 dataset and compare it to baseline models.

5.1 ArgKP-2021 Dataset

The ArgKP-2021 dataset contains 5,583 training and 932 development arguments, averaging 18.22 words per argument. The data is split 24:4 for training and development, with few multiple key point matches.

5.2 Evaluation Protocol

We use strict and relaxed mean Average Precision (mAP) to evaluate the models. The relaxed mAP treats ambiguous matches as correct, while the strict mAP does not.

5.3 Embeddings Quality

MTS's embeddings improve after training, with mAP increasing from 0.45 to 0.84 (strict) and from 0.62 to 0.94 (relaxed), showing better differentiation between matching and non-matching pairs.

5.4 Baselines

We compare MTS to two baselines: **SimAKP**, which uses pairwise classification, and **QA**, inspired by Question Answering systems.

5.5 Results

In 7-fold cross-validation, MTS outperforms baselines, except in fold 7, where smaller development sets lead to performance drops.

5.6 Hard Negative Mining

Introducing hard negative mining improves most models' mAP, with SimAKP showing a slight drop in relaxed mAP.

5.7 Differential Analysis

MTS with multi-similarity mining performs best. Switching to tuplet margin loss increases both strict and relaxed mAP by 0.2. An ensemble of top models ranks MTS third in strict mAP and seventh in relaxed mAP.

Stance Effect Removing stance components reduces strict mAP to 0.741 but increases relaxed mAP to 0.952, indicating that stance inference could enhance the model through attention mechanisms.

$$\textbf{Precision} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Positive}}$$

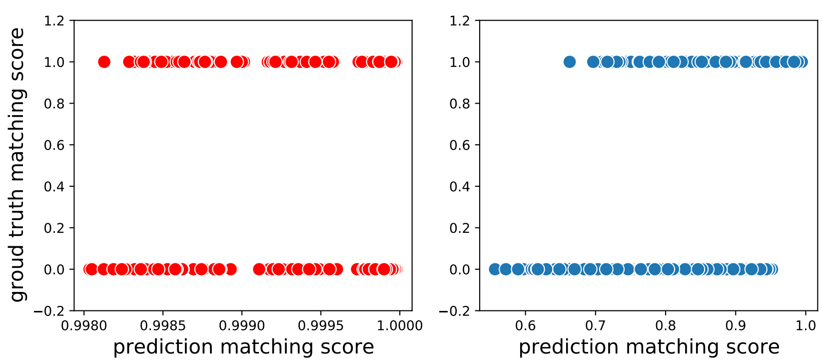

Fig. 3. Statement representation before (left) and after (right) training.

BERT embeddings

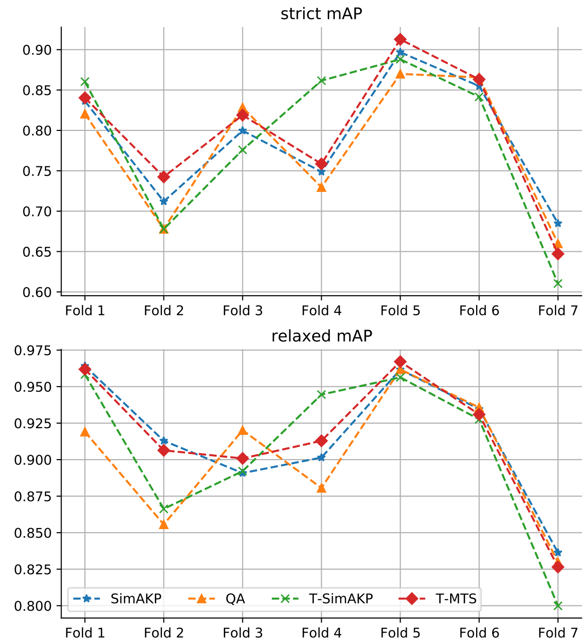

Fig. 4. Mean Average Precision (mAP) scores over 7 folds. Models with the "T-" prefix use triplet loss [6], while the others use contrastive loss [3].

6 Limitations

Despite the promising results achieved, our approach has several limitations that warrant further consideration. One of the primary challenges is the heavy reliance on large labeled datasets for supervised contrastive learning. While the current work benefits from a well-defined argument-key point dataset, the effectiveness of the MTS model might degrade when applied to domains or tasks where labeled data is sparse or expensive to obtain. Semi-supervised or unsupervised learning strategies could alleviate this issue, but they come with their own set of challenges in terms of ensuring sufficient representation learning.

Another limitation stems from the model's sensitivity to the choice of hard negatives during the training process. Although hard negative mining improves the model's discriminative power, it can introduce biases depending on the selection of these hard negatives. In particular, it may overfit to difficult samples, neglecting easier but equally important cases. An adaptive negative mining strategy that adjusts to the distribution of argument-key point pairs during training could address this concern. Furthermore, the model's reliance on manually specified negative samples for training limits its generalizability in environments where negative samples are less clear-cut or require more nuanced generation.

The computational cost of the MTS model also represents a significant limitation, particularly when scaling to larger datasets or real-time applications. The

Model	strict mAP	relaxed mAP
SimAKP	0.790 ± 0.072	0.914 ± 0.041
SimAKP w.o mining	0.783 ± 0.074	0.917 ± 0.037
T-SimAKP	0.788 ± 0.098	0.906 ± 0.054
T-SimAKP w.o mining	0.782 ± 0.101	0.901 ± 0.076

Table 1. The effect of hard sample mining in baselines.

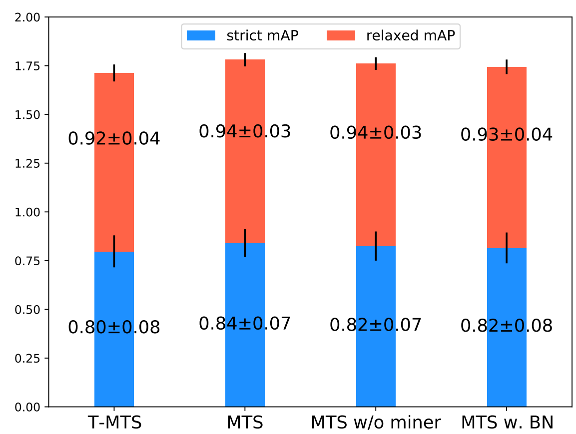

Fig. 5. Disabling different configurations demonstrates that each element of the original MTS setup plays a crucial role in its overall performance.

use of large pre-trained language models like RoBERTa and the concatenation of multiple hidden layers for the [CLS] token representation increases the model's complexity and resource requirements. While this approach improves accuracy, it may not be feasible in resource-constrained settings, particularly when deployment efficiency is a key concern. Optimizing the model's efficiency without sacrificing performance is an important future research direction, potentially through techniques such as model distillation, knowledge transfer, or pruning.

Additionally, while our experimental setup demonstrates strong performance across multiple folds, the model's variability in performance across different folds—especially in folds with fewer labeled examples—indicates that the model may be sensitive to the distribution of argument-key point pairs. This variability highlights the importance of carefully balancing training data across different folds or datasets to mitigate overfitting. It also raises the issue of generalization when the distribution of topics or argument structures changes. Future research should explore techniques such as domain adaptation or active learning to ensure that the model is robust to changes in data distribution.

Finally, while the stance information embedded in our model contributes to improved performance, it remains a relatively underexplored aspect of ar-

#	Team	strict mAP	relaxed mAP
1	mspl	0.908 (2)	0.972 (3)
2	heinrichreimer	0.912 (1)	0.967 (5)
3	vund	0.878 (4)	0.968 (4)
4	**HKL (ours)**	**0.896 (3)**	**0.963 (7)**
5	sohanpatnaik	0.872 (5)	0.966 (6)
6	fengdoudou	0.853 (10)	0.98 (2)
7	mozhiwen	0.833 (12)	0.985 (1)
8	Fibelkorn	0.869 (6	0.952 (10)
8	emanuele.c	0.868 (7)	0.956 (9)
10	niksss	0.858 (8)	0.95 (11)

Table 2. Leaderboard of the Track 1 Quantitative Summarization – Key Point Analysis.

Embedding	strict mAP	relaxed mAP	#Param
Sum all tokens	0.834 ± 0.065	0.938 ± 0.037	
Mean all tokens	0.796 ± 0.068	0.916 ± 0.034	125M
[CLS] last hidden layer	0.823 ± 0.072	0.937 ± 0.038	
[CLS] 4 hidden layers	$\mathbf{0.840 \pm 0.071}$	$\mathbf{0.941 \pm 0.034}$	126M
LUKE	0.808 ± 0.096	0.926 ± 0.056	276M
ALBERT	0.748 ± 0.071	0.879 ± 0.044	13M
MPNet	0.839 ± 0.059	0.940 ± 0.029	111M
DistilBERT	0.724 ± 0.065	0.864 ± 0.058	68M
BERT (uncased)	0.746 ± 0.062	0.888 ± 0.035	110M
BERT (cased)	0.752 ± 0.073	0.883 ± 0.057	

Table 3. Examination between various installing procedures and pre-prepared language models. In this examination, we report the aftereffect of the base variant.

gumentation matching. The lack of a robust method for dynamically handling stance information in more complex scenarios—where stances may be implicit or conflicting—limits the model's full potential. We believe that incorporating more sophisticated attention-based mechanisms could address this limitation, allowing the model to more flexibly capture and adapt to the stance of various arguments and key points.

7 Conclusion

This paper introduces a robust method for argument-key point matching (AKPM) that enhances the representation learning process using supervised contrastive learning. The proposed Matching The Statements (MTS) model capitalizes on the potential of clustering, contrastive loss functions, and hard negative mining to improve argument-key point alignments. By applying clustering methods that group statements based on key points, we successfully capture the underlying structure of argumentation in the dataset, enabling more accurate matching. Through comprehensive evaluation, including experiments on the Quantitative

Summarization – Key Point Analysis shared task, we demonstrate that MTS outperforms baseline models, showcasing a clear advantage in matching accuracy.

Our work highlights the importance of leveraging well-crafted loss functions in conjunction with powerful transformer-based embeddings to achieve state-of-the-art results. We also emphasize the necessity of accounting for semantic similarities in argument-key point relationships, which led to significant improvements in matching performance. The results presented, including the use of RoBERTa-based embeddings and the exploration of different pooling strategies for token representations, reveal that fine-tuning transformer architectures can significantly contribute to better performance.

Moreover, our model's consistency across seven-fold cross-validation further underscores its stability and generalizability across different subsets of the dataset. The observed performance on the leaderboard, with our model securing competitive positions in strict and relaxed mean Average Precision (mAP) metrics, validates the effectiveness of our approach. This confirms that the model is capable of not only handling the inherent complexities of argumentation but also generalizing well to unseen data in a structured evaluation setting.

In conclusion, this work lays the foundation for future advancements in AKPM tasks by combining the strengths of clustering, contrastive learning, and transformer embeddings. By demonstrating the practical applications of these methods in a real-world shared task, we hope to inspire further research into integrating clustering techniques and contrastive loss functions for other complex NLP tasks such as argumentation mining, fact-checking, and summarization.

8 Future Work

While the MTS model presents a significant advancement in the field of AKPM, there are numerous directions for future work that could further improve the model's performance, adaptability, and efficiency. One potential area for improvement is the expansion of clustering methods. While our current approach clusters based on key points, a more sophisticated clustering mechanism that integrates both semantic similarity and context-based factors could better capture nuanced argument-key point relationships. Furthermore, experimenting with hierarchical clustering techniques could allow the model to capture multi-level dependencies, enriching its representation of argument structures.

Another promising direction is the exploration of alternative loss functions. While contrastive learning has proven effective for this task, alternative loss functions, such as those based on multi-similarity or triplet loss, could be adapted to improve performance in more challenging cases where arguments and key points are context-dependent or less directly aligned. We also intend to experiment with dynamic loss weighting mechanisms that can account for varying difficulty levels across different training samples, which might further enhance the learning process.

The current framework also relies heavily on stance-related information embedded within the model. However, future work could investigate the use of an attention-based mechanism that dynamically identifies and weighs the stance of arguments relative to key points. This would allow the model to more accurately infer relationships in cases where stance is ambiguous or implicit. Additionally, research into unsupervised or semi-supervised learning techniques could reduce the dependence on large labeled datasets, enabling the model to generalize to new domains with less human intervention. Semi-supervised approaches, such as using self-training or graph-based methods, could leverage large amounts of unlabeled data to further improve the model's performance.

Expanding the model's applicability to multilingual datasets is another key area for growth. Although our work is based on English-language data, applying MTS to multilingual scenarios would be valuable. This could involve using multilingual embeddings or fine-tuning the model with specific linguistic features from multiple languages. Furthermore, scaling the model to handle larger datasets, particularly in real-time applications, will require exploration into more efficient architectures, including lightweight transformer variants like DistilBERT or TinyBERT, or pruning techniques that retain performance while reducing computational overhead.

Lastly, exploring the domain adaptation capabilities of MTS would help in its application to diverse fields, such as legal document analysis, political discourse, or scientific literature, where argumentation structures may differ significantly from the standard datasets used here. Techniques such as domain adversarial training or transfer learning could allow MTS to learn from diverse sources, improving its robustness across different domains and tasks.

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Transforming Markets with Automated Liquidity

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Transforming Markets with Automated Liquidity

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Abstract*—*In a world characterized by constant innovation and digitalization, the financial markets are undergoing a profound metamorphosis. This paradigm shift is being orchestrated by the integration of cutting-edge technology, specifically automated liquidity provision, into the heart of market dynamics. This seismic shift promises to redefine market dynamics, ushering in an era where algorithms, not humans, act as the primary market makers. This paper delves into the transformative potential of ALP, examining its impact on liquidity, price efficiency, and market resilience. This transformation promises enhanced market efficiency, reduced spreads, increased trading volumes, and heightened accessibility for market participants, ultimately fostering a more inclusive and dynamic financial ecosystem. As I navigate this brave new world, it is evident that automated liquidity provision is not just a trend; it is the catalyst for a financial revolution that will reshape the future of markets.

I. Introduction

Market makers create liquidity in a market by quoting bids and asking prices for a trading asset near the market price. Market makers profit by quoting asks at a premium and bids at a discount to the market price. This premium or discount is referred to as the market maker *spread*. Market makers realize the spread each time an order is matched at their quoted price. The *arrival rate* of orders is lower for market makers that charge high spreads, and both spread and arrival rates must be balanced for a market maker to maximize profit. The market maker must also manage the *inventory* of cash and assets available to fulfill market demand, as well as the opportunity cost of taking a net long position in inventory. In all, the market maker must consider:

- The spread charged
- The arrival rate of orders
- Available inventory of cash and asset
- Opportunity cost of holding inventory

While profitable market making is a complex and multi-dimensional problem, it has also been extensively studied in the literature, particularly in two seminal papers. Ho & Stoll studied the problem of dealing under competition and found that the bid and ask quotes are related to the reservation, or indifference, price of the dealer [1]. Then Avellaneda & Stoikov proposed a model combining the utility formulation of Ho & Stoll with statistical modeling of the microstructure of a limit order market and solved optimal market pricing under this model [2]. The solution of Avellaneda & Stoikov is notable because it demonstrates a stochastic optimal control policy under a reasonable stochastic model for order arrivals [3]. Subsequent work by Guéant, Lehalle, & Tapia extended this solution to consider management of a finite inventory of cash and asset [4]. In Section II, I review the state-of-the-art algorithms for market-making to provide context for my algorithm.

In the first paragraph of their seminal 2008 paper, Avellaneda & Stoikov noted market making:

> Traditionally, this role has been filled by market makers or specialist firms. In recent years, however, with the growth of electronic exchanges such as Nasdaq's Inet, anyone willing to submit limit orders in the system can effectively play the role of a dealer. Indeed, the availability of high-frequency data on the limit order book (see www.inetats.com) ensures a fair playing field where various agents can post limit orders at the prices they choose.

While in principle, anyone may play the role of market maker in a market, various limitations prevent this in practice. US securities law limits who may make the market based on accreditation rules, brokerage licensing requirements, and other considerations. In commodities markets, including cryptocurrency spot markets, the high technical complexity of market making 24/7, as well as fee discounts offered to incumbents, create competitive barriers to entry for retail participants. While the barriers to entry for automated market making remain high, automation technology has made other active strategies such as market-weighted rebalancing and tax-loss harvesting widely available to retail customers in products such as Wealthfront and Betterment [5], [6].

In using automation to provide retail access to active strategies, particular attention must be paid to both *algorithm design* and *interface design*. Making investment decisions is obviously complex. Monti, Martignon, Gigerenzer, & Berg studied high-stakes financial decisions made by bank customers. He found that investors cling to the information available to them, ignoring more complex variables that are often assumed in economic models [7]. To prevent the end user from adversely selecting a non-competitive policy configuration, I focus on making the policy configuration human-readable and educating investors on the underlying dynamics of their decisions. My objective is to devise an automated strategy for continuous market-making that considers the traditional utility objectives of market-making, as well as the usability objectives of broadly offering market-making to retail users for the first time. In total, the considerations include:

- The spread charged
- The arrival rate of orders
- Available inventory of cash and asset
- Opportunity cost of holding inventory

- Practical deployment across user accounts
- Intuitive policy configuration

In Section II, I review the state-of-the-art algorithms for optimal market making. In Section III, I propose an algorithm that reflects the structure of optimal market making while simplifying parameterization of the algorithm to promote optimal policy configuration. In Section IV, I demonstrate the performance of this algorithm in simulation.

II. Optimal Market Making

In this section, I re-summarize the model of Avellaneda & Stoikov based on the notation and summary of Guéant, Lehalle, & Tapia. I refer to this model herein as the *standard model*.

In the standard model, the market price, which may be the market mid-price or a reference quote, moves as arithmetic Brownian motion:

$$dS_t = \sigma dW_t \tag{1}$$

Guéant, Lehalle, & Tapia note in a footnote that Equation 1 is almost equivalent to the standard Black-Scholes model on a short time horizon, i.e., in a narrow time window, the price is exclusively affected by random, drift-free arrival of the arrival of order matches on the limit order market. The market-making agent continuously quotes bid and ask prices, S_t^b and S_t^a respectively, and will therefore buy and sell shares of the asset based on the random arrival of orders matched at the quoted prices. In the standard model, the agent holds accumulative inventory q_t given by:

$$q_t = N_t^b - N_t^a \tag{2}$$

where N_t^b and N_t^a are the point processes representing the number of assets bought or sold, respectively, as order matches arrive at the quoted prices. The standard model assumes that the intensity of arrival of order matches decreases monotonically in the spread offered on the quoted price. Assuming a bid spread of $\delta_t^b = S_t - S_t^b$ and an ask spread of $\delta_t^a = S_t^a - S_t$, the intensity of arrivals for bids and asks, λ^b and λ^a respectively, are given by:

$$\lambda^b = A \exp^{-k\delta_t^b}, \quad \lambda^a = A \exp^{-k\delta_t^a} \tag{3}$$

where A and k are positive constants characterizing the liquidity of the asset. Modeling the arrival of order matches leads the agent's net cash holdings to be characterized as:

$$dX_t = (S_t + \delta_t^a)dN_t^a - (S_t - \delta_t^a)dN_t^b \tag{4}$$

A notable contribution of Guéant, Lehalle, & Tapia is the introduction of an inventory bound Q. The inventory held by the agent, q_t, which is signed in the standard model, is bounded in the interval $|q_t| < Q$. Put differently, the agent may never hold more than Q asset, and the agent may never go net short Q. While this constraint imposes a realistic risk limit, it does not lead immediately to a risk-based *inventory policy*. For example, the standard model does not model the agent's starting inventory. I address these practical limitations in Section III.

The standard model culminates in the proposal of a utility function, which is maximized by the optimal control policy $(\delta_t^b, \delta_t^a)_t$. The utility function and control policy are given by:

$$\max_{(\delta_t^b, \delta_t^a)_t \in \mathcal{A}} \mathbb{E}[-\exp(-\gamma(X_T + q_T S_T))] \tag{5}$$

where T is the terminal time, $\mathcal{A}$ is the set of predictable policies and γ is the agent's risk aversion coefficient. Note that $X_T + q_T S_T$ is the value of the portfolio at time T, which is directly proportional to agent P&L, and that $f(x) = \exp(-\gamma x)$ is monotonic in x. As a result, the stochastic optimal control objective can be seen as related to maximizing agent P&L.

The canonical solution to this problem, provided by Avellaneda & Stoikov, is given by the following quoting policy:

$$r_t(s) = s - q\gamma\sigma^2(T - t) \tag{6}$$

$$\delta_t^a + \delta_t^b = \gamma\sigma^2(T - t) + \frac{2}{\gamma}(1 + \frac{\gamma}{k}) \tag{7}$$

Here, $r_t(s)$ is the reservation price of the agent, and $\delta_t^a + \delta_t^b$ is the spread. I can make several intuitive observations about the optimal policy. The reservation price is the market reference price, adjusted by a give of $q\gamma\sigma^2(T - t)$. I refer to this as a give because it manifests as a discount to the ask quote when the agent is overweight and a premium to the bid quote when the agent is overweight, both of which give an advantage to the taker relative to the reference price s. The give is linear in inventory q, proportional to volatility σ^2, and straight lines to zero as the trading interval elapses. The spread $\delta_t^a + \delta_t^b$ follows a similar formula but does not rely on inventory and straight lines to the constant $\frac{2}{\gamma}(1 + \frac{\gamma}{k})$ as the trading interval elapses.

In summary, the optimal control policy charges a spread independent of inventory against a price adjusted to manage inventory. In the next section I simplify the structure of these equations to arrive at a policy in terms of spread and give.

III. Retail Market Making

In this section, I propose a policy for market making that reflects the dynamics of the policies discussed in Section II, but that is also formulated to be easily configured by a casual user in terms of two parameters: *spread* and *give*. Designing simple-to-use configuration interfaces for automated strategies mitigates adverse selection risk. It maintains efficient market operation in a market where potentially most agents operate identical policies (up to configuration).

Our policy replaces the spread Equation 7 with a user specified percentage spread Δ, resulting in the overall spread:

$$\delta_t^a + \delta_t^b = 2\Delta s \tag{8}$$

We believe a user's selection of Δ encapsulates their thinking about arrival rate k and risk coefficient γ without requiring education on either auxiliary variable. For example, a user will choose a lower spread to encourage faster order arrivals. The spread is clearly no longer a linear form or even a function of volatility σ. I believe this is justified because their selection of spread also captures the user thesis on market volatility since overwide spreads will not experience order arrivals. By wholely substituting spread with a user-specified quantity, my algorithm does not impose an automatic policy for spreads but rather requires the user to configure spread *as policy*. I believe this decision is justified since any marginal decision to expand the complexity of Equation 8 introduces advanced market concepts to the interface while eroding understanding of what net spread the agent charges the market for its services.

Recall the formulation of reservation price from Section II, $r_t(s) = s - q\gamma\sigma^2(T-t)$. By performing the change of variables $q \mapsto q/Q = q'$, I arrive at the alternative formulation:

$$r_t(s) = s - q'Q\gamma\sigma^2(T-t) = s - q'G' \quad (9)$$

We recall the inventory risk constraint $|q| < Q$ and note that if the agent enforced it, then $|q'| < 1$ achieving the limits $q = -1$ when the agent is totally underweight the asset and $q = 1$ when the agent is totally overweight the asset. Therefore G' may be interpreted as the maximum give-on price the agent will provide to rebalance inventory. Performing the additional change of variables $G' \mapsto G'/s = G$, the equation can be written as:

$$r_t(s) = s - q'Gs = s(1 - q'G) \quad (10)$$

Here, G is the maximum given as a percentage of asset price. This modification normalizes the specification of give for any market price. I believe the most intuitive experience for the user is to specify the give outright since the give is a percentage-like spread, characterizes the loss in profit offered to rebalance explicitly, and encapsulates user thinking on volatility and risk.

The quoted pricing in my policy is then given as follows:

$$s_t^b = s_t(1 - q_t'G - \Delta) \quad (11)$$

$$s_t^a = s_t(1 - q_t'G + \Delta) \quad (12)$$

$$q_t' = \frac{s_t q_t - x_t}{s_t q_t + x_t} \quad (13)$$

This policy quotes a spread that is constant in inventory and a reservation price that is linear in inventory, which I believe to be the most important dynamics of the linear stochastic control policy. However, the simplification of the policy configurations as (Δ, G) reduces the risk of adverse selection of noncompetitive policy configurations.

While the policy reflects inverse linear control of reservation price like the optimal policy, I do not claim that the modified policy is optimal in any sense. I believe that it provides only an engineered compromise between optimal policy, ease of configuration, and practical considerations such as finite, non-negative inventory.

IV. Experiments

There have been numerous recent numerical reproductions of the results of Avellaneda & Stoikov [8] as well as commercial deployments of the algorithm. In this Section, I simulate my algorithm for a single parameterization of market dynamics across hundreds of simulations. This is not intended to serve as an exhaustive numerical study of the algorithm but rather as a pathfinder for further experimentation and optimization. The source code has been made public at https://github.com/chriscslaughter/amm.

We modeled market dynamics for $M = 4000$ time steps across $N = 100$ simulations. I modeled the agent's holdings as starting at \$4,000 in cash and \$4,000 in shares, each priced at \$100 / share. The market evolved according to Brownian dynamics using $\sigma = 0.05$, or 5 cents average deviation per time stamp. I modeled $A = 0.5$ and $k = 1.5$.

We configured my agent to trade with spread $\Delta = 0.1$ and give $G = 0.5$. The agent achieved an average ROI of 4%, with almost every agent achieving an ROI of some kind. Figure 1 breaks down the simulations in detail. I found that the agent produced a profit consistently in a variety of market conditions while maintaining sufficient inventory for exposure to matches on both market sides.

V. Conclusion

In this paper, I review the state-of-the-art algorithms for optimal market-making in a limit-order market. Then, I propose a simplified algorithm that balances the mathematical structure of optimal market-making while providing a streamlined parameterization for users. I demonstrate the algorithm's performance in simulation.

In future work, I can open source the deployment infrastructure for my retail automated market-making strategies at Level. I can also more extensively explore the algorithm's configuration space in a wider variety of simulations. Various additional considerations, such as competitive dynamics, multi-agent simulation, and market impact, may be taken into account.

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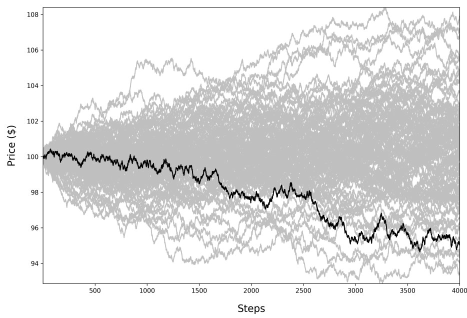
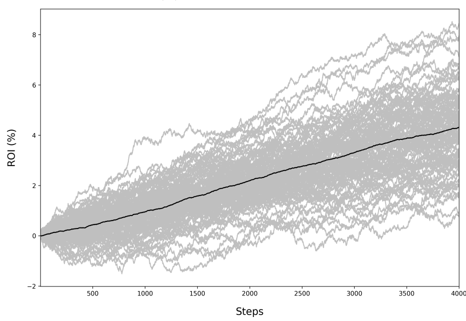
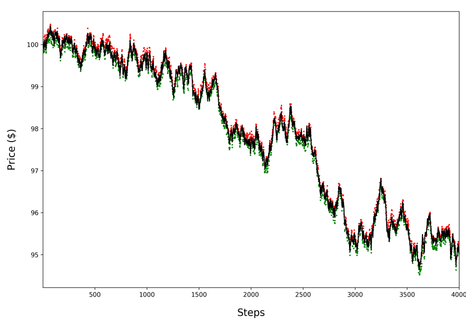


(a) Market Price



(b) Return on Investment (ROI)



(c) Orders Matched

(d) Inventory Management

Fig. 1: Experimental results of numerical simulation for the algorithm proposed in Section III. The algorithm was simulated for a broad range of market evolutions (a), while the algorithm achieved an ROI on average (b). Quotes offered by the agent received consistent bid and ask action (c), while the agent's give policy maintained inventory balance over time (d).

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Advancing Classification Algorithm Selection with Ensemble Meta-Learning: A Data-Driven Approach

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***Abstract*—Selecting the optimal classification algorithm for diverse datasets remains a significant challenge in data mining. This study introduces a robust Ensemble Meta-Learning (EML) framework that automates the selection process by leveraging the diversity of meta-features. Our approach dynamically adjusts the number of recommended algorithms based on dataset characteristics, demonstrating substantial improvement over traditional methods. Through empirical evaluations on 183 datasets and 20 classification algorithms, EML outperforms established single-link and ML-KNN-based methods in terms of recommendation accuracy and offers more precise algorithm selection. This paper underscores the potential of ensemble meta-learning in enhancing algorithmic recommendations, paving the way for future innovations in meta-learning applications.**

I. Introduction

Data mining extensively addresses classification, a pivotal task. A multitude of classification algorithms exists, encompassing tree based (e.g., ID3[1], C4.5[2], and CART[3]), probability-based (e.g., Naive Bayes[4] and AODE[5]), and rule-based (e.g., OneR[6] and Ripper[7]) methods.

Nonetheless, the "No Free Lunch" theory[8] and empirical evidence[9], [10] assert the absence of a universally effective algorithm for all classification problems. Hence, the challenge lies in selecting suitable algorithms, particularly for non-experts.

Research indicates algorithm performance correlates closely with dataset characteristics[11]. Thus, addressing this challenge involves exploring dataset characteristics' relationship with algorithm performance to recommend appropriate algorithms. This field, termed algorithm recommendation, garners significant attention[12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22].

The process of suggesting algorithms is frequently conceptualized as a meta-learning endeavor [12], [23], [24], [18], [19], [25], [20]. Meta-features represent dataset attribiutes, and the meta-target denotes candidate algorithm performance relative to the given set of data.

Formally, the process of recommending a classification algorithm entails identifying a function $f : \mathcal{X} \mapsto \mathcal{Y}$, where $\mathcal{X} = \mathbb{R}^p$ (meta-feature space with p meta-features) and $\mathcal{Y} = y_1, y_2, ..., y_q$ (meta-target space with q candidate algorithms). It aims to recommend appropriate algorithms $Y_{new} \subseteq \mathcal{Y}$ for a new dataset d_{new} based on $f(x_{new})$, where $x_{new} \in \mathcal{X}$ represents d_{new}'s meta-features.

Three common meta-target representations exist: single-label-based, ranking-based, and multi-label-based. Single-label methods recommend a single algorithm[9], [23], [26], [21]. Ranking-based methods suggest a ranked list[10], [25]. Multi-label methods identify all algorithms statistically equivalent to the best[30].

This paper proposes a two-layer learning method to address challenges like variability in recommended algorithms and scalability, *EML*. It is an ensemble of *ML-KNN*, based on stacking[33]. *EML* offers several advantages:

(1) Combining *ML-KNN* enhances recommendation performance.
(2) It leverages complementarity and diversity among meta-features.
(3) It dynamically recommends an appropriate number of algorithms, removing the need for pre-specification.

The paper is structured as follows: Section II outlines related work. Section III details the proposed *EML* method. Section IV presents empirical findings. Section **??** discusses validity threats. Finally, Section **??** concludes.

II. Related Work

This paper addresses the classification algorithm recommendation challenge, particularly focusing on ensemble learning. Related works primarily fall within the realm of classification algorithm recommendation.

A. Classification Algorithm Recommendation

Researchers have approached the classification algorithm recommendation problem through various perspectives, often analyzing dataset characteristics' relationship with algorithm performance experimentally. Methods can be broadly categorized into theoretical and experimental approaches.

Brodley[34] proposed a heuristic method to automatically identify the best classification algorithm by theoretically assessing their applicability. However, such theoretical approaches demand substantial domain expertise and may not cover all algorithm applicability scenarios, rendering them impractical.

To address the limitations of theoretical approaches, most methods adopt experimental strategies based on meta-learning. These approaches involve analyzing interactions between dataset characteristics and algorithm performance through scientific experiments[9], [15], [23], [20], [25], [35]. Variations among these methods lie in dataset characteristics (meta-features), representation of appropriate algorithms (meta-target), and recommendation models.

Meta-features typically fall into five categories: statistical and information-theory based[25], [36], [37], [21], [38], model structure based[39], [40], landmarking based[41], [42], [28], [29], problem complexity based[43], [44], [45], and structural information based[11], [16].

Meta-target expressions vary, including single label[11], [21], multi-label[30], [38], continuous variable[28], [27], [29], and ranking[25], [46].

Recommendation models employ three main techniques:

1) Classification: For single-algorithm selection, single-label classification methods are common[9], [47], [48]. For multi-algorithm recommendation, multi-label classification methods are favored[26], [30], [38], [32].
2) Regression: When users seek performance insights, regression methods predict continuous values[27], [28].
3) Ranking: For relative algorithm performance, ranking techniques generate ordered lists[10], [25].

This paper aligns with multi-label learning approaches[30], yet distinguishes itself by harnessing ensemble techniques featuring two-tiered learners to enhance recommendation effectiveness.

III. Our proposal: *EML* Methodology

This section introduces the *EML* method, an ensemble learning approach for classification algorithm recommendation. It begins with an overview of the method, followed by a discussion on the rationale and feasibility of utilizing ensemble learning in recommendation tasks. Subsequently, I delve into the detailed process of constructing the *EML* model. To aid clarity and understanding, I present relevant notations in Table I.

A. General point of view

EML approach's methodology is being depicted by Figure 1. It encompasses three key stages: extraction of meta-data, establishment of Tier-1 and Tier-2 models, and recommendation through ensemble learning.

Initially, a diverse array of meta-features is harvested from a collection of past classification tasks; as each potential classification algorithm is applied to these tasks, meta-targets are identified. These meta-features and targets are then amalgamated into various sets of multi-label meta-data.

Subsequently, individual Tier-1 models are crafted based on each meta-dataset, with their outcomes forming the Tier-2 training datasets. A binary classification model is subsequently crafted using these Tier-2 datasets to recommend suitable algorithms. When confronted with a new classification task, fresh meta-features are collected and Tier-2 data is generated using the Tier-1 model. This data is then subjected to the pre-established binary classification model to identify appropriate algorithms for the new task.

The justification and viability of constructing such an algorithm recommendation model via ensemble learning will be elaborated upon in the subsequent discussion.

B. Rationality and Feasibility

Ensemble learning often outperforms individual learners by addressing two common challenges: the statistical and representational problems[49]. These challenges also arise in constructing recommendation models using single learners.

The statistical problem emerges when the search space is extensive, making it difficult to find the true function ϕ. With a limited dataset, employing numerous meta-features can exacerbate this issue, increasing the likelihood of a single learner failing to find the true function ϕ. Ensemble learning mitigates this by enhancing generality.

Additionally, the effectiveness of a classification algorithm on a given problem is influenced by various factors, or meta-features, each playing a unique role[30]. Single learners may struggle to handle this complexity due to limited representational capacity. Ensemble learning overcomes this by combining diverse single learners, thus alleviating the representational problem.

Based on ensemble learning research[49], [50], I present Corollary 1 guiding the construction of an accurate ensemble learning model. This highlights the importance of developing accurate and diverse base recommendation models. In this study, I propose to construct various base learners based on different combinations of meta-features as Tier-1 models.

TABLE I

LIST OF NOTATIONS

Symbol	Notation
$\mathcal{P}$	the set of n historical classification problems $\mathcal{P} = \{p_i \| i = 1, 2, ..., n\}$
p_{new}	the new classification problem
$\mathcal{A}$	the set of k candidate classification algorithms $\mathcal{A} = \{a_j \| j = 1, 2, ..., k\}$
F	the set of q meta-feature extraction functions $\{F_1, F_2, ..., F_q\}$
$X_i^{'}$	the meta-feature combinations $X_i^{'} = \{X_{i1}, X_{i2}, ..., X_{it}\}$
X_i	the set of meta-features of the problem p_i, $X_i = \{X_i^j \| 1 \leq j \leq q\}$
X_i^j	the meta-features of p_i extracted by F_j
Y_i	the meta target of the problem p_i, $Y_i = \{Y_{i,j} \| 1 \leq j \leq k \wedge Y_{i,j} \in \{0, 1\}\}$
D_t	the multi-label meta data whose features are extracted by tth combination of functions in F $D_t = \{(X_{it}, Y_i) \| i = 1, 2, ..., n\}$
D	the set fo meta data extracted from the historical problems $\mathcal{P}$, $D = \{D_t \| 1 \leq t \leq 2^q - 1\}$
ϕ	the algorithm recommendation model
$nchoosek(Z)$	the function to get all combinations of elements in Z
L	the set of Tier-1 learners, $L = \{L_t \| 1 \leq t \leq 2^q - 1\}$
$L^{'}$	the set of selected trained Tier-1 learners used in recommending algorithms for the new problem
Out	the set of Tier-1 base models' output datasets, $Out = \{Out_t \| 1 \leq t \leq 2^q - 1\}$
Out_t	the output of corresponding model L_t, $Out_t = \{(v_{i,1}, v_{i,2}, ..., v_{i,k}) \| 1 \leq i \leq n\}$ where $v_{i,k}$ is the confidence of k_{th} label of i_{th} meta instance predicted by L_t
D^2	the set of Tier-2 training datasets, $D^2 = \{D_j^2 \| 1 \leq j \leq k\}$
D_j^2	Tier-2 training dataset transformed from Tier-1 models' output, $D_j^2 = \{(v_{i,1}, v_{i,2}, ..., v_{i,t}, label(i,j)) \| 1 \leq i \leq n \wedge t = 2^q - 1 \wedge label(i,j) \in \{0, 1\}\}$ where $v_{i,t}$ is the confidence of j_{th} label of i_{th} meta instance predicted by L_t
M^2	the Tier-2 classification model, $M^2 = \{M_j^2 \| 1 \leq j \leq k\}$
M_j^2	Tier-2 binary classification model constructed based on D_j^2

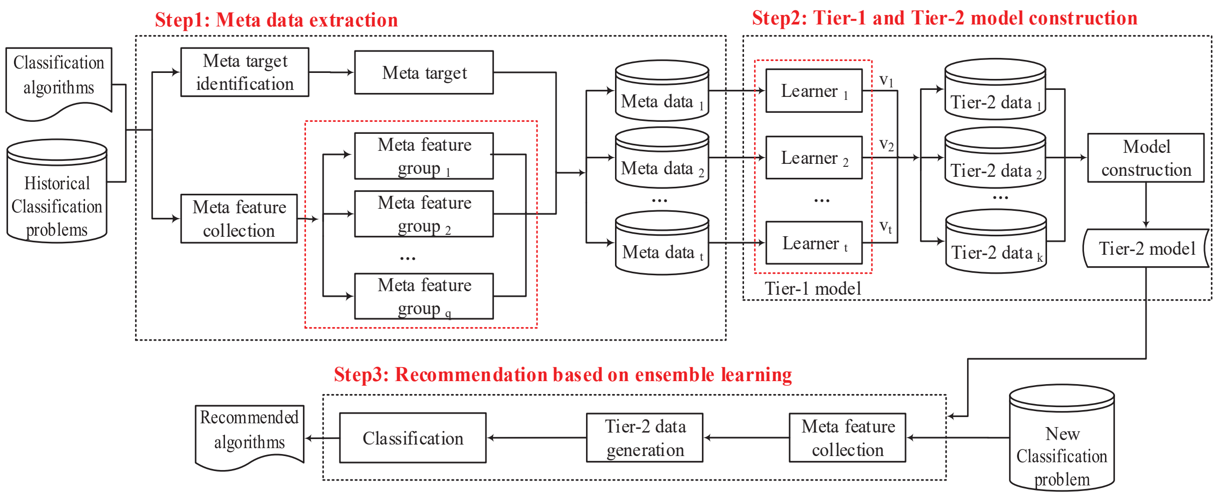

Fig. 1. Framework of the *EML* method

Utilizing the stacking framework, where the output of Tier-1 models serves as input for the Tier-2 model, I aim to build a two-layer recommendation model. Considering Corollary 1, this approach demonstrates feasibility from various perspectives.

1) Diverse base model construction

In the domain of algorithm recommendation[30], various types of meta-features have been explored. The extraction of meta-features involves analyzing classification problems from diverse perspectives. Figure 2 presents the correlation coefficients among five different sets of features derived from 183 benchmark classification problems (refer to the Appendix for detailed information). These feature groups include: 1) statistical and information-theory-based characteristics, 2) features based on model structure, 3) landmarking-derived features, 4) features related to problem complexity, and 5) structural information-based features.

From Figure 2, it is evident that the correlation among

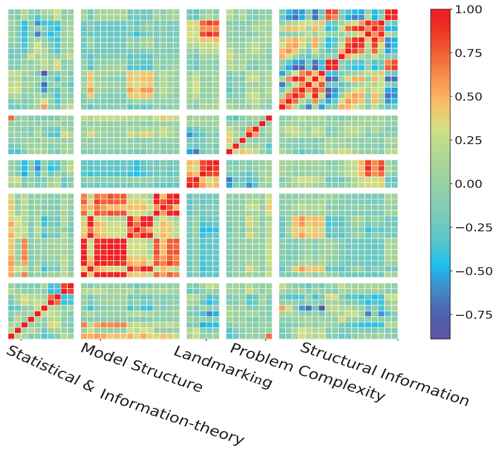

Fig. 2. Pearson's Linear Correlation Coefficients among Five Different Kinds of Meta features over 183 Classification Problems

different meta features is lower.Based on empirical evidence, it appears that various kinds of meta-features demonstrate independence from one another. Moreover, this independence implies that recommendation models constructed using these varied meta-features are expected to exhibit independence and diversity in their characteristics.

One way of the ensemble is to apply the same models to different training data, while another is to apply different models to the same training data. In this paper, the former is adopted. To guarantee the diversity of Tier-1 learners, all combinations of different kinds of meta-features are used to generate different Tier-1 training data, which also utilizes the complementary and diversity of meta-features. I use the attribute selection method on Tier-2 training data to further delete the redundant attributes (Tier-1 learners' output), equivalent to deleting corresponding Tier-1 learners, to promote base models' diversity.

2) Accurate base model construction

Several recommendation models have been developed based on various types of meta-features and employing a single learning approach[9], [47], [48], [26], [38], [30], [32]. To construct accurate base models, I can apply one of these recommendation models, which has good accuracy and great generalization, as the base model of the ensemble on different training data. Furthermore, I deal with the recommendation problem as a multi-label problem, so *ML-KNN* based recommendation model[30] would be a good choice for its speed and accuracy.

As discussed in a former item, the attribute selection method employed on Tier-2 training data will choose attributes highly related to labels. This means that Tier-1 learners whose performance is better will be selected for recommendation.

The description above demonstrates the possibility of creating a collection of precise base recommendation models within the ensemble.

C. Meta data extraction

It involves two main approaches: meta target identification and meta feature collection.

For meta-target identification, a statistical test method is utilized to determine appropriate algorithms for a specific evaluation metric on a given problem $p_i \in \mathcal{P}$. This approach identifies algorithms that exhibit no significant deviation from the top-performing one based on a specified metric forming the multi-label-based meta-target Y_i.

Meta-feature collection entails applying all q data characterization methods in F to historical classification problems, resulting in q meta-feature groups. These diverse meta-features capture the characteristics of a classification problem from various perspectives. This paper aims to construct base recommendation learners based on different combinations of these meta-features, effectively leveraging their complementarity.

Algorithm 1. Meta data extraction

Require:
$\mathcal{P}$: the historical classification problems, $\{p_i|i=1,2,...,n\}$
$\mathcal{A}$: the candidate classification algorithms, $\{a_j|j=1,2,...,k\}$
F: the set of meta feature extraction functions, $\{F_1,F_2,...,F_q\}$
Ensure:
$\{D_1,D_2,...,D_{2^q-1}\}$: the extracted meta datasets
$D_1,D_2,...,D_{2^q-1}=Null$;
for each $p_i \in \mathcal{P}$ **do**
    Y_i = targetIndentify(p_i, $\mathcal{A}$);
    for each data characterization method $F_j \in F$ **do**
        X_i^j = featureCollect(p_i, F_j);
        $X_i = X_i \cup X_i^j$;
    end for //Therer are q kinds of meta features
    $X_i^{'} = \{X_{i,t}|1 \le t \le 2^q-1\} = nchoosek(\{X_i\})$;
    //There are $t = 2^q - 1$ kinds of meta feature combinations
    for each $X_{i,t} \in X_i^{'}$ **do**
        $inst = (X_{i,t}, Y_i)$;
        $D_t = D_t \cup inst$;
    end for
end for
return $\{D_1,D_2,...,D_{2^q-1}\}$;

Procedure 1 outlines the metadata extraction process. Given classification problems $\mathcal{P}$, candidate classification algorithms $\mathcal{A}$, and feature extraction functions F, the procedure generates multiple meta-datasets $D_1,D_2,...,D_{2^q-1}$.

Initially, meta datasets are initialized. For each historical classification problem $p_i \in \mathcal{P}$, its meta-target Y_i is identified, and its meta-features X_i are collected.

All combinations of meta-features in X_i are then generated using the $nchoosek()$ function, resulting in 2^q-1 distinct sets of metadata. Each combination is associated with a corresponding instance $inst$, where its attributes are based on the meta-features and its label is Y_i.

Finally, the procedure returns the meta datasets $D_1, D_2, ..., D_{2^q-1}$.

The choice of the $nchoosek()$ function enables the creation of diverse sets of metadata, facilitating the exploration of different combinations of meta-features and their impact on algorithm recommendation. After metadata extraction, the historical classification problems $\mathcal{P}$ are transformed into meta datasets $D_1, D_2, ..., D_{2^q-1}$.

D. Tier-1 and Tier-2 model construction

This subsection depicts the Tier-1 and Tier-2 model construction process based on meta datasets extracted in the above section III-C.

For convenience to describe, $L = \{L_t | 1 \leq t \leq 2^q - 1\}$ represents Tier-1 learners built on each meta dataset D_t. $Out = \{Out_t | 1 \leq t \leq 2^q - 1\}$ is the set of Tier-1 output datasets, where Out_t is produced by L_t. $D^2 = \{D_j^2 | 1 \leq j \leq k\}$ represents the set of Tier-2 training datasets which are transformed from Tier-1 output. And D_j^2 will be used to construct a Tier-2 model M_j^2 to judge whether algorithm a_j is appropriate for the new classification problem.

The pseudo-code of Tier-1 and Tier-2 model construction is given in the procedure 2. First, the Tier-1 base learners are built over the meta datasets $\{D_t | 1 \leq t \leq 2^q - 1\}$ in lines from 3 to 5, where meta instances corresponding to the same historical classification problem p_i have different attributes(meta features) but same labels(meta target). As can be seen in framework 1, Tier-1 learner construction is identical and simple. Each L_t is trained based on each corresponding meta dataset D_t by *ML-KNN*. After model construction, each instance is predicted by each corresponding Tier-1 learner in lines from 6 to 11; that is, each instance of D_t is not only used to build base model L_t, but also predicted by L_t to generate Out_t. Then the prediction output datasets $\{Out_1, Out_2, ..., Out_{2^q-1}\}$ of Tier-1 model are transformed to Tier-2 training datasets $\{D_1^2, D_2^2, ..., D_k^2\}$ in lines from 13 to 15 as shown in Figure 3. Each instance of D_j^2 is labeled in lines from 16 to 18. After Tier-2 training data is generated, each Tier-2 dataset D_j^2 is first selected useful features in line 19 and then applied to construct a Tier-2 model M_j^2 in line 20. Finally, Tier-1 selected trained learners $L' = \{L_t' | 1 \leq t \leq m\}$ and Tier-2 binary classification model $M^2 = \{M_j^2 | 1 \leq j \leq k\}$ is returned to recommend algorithm(s) for a new classification problem.

Algorithm 2. Tier-1 and Tier-2 model construction

Require:
D: the set fo meta datasets, $D = \{D_t | 1 \leq t \leq 2^q - 1\}$
$MLkNN$: the multi-label classification algorithm *ML-KNN*
L: the set of untrained Tier-1 learners, $L = \{L_t | 1 \leq t \leq 2^q - 1\}$
Ensure:
L': the set of selected trained Tier-1 learners, $L' = \{L_t' | 1 \leq t \leq m\}$
M^2: the Tier-2 classification model, $M^2 = \{M_j^2 | 1 \leq j \leq k\}$
1: $Out = \{Out_1, Out_2, ..., Out_{2^q-1}\} = Null$;
2: $D^2 = \{D_1^2, D_2^2, ..., D_k^2\} = Null$;
3: **for** each $L_t \in L$ **do**
4: $L_t = MLkNN.build(D_t)$; //Tier-1 learner construction
5: **end for**
6: **for** each $D_t \in D$ **do**
7: **for** each $inst_i \in D_t$ **do**
8: $\{v(i,1), v(i,2), ..., v(i,k)\} = L_t.predict(inst_i)$;
9: $Out_t = Out_t \cup \{v(i,1), v(i,2), ..., v(i,k)\}$;
10: **end for**
11: **end for**
12: $D^2 = transform(Out)$;
13: **for** each instance $D_j^2 \in D^2$ **do**
14: **for** each instance $inst_i \in D_j^2$ **do**
15: $inst_i.label(i,j) = Y_{i,j}$;
16: **end for**
17: **end for**
18: **for** each $D_j^2 \in D^2$ **do**
19: $D_j^{2'} = featureSelect(D_j^2)$;
20: **for** each $attribute_t \in D_j^2$ **do**
21: **if** $attribute_t$ is selected **then**
22: $L' = L' \cup L_t$
23: **end if**
24: **end for**
25: $M_j^2.build(D_j^{2'})$; //Tier-2 model construction
26: **end for**
27: return L' and M^2;

It's noted that, before constructing a binary classification model, I conduct attribute selection to D_j^2 for the following three reasons:

- It will remove redundant and irrelevant attributes that may lead to the loss of the binary classification performance. Because each attribute is produced by each Tier-1 learner, removing redundant and irrelevant attributes is equivalent to selecting diverse and accurate Tier-1 learners to achieve better ensemble learning.
- It will help us to find which combination of meta-features is more useful since different meta datasets only have different attributes but have the same labels.
- With fewer attributes, fewer Tier-1 learners will be utilized to generate the Tier-2 attributes for a new classification problem and thus reduce the consuming time in the recommendation procedure.

In the *EML* algorithm, CFS[53] attribute selection method with the BestFirst[54] search strategy are employed.

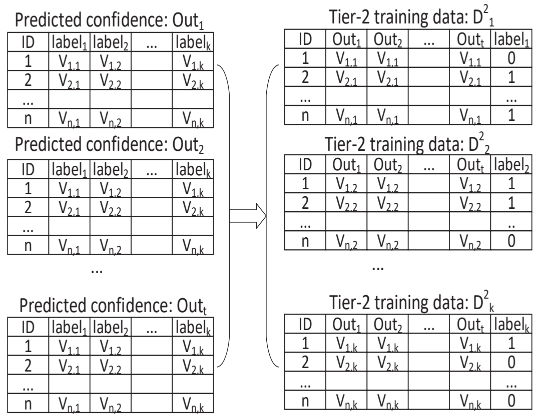

Fig. 3. Tier-2 training data generation based on Tier-1 models' output

Figure 3 displays the transformation from Tier-1 output Out to Tier-2 input D^2. In this figure, ID number represents each meta instance corresponding to each classification problem p_i and $label_k$ is the k_{th} label of metadata corresponding to each classification algorithm a_k. $v_{i,k}$ is the confidence of $label_k$ in the i_{th} instance, which is predicted by corresponding Tier-1 learner.

Each table in the left part of Figure 3 represents the output Out_t of each Tier-1 learner L_t, and each table in the right part represents the Tier-2 training dataset D_j^2 for each label $label_j$. $v_(i,j) \in Out_t$ is the confidence of $label_j$ of the i_{th} instance predicted by L_t, which will be transformed as $v(i,t) \in D_j^2$. In other words, all the j_{th} columns of $Out_t \in Out$ are incorporated together as attributes of D_j^2. In addition, $label_{i,j}$ of D_j^2 is meta target $Y_{i,j} \in Y_i$ and $label_{i,j}$ = 1 or 0 indicates the algorithm a_j is appropriate or inappropriate on p_i.

The reason why I generate Tier-2 training dataset D_j^2 for each algorithm a_j respectively, instead of combining them into a whole, is shown in Figure 4.

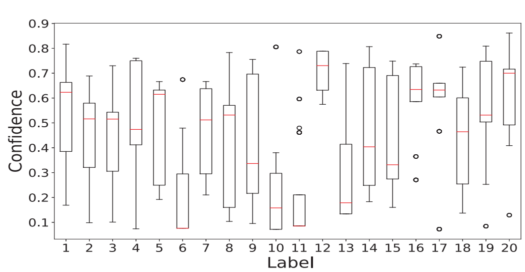

Fig. 4. Confidence comparison between different labels

Figure 4 compares the confidence values across different labels using the same metadata, with attributes combining various meta-features. The X-axis represents 20 labels, while the Y-axis shows the confidence value range. Each boxplot illustrates the confidence distribution for a label generated by *ML-KNN*. Notably, confidence values vary across labels, underscoring the need for individual label prediction. Additionally, each binary model in *EML* is built using C4.5 + AdaBoost.

E. Recommendation based on ensemble learning

In this section, I employ ensemble learning to recommend suitable algorithms for a novel classification problem.

By leveraging the ensemble learning approach discussed earlier, I create trained Tier-1 learners $L^{'}$ and Tier-2 binary classification models $M^2 = M_j^2 | 1 \leq j \leq k$ based on metadata, forming an ensemble learner for algorithm recommendation.

Procedure 3 outlines the recommendation process using ensemble learning, taking into account five input parameters: p_{new} (the new classification problem), $\mathcal{A}$ (the set of candidate classification algorithms), F (the set of meta feature extraction functions), $L^{'}$ (the set of selected trained Tier-1 learners), and M^2 (the Tier-2 binary classification model). The output $Algs$ represents the recommended appropriate algorithm(s) for p_{new}.

Algorithm 3. Recommendation based on ensemble learning

Require:
 p_{new}: the new classification problem
 $\mathcal{A}$: the candidate classification algorithms, $\{a_j | j = 1, 2, ..., k\}$
 F: the set of meta feature extraction functions, $\{F_1, F_2, ..., F_q\}$
 $L^{'}$: the set of selected trained Tier-1 learners
 M^2: the Tier-2 classification model, $M^2 = \{M_j^2 | 1 \leq j \leq k\}$
Ensure:
 $Algs$: set of recommended appropriate algorithms for p_{new}

```
for each data characterization method F_j in F do
    X^j_new = featureCollect(p_new, F_j);
    X_new = X_new ∪ X^j_new;
end for
X'_new = {X_new,t | 1 ≤ t ≤ 2^q − 1} = nchoosek({X_new});
for each X_new,t ∈ X'_new do
    inst_t = (X_new,t, '?');
    D_new = D_new ∪ inst_t;
end for
Out_new = L'.predict(D_new);
D^2_new = transform(Out_new);
for each instance inst_j ∈ D^2'_new do
    C_j = classify(M^2_j, inst_j);
    if C_j == 1 then
        Algs = Algs ∪ {a_j};
    end if
end for
return Algs;
```

Procedure 3 outlines the process for recommending suitable algorithms for a new classification problem p_{new}. Here's how it unfolds:

p_{new} initially gathers q types of meta-features to create its feature set X_{new} (lines 1-4).

The $nchoosek$ function is then utilized to generate all possible combinations of elements in X_{new} (line 5), which constructs D_{new} with these combinations serving as attributes (lines 6-9).

The unknown labels of D_{new} are represented as '?' to indicate their uncertainty.

Following this, Out_{new}, the output of the Tier-1 model $L^{'}$ on D_{new}, is obtained (line 10). It is then transformed into D^2_{new}, the input for the Tier-1 model (line 11). Next, each instance $inst_j$ in D^2_{new} is classified by M^2_j, resulting in label C_j (lines 12-17). If C_j is 1, the corresponding algorithm a_j is added to the set $Algs$. Finally, the set of recommended appropriate algorithms $Algs$ for p_{new} is returned, signifying the conclusion of the recommendation process.

IV. Empirical Study

In this section, I conduct an empirical investigation to assess the performance of the *EML* method. I begin by outlining the experimental setup, followed by a comparison of *EML* with baseline methods. Finally, I present a comparison of the number of recommended algorithms between *EML* and baseline methods.

A. Experimental setup

To ensure the reproducibility of our experiment, I establish the following setup:

1) Benchmark datasets: I utilize a collection of 183 publicly available datasets sourced from prominent repositories such as the UCI repository[56], StatLib[57], openML[58], and KEEL[59]. The statistical summary of these datasets, including their names, number of features, instances, and classes, is provided in the appendix. These datasets are widely employed in classification research and represent real-world classification problems.

2) Candidate Classification Algorithms: To ensure the robustness of our experimental findings, I include a diverse set of 20 well-established classification algorithms, each utilizing distinct methodologies. These algorithms are classified into various categories:

- Probability-based algorithms: Aggregating One-Dependence Estimators (AODE), Naive Bayes (NB), Bayes Network.
- Tree-based algorithms: C4.5, CART, Random Tree.
- Rule-based algorithms: Ripper, PART, OneR, NNge.
- Support-vector-machine-based algorithm: SMO.
- Lazy learning-based algorithm: IB1.
- Gaussian function-based algorithm: RBF-Network.
- Ensemble learning-based algorithms: RandomForest, Boosting+NB, Boosting+C4.5, Boosting+PART, Bagging+NB, Bagging+C4.5, Bagging+PART.

3) Performance Evaluation Metrics: IIn our experimental setup, I rely on two primary metrics to gauge the effectiveness of the candidate classification algorithms. The foremost metric is accuracy, a widely adopted measure in performance evaluation. Additionally, I incorporate the Adjusted Ratio of Ratios (ARR)[25] metric, which factors in both classification accuracy and runtime, providing a more comprehensive evaluation of algorithmic efficacy.

Moreover, a 5× 10-fold cross-validation procedure is performed when evaluating the classification algorithms on the given dataset.

4) Baseline Methods and Performance Measures: To evaluate the efficacy of our proposed *EML* method, I conduct a comparative analysis against two existing approaches for multi-label-based classification algorithm recommendation: the *ML-KNN* method[30] and the single-link prediction (*SLP*) method[32], which employs the *RWR* algorithm[60] for link prediction.

This comparison is based on four key performance metrics: Hamming Loss, F-measure, Accuracy, and Hit Ratio. These metrics, commonly used in related studies[30], [32], comprehensively evaluate recommendation effectiveness.

5) Experimental Procedure and Parameter Setting: I employ a *leave-one-out* cross-validation approach, where each dataset takes turns as the new dataset while the rest serve as historical datasets. This ensures that all 183 datasets are utilized as new datasets during the experiment. To maintain fairness, I set the parameter k (the number of nearest neighbors) of *ML-KNN* to 5, aligning with the linking of each dataset node with its five nearest neighbor nodes in *SLP*.

The number of recommended algorithms is not predetermined for *EML*; it dynamically determines the appropriate number. However, for baseline methods, I set the recommended algorithm number to 5, per their respective papers' recommendations.

B. Performance Evaluation of EML

In this section, I present and analyze the performance of *EML*. Firstly, I report the average performance of *EML* and compare it to that of the baseline methods. Subsequently, I conduct a significance test to determine if the observed differences between *EML* and the baseline methods are statistically significant.

1) Average performance comparison: Within this section, I conduct a comparative analysis between *EML* and the baseline methods across key performance metrics, including *Hamming Loss*, *F-Measure*, *Accuracy*, and *Hit Ratio*. The outcomes of this comparison are visualized in Figure 5.

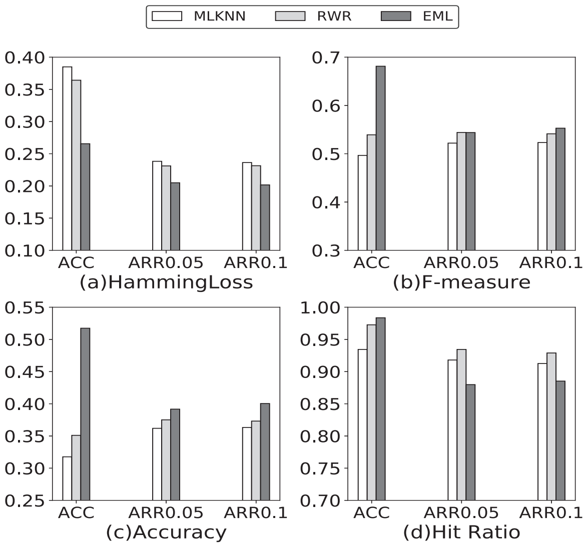

Fig. 5. Comparison on *Hamming Loss*, *F-Measure*, *Accuracy* and *Hit Ratio* between *MLKNN* based, *RWR* based and *EML* recommendation methods

2) Comparison of Performance Metrics: **Hamming Loss:**

The *Hamming Loss* assesses recommendation accuracy, with lower values indicating better performance.

In Figure 5(a), *EML* consistently achieves lower *Hamming Loss* values across all evaluation metrics compared to *SLP* methods.

F-Measure:

F-Measure balances *Precision* and *Recall*, with higher values indicating better recommendations.

Figure 5(b) shows that *EML* outperforms other methods, particularly in ACC.

Accuracy:

EML consistently achieves higher *Accuracy* compared to other methods, especially in ACC, as depicted in Figure 5(c).

Hit Ratio:

The *Hit Ratio* reflects recommendation appropriateness, with higher values indicating better performance.

Figure 5(d) shows that *EML* recommends fewer algorithms, yet achieves comparable or higher *Hit Ratio* values than baseline methods.

In summary, *EML* consistently outperforms baseline methods across various metrics.

3) Significance Test: To validate the significance of *EML*'s improvements, a Wilcoxon signed-rank test at a significance level of 0.05 compares *EML* with baseline methods.

TABLE II
SIGNIFICANCE TEST RESULT OF COMPARISON BETWEEN *ML-KNN* BASED, *RWR* BASED AND *EML* RECOMMENDATION METHODS

(a) Statistical test result between *ML-KNN* based and *EML* methods

Alternative Hypothesis	Performance measures	Evaluation Metric ACC	$ARR_{0.05}$	$ARR_{0.1}$
EML >ML-KNN	Hamming Losses	1.00	1.00	1.00
	F-Measures	**0.00**	0.27	0.10
	Accuracy	**0.00**	0.08	**0.02**
	Hit Ratios	**0.01**	0.97	0.94
EML <ML-KNN	Hamming Losses	**0.00**	**0.00**	**0.00**
	F-Measures	1.00	0.73	0.90
	Accuracy	1.00	0.92	0.98
	Hit Ratios	0.99	**0.04**	0.07
	Win/Draw/Loss	4/0/0	1/2/1	2/2/0

(b) Statistical test result between *RWR* based and *EML* methods

Alternative Hypothesis	Performance measures	Evaluation Metric ACC	$ARR_{0.05}$	$ARR_{0.1}$
EML >RWR	Hamming Loss	1.00	1.00	1.00
	F-Measure	**0.00**	0.71	0.40
	Accuracy	**0.00**	0.37	0.13
	Hit Ratio	0.26	0.99	0.98
EML <RWR	Hamming Loss	**0.00**	**0.00**	**0.00**
	F-Measure	1.00	0.29	0.60
	Accuracy	1.00	0.63	0.87
	Hit Ratio	0.78	**0.01**	**0.02**
	Win/Draw/Loss	3/1/0	1/2/1	1/2/1

The statistical test results in Table II compare the performance of *EML* with baseline methods. Each subtable presents two alternative hypotheses regarding whether *EML* outperforms or is inferior to the baseline method across different evaluation metrics.

A p-value < 0.05, indicated in bold, supports the alternative hypothesis. For instance, in Subtable II(a), a p-value of 0.00 for *F-Measure* suggests that *EML* is statistically better than the *ML-KNN* method. The "Win/Draw/Loss" record in each subtable shows the number of cases where *EML* is statistically superior to/equal to/inferior to the compared method.

From Table II, it is evident that *EML* statistically outperforms baseline methods across various metrics.

C. Comparison on Recommended Algorithm Numbers

This section compares the number of recommended algorithms between baseline methods and *EML*. Since *RWR* and *ML-KNN* methods recommend a fixed number of algorithms, *RWR* is chosen as a representative. It is set to recommend 5 algorithms, as suggested in its paper.

The results show that *EML* recommends a variable number of algorithms automatically, adapting to the problem's complexity, whereas *RWR* recommends a fixed number. This flexibility suggests a potential advantage of *EML* over baseline methods.

TABLE III
THE COMPARISON ON THE RECOMMENDED ALGORITHM NUMBER BETWEEN *RWR* BASED AND *EML* METHODS

Evaluation Metric	Win/Draw/Loss		
	Win	Draw	Loss
ACC	94	28	61
$ARR_{0.05}$	83	37	63
$ARR_{0.1}$	84	40	59

Table III presents the "Win/Draw/Loss" outcomes of the comparison on 183 historical classification problems. The squared error is used to assess the proximity of the recommended and actual numbers of algorithms, with the "Win/Draw/Loss" record indicating whether the squared error of *EML* is smaller than/equal to/larger than the compared method.

The results indicate that regardless of using ACC, $ARR_{0.05}$, or $ARR_{0.1}$, the recommended algorithm number of *EML* is closer to the actual number. The disparity is most significant in ACC, where the performance of *EML* notably surpasses the two baseline methods. This suggests that *EML* adeptly adjusts the recommended number of algorithms according to different classification problems.

V. POTENTIAL LIMITATIONS

A possible limitation of this study concerns the diversity of the 183 datasets and the 20 candidate classification algorithms used. Ensuring a representative sample by selecting widely-used datasets and established algorithms aims to mitigate this issue.

Another aspect to consider is the reliance on *Accuracy* and *ARR* as primary evaluation metrics for classification. It's worth noting that these metrics are also employed in the baseline methods of this study.

VI. CONCLUDING REMARKS

This paper presents *EML*, a two-layer classification algorithm recommendation framework based on ensemble learning. Leveraging diverse combinations of meta-features, *EML* autonomously suggests the most suitable algorithm(s) for diverse classification problems.

The methodology involves generating varied meta-feature combinations to construct Tier-1 learners, establishing Tier-2 training datasets based on Tier-1 predictions, and utilizing Tier-2 models to recommend appropriate algorithms for new tasks.

Empirical findings, based on 183 datasets and 20 classification algorithms, demonstrate *EML*'s superiority over single-link prediction and *ML-KNN* approaches. Moreover, *EML* provides recommendations closer to actual requirements compared to baseline methods.

Future research will focus on enhancing *EML*'s efficiency and effectiveness, exploring alternative distance metrics for *ML-KNN*, and identifying more effective meta-features or combinations for accelerated Tier-2 classification.

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Study on Dumping Grounds in Urban Areas with specific reference to Waste Management and Sustainability

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***Abstract*— Due to rapid urbanization, managing daily generated waste has become a significant challenge. This waste typically originates from industrial, commercial, and residential areas. If the waste is not properly disposed, it can harm public health and negatively impact the cleanliness and appearance of the area.**

This paper presents a study focused on the current state of solid waste management at the dumping ground in urban areas. It also proposes practical methods to address the issues caused due to improper waste management and provides solutions to mitigate these issues.

Keywords—Dumping ground, waste management, sustainability

I. INTRODUCTION

In urban areas, managing waste daily has become a serious problem, especially in urban areas with high population density. A densely populated region, faces major waste management challenges that affects the public health and environment. Generally, these wastes are disposed of at dumping grounds. When the waste is not properly disposed of at dumping grounds, it degrades soil quality, air quality and water quality (especially ground water quality). Further, it increases the risk of air-borne and water-borne diseases. Additionally, the waste dumped at the dumping grounds may include resources that could be have been recycled which leads to wastage of resources.

Another problem associated with the improper waste management is lack of waste segregation. When the waste is not segregated into categories like organic, recyclable, and hazardous, it becomes challenging to recycle. This issue is worsened by the fact that the population in the area keeps growing, but the size of the dumping ground stays the same. As a result, there is more waste to handle in the same amount of space.

Moreover, the ability of municipal corporation of the urban areas to collect, separate, and dispose of solid waste is limited and does not keep up with the increasing amount of waste. The current system adopted by the municipal corporation is not sufficient to handle the waste disposals at the dumping grounds.

Therefore, there is a need for a sustainable waste management system to address the issues associated with the waste disposals at the dumping grounds. This paper aims to examine the current waste management practices in the urban areas, identify the key problems, and suggest sustainable solutions.

II. LITERATURE REVIEW

In recent studies, various researchers have explored the critical issues surrounding waste management and its effects on public health and the environment.

In [1], authors discuss the health risks associated with improper waste disposal, particularly in densely populated urban areas. [1] highlights the direct impact of poorly managed waste on respiratory diseases, eye infections, and other morbidities. They emphasize the need for improved waste segregation and management systems to mitigate these health risks.

In [2], authors discuss the severe environmental and health impacts of inadequate solid waste management. With increasing urbanization, improper disposal and treatment of waste result in hazardous effects. Urgent and effective actions, along with strict policies, are needed to mitigate the long-term health risks and environmental degradation caused by improper waste management.

In [3], authors propose a microeconomic framework for sustainable waste management, emphasizing the importance of recycling, composting, and stakeholder collaboration. Further, [3] highlights the need for efficient resource use and reduced environmental impact, promoting a holistic approach to waste management for sustainable development.

In [4], authors provides a significant evaluation of compost production from vegetable and food market waste in Ulaanbaatar, Mongolia. [4] highlights the potential for generating 657,621 tons of compost annually from 1,826.7 tons of vegetable market waste collected daily. The composting process, however, revealed the presence of intestinal bacilli at 21 days, indicating that the compost was not fully mature. The study shown in [3] concluded that a maturation period of 60 days is essential for achieving fully mature compost. Furthermore, [4] demonstrated that compost fertilizer derived from food market waste could be effectively applied to soil at a rate of 15-20 tons per hectare, supporting sustainable agricultural practices. The study shown in [4] highlights the feasibility and environmental benefits of utilizing vegetable market waste for compost production. [4] emphasize the importance of proper composting durations to ensure maturity and safe application to agricultural land, contributing to waste management and soil fertility enhancement.

III. RESEARCH OBJECTIVE

1. To study how waste, including dry and wet waste, is currently managed at dumping grounds in urban areas.
2. To find problems in the waste collection, segregation, and disposal processes and suggest better ways to fix them.
3. To analyse the environmental, social, and economic impacts of current waste management practices and assess the feasibility and effectiveness of proposed solutions.

IV. HYPOTHESIS

Ho: Null Hypothesis

The current waste management system at the dumping ground, including the handling of dry and wet waste, does not significantly impact environmental quality, public health, or resource optimization.

H1: Alternative Hypothesis

The current waste management system at the dumping ground, including inadequate handling of dry and wet waste, significantly affects environmental quality, public health, and resource optimization.

V. LIMITATION OF THE STUDY

1. Inadequate understanding or compliance by residents and businesses regarding waste segregation and disposal practices.
2. Unpredictable weather conditions, such as heavy rains, could impact data collection and site visits.
3. Changes in local government policies during the study period could affect findings or recommendations.

VI. RESEARCH METHODOLOGY

A. *Experimental Methodology: Setting Up a Waste Processing Center*

- The study involves redirecting waste from the dumping ground to a designated research centre where waste will be handled and processed daily.
- The research centre will implement segregation practices to separate dry and wet (organic) waste for further processing.

B. *Methodology for Organic Farming Fertilizer Production*

- To convert wet waste into organic fertilizer using composting methods.
- Composting Process: Use aerobic or anaerobic composting techniques to process wet waste into high-quality organic fertilizer**.**

C. *Methodology for Dry Waste Management*

- To create a supply chain for segregated dry waste by selling it to multiple buyers.
- Sorting and Classification: Separate dry waste into categories (e.g., paper, plastic, metal, glass) for recycling.

- Market Identification: Identify buyers and recycling companies willing to purchase sorted dry waste.
- Contracts with Buyers: Establish agreements with multiple buyers to ensure a steady flow of recycled materials.
- Data Collection & Analysis:
- Monitor the quantity of dry waste collected, segregated, and sold.
- Analyse revenue generation trends from dry waste sales.
- Methodology Type: Market Research and Feasibility Analysis

D. Methodology for Securing Government Funds

- To draft and propose projects to obtain government funding for sustainable waste management initiatives.
- Develop detailed project proposals focusing on the research centre, composting, recycling, and waste segregation initiatives.
- Align proposals with government waste management policies and sustainability goals.
- Submit proposals to relevant government departments and monitor approval status.
- Methodology Type: Policy Analysis and Proposal Writing.

E. Methodology for Attracting Private Investment

- To attract investments from private companies interested in sustainable waste management projects.
- Design a viable business model showing the financial and environmental benefits of the research centre's activities.
- Present the model to potential investors through meetings, presentations, and reports.
- Collaborate with private players to co-fund projects and share responsibilities.
- Methodology Type: Business Analysis and Financial Modelling.

VII. DATA ANALYSIS

A. Quantitative Analysis:

a.) How Much Waste is Processed Every Day:

- Measure the total amount of waste processed at the research centre every day. This includes both wet (organic) waste and dry waste separately.
- Use tools or manual tracking to record how much waste is collected each day.

b.) Money Made from Selling Dry Waste and Organic Fertilizers:

- Track how much money is earned from selling the recycled dry waste and the organic fertilizers made from wet waste.
- Look at how the prices and sales are doing to understand how much income the project brings in.

c.) Government and Private Funds Received:

- Keep a record of all the money received from the government and private investors.
- Check how this money is being used for the sustainability projects.

d.) Reduction in Waste Sent to the Dumping Ground:

- Track how much waste is being kept out of the dumping ground due to the new waste management practices.
- Compare how much waste was going to the dumping ground before and after the new system was put in place.

B. Qualitative Analysis:

a.) Feedback from Farmers Using Organic Fertilizers:

- Collect opinions from farmers who are using the organic fertilizers made from wet waste.
- See how effective the fertilizers are for crops and how they impact soil quality.

b.) Community Response to Improved Waste Management Practices:

- Ask local residents and businesses for their opinions on the new waste management methods.
- Find out if people's attitudes toward waste separation, recycling, and pollution control have changed.

c.) Investor and Buyer Satisfaction with Project Outcomes:

- Ask investors and buyers how satisfied they are with the results of the project.
- Use their feedback to make improvements in future projects.

C. Statistical Tools:

a.) Microsoft Excel or SPSS (Statistical Package for the Social Sciences):

- These tools will be used to organize and analyse the data.
- SPSS can help us generate simple statistics to understand how things like waste amounts and money made are connected.

b.) Machine Learning Algorithms:

- Regression Analysis: This will help us see how different things like waste generation and revenue are related.
- Classification Algorithms (e.g., Decision Trees): These will help sort different types of waste (like organic and recyclable) more efficiently.
- Clustering Algorithms (e.g., K-means): This will help us find patterns in where and when the most waste is generated, helping us plan better collection schedules.
- Predictive Modelling (e.g., Linear Regression): This will help us predict future waste generation trends and how much money we might make, so we can plan for the future.

VIII. Suggestions and Recommendations

A. Improve Waste Segregation at Source:

Suggestion: Encourage residents and businesses to segregate waste into wet (organic) and dry waste at the source.

Recommendation: Conduct community workshops and awareness campaigns on the importance of waste segregation. Provide residents with separate bins for organic and recyclable waste. This will make the entire process more efficient and help reduce contamination.

B. Set Up More Waste Processing Centers:

Suggestion: Expand the research centre and set up more processing units in different parts of the city to handle the increasing waste.

Recommendation: The local government and private companies should collaborate to establish additional facilities for waste processing, composting, and recycling. This will reduce the load on existing sites and help manage waste more effectively.

C. Incentivize Recycling and Waste Minimization:

Suggestion: Offer incentives to residents and businesses that actively participate in recycling and waste reduction efforts.

Recommendation: Introduce reward systems, such as discounts on utility bills or coupons for eco-friendly products, for those who properly segregate and recycle their waste. This will encourage more people to participate in sustainable practices.

D. Promote the Use of Organic Fertilizer in Farming:

Suggestion: Encourage local farmers to use organic fertilizers made from wet waste.

Recommendation: Set up training programs for farmers to educate them on the benefits of organic fertilizers. Additionally, offer subsidies or discounts on fertilizers produced at the research centre to make them more affordable and accessible.

E. Government and Private Sector Collaboration for Funding and Investment:

Suggestion: Strengthen collaboration between the government, private investors, and the community to secure funding for waste management projects.

Recommendation: The government should create clear policies and financial incentives to attract private investments in waste management. Proposals for new projects should be submitted regularly to ensure continuous funding and support.

F. Increase Public Awareness and Community Engagement:

Suggestion: Launch continuous public awareness campaigns to educate the community about the importance of waste management and the impact of improper disposal.

Recommendation: Use social media, local newspapers, and community events to spread information. Schools and community centres can also be involved in training the next generation on sustainable waste practices.

G. *Adopt Technology for Waste Monitoring and Data Collection:*

Suggestion: Implement technology to monitor waste generation and track the effectiveness of the waste management system.

Recommendation: Use sensors, smart bins, and mobile apps to track waste collection, segregation, and disposal. This data can help optimize collection schedules, improve efficiency, and ensure that resources are used effectively.

H. *Evaluate and Improve Existing Waste Management Systems:*

Suggestion: Continuously evaluate the effectiveness of current waste management systems to identify areas for improvement.

Recommendation: Regular audits of waste management practices should be conducted by independent bodies. Based on the findings, adjustments should be made to improve efficiency and reduce costs.

IX. CONCLUSION

The study of waste management at dumping grounds highlights serious challenges in handling the increasing volume of waste. Poor waste sorting, insufficient processing facilities, and lack of public participation are key contributors to pollution and health issues.

Improving waste management practices, such as separating wet and dry waste, establishing processing centres, and raising public awareness, can significantly reduce the burden on dumping grounds. Utilizing wet waste to produce compost can benefit farmers, while recycling dry waste can create new business opportunities. Additionally, government funding and private investments are essential to support and expand these initiatives.

By implementing these suggestions, urban areas can develop a more sustainable and efficient waste management system. This will enhance residents' quality of life and help protect the environment. Effective waste management can reduce pollution, conserve resources, and ensure a cleaner, healthier environment for future generations

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I would like to express my heartfelt gratitude to Dr. Rinkesh Chheda, Assistant Professor, S.I.E.S College of Commerce & Economics (Autonomous), Mumbai University, for his invaluable guidance and encouragement throughout the course of this work. His insights and constructive feedback have been instrumental in shaping this research. I deeply appreciate his unwavering support and mentorship, which have greatly contributed to the successful completion of this paper.

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A Study on Impact of Green Marketing on Consumer Purchaisng Decision of Mumbai Region

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A Study on Impact of Green Marketing on Consumer Purchaisng Decision of Mumbai Region

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***Abstract*— Green marketing plays a crucial role In sustainable development and environmental preservation. This study examines green marketing practices in India, focusing on Mumbai. Key objectives include assessing public awareness, perceptions, and benefits of green products, and understanding challenges in green marketing. Findings reveal substantial consumer awareness but limited knowledge of organizational initiatives, with the internet as a key information source. Consumers show growing interest in eco-friendly practices, highlighting opportunities for green strategies. Challenges include economic constraints and sector-specific behaviours. The study underscores integrating green marketing into business operations and leveraging digital platforms to align with consumer expectations and environmental goals.**

Keywords—Eco- Friendly, sustainability development

I. INTRODUCTION

Green Marketing refers to the process of selling products and services based on their environmental benefits. Such a product or service may be environmentally friendly in itself or produced in an environmentally friendly way, such as: Being manufactured in a sustainable fashion. Not containing toxic materials or ozone depleting substances. Able to be recycled and/or is produced from recycled material. Being made from renewable materials (such as bamboo, etc). Not making use of excessive packaging. Being designed to be repairable and not "throwaway". GREEN Marketing and Sustainable development. Green marketing is typically practiced by companies that are committed to sustainable development and corporate social responsibility. More organizations are making an effort to implement sustainable business practices as they recognize that in doing so, they can make their product more attractive to consumers and also reduce expenses, including packaging, transportation, energy/water usage, etc. Businesses are increasingly discovering that demonstrating a high level of social responsibility can increase brand loyalty among socially conscious consumers; green marketing can help them do that..

II. LITERATURE REVIEW

In recent studies, various researchers have explored the analysis on Green Marketing

In [1], Oyewole, P. (2001). In his paper presents a conceptual link among green marketing, environmental justice, and industrial ecology. It argues for greater awareness of environmental justice in the practice of green marketing. A research agenda is finally suggested to determine consumers' awareness of environmental justice, and their willingness. Brahma, M. & Dande, R. (2008), The Economic Times, Mumbai, had an article which stated that Green Ventures India is a subsidiary of New York based asset management firm Green Ventures International. The latter recently announced a $300 million India focused fund aimed at renewable energy products and supporting trading in carbon credits.

In [2], Sanjay K. Jain & Gurmeet Kaur (2004), in their study environmentalism has fast emerged as a worldwide phenomenon. Business firms too have risen to the occasion and have started responding to environmental challenges by practicing green marketing strategies.

Green consumerism has played a catalytic role in ushering corporate environmentalism and making business firms green marketing oriented. Based on the data collected through a field survey, the paper makes an assessment of the extent of environmental awareness, attitudes and behavior prevalent among consumers in India.

policies, are needed to mitigate the long-term health risks and environmental degradation caused by improper waste management.

In [3] Bhanu Pratap Singh and Dr. Ruchi Kashyap Mehra (2019), the study reveals that the consumer awareness towards green marketing and buying behaviour of green products and green marketing impact on society. The author reveals that the people of the Indore city consumers are aware of green marketing. Deepa Ingavale and Auradha Gaikwad (2011), had observed that there is no significance relation between income, educational qualification and occupation with respect to awareness about the Green Marketing. Nik Ramli Nik Abdul Rashid (2009), the study reveals that the Malaysian consumers will react positively towards eco-label. Polanski, Michael Jay (1994), the study reveals that green marketing covers more than a firms marketing claim. The firms are responsible for the environmental degradation but it the consumers who demand those products. So, it is not only the responsibility of the firms but also of the consumers.

In [4] Dr.Patel& Dr. Pawan K.(2016) Chugan in their study confirmed that environmental knowledge, corporate image, the agility of product functions, and the ethical impact of were aspects of green advertising that had a significant positive impact on consumers' green purchasing intentions. In contrast, this study found that neither skepticism about green claims nor the credibility of advertising was significant in influencing green purchase intentions. However, since this study was applied to general advertising for research purposes, further investigation may be conducted by examining certain types of green advertisements, including online advertisements, print advertisements, radio advertisements, and TV advertisements. Thus, a more specific understanding can be obtained from the literature, where consumer perceptions of green advertising will vary depending on the format or medium used. In this study, the impact of consumers' perceptions of green/environmental advertising on purchase intentions was measured.

III. RESEARCH OBJECTIVE

1. To study the concept of Green Marketing w.r.t. Indian context.
2. To determine the Mumbai Region's general public's level of awareness on environmental sustainability.
3. To identify the factors that influence the customer persuasion to buy green products.
4. To identify the factors affecting Green Marketing strategies & purchasing decisions.
5. To identify the correlation between Green Marketing & purchasing decisions

IV. HYPOTHESIS

Ho: Null Hypothesis

There is no awareness of environmental sustainability among consumers

H1: Alternative Hypothesis

There is an awareness of environmental sustainability in consumers.

Ho: Null Hypothesis

There are no such factors which affect the influence of customers' persuasion to buy green products.

H1: Alternative Hypothesis

There are factors which affect the influence of customer persuasion to buy green products.

Ho: Null Hypothesis

There is a positive consumer perception towards green products.

H1: Alternative Hypothesis

There is a negative consumer perception towards green products.

Ho: Null Hypothesis

There is a negative correlation between green marketing and purchasing decisions.

H1: Alternative Hypothesis

There is a positive correlation between green marketing and purchasing decisions.

V. LIMITATION OF THE STUDY

1. The study is limited to only the Mumbai region.
2. The study does not cover core psychological aspects of individual consumers.
3. The study will only focus on consumer perception towards green products in general.
4. The study will not consider any other economic variables affecting green marketing

VI. RESEARCH METHODOLOGY

A. RESEARCH DESIGN:
Descriptive & Diagnostic research design

B. DATA COLLECTION:

Secondary Data
The secondary data will be collected from various national & International Journals, Government websites & magazines along with new articles & thesis.

C.Primary Data

Method of Data Collection
Survey method
Population
General public of Mumbai Region

D.Sample Size

The estimated sample size is 100 people from the Mumbai region.
Sampling Method
Random Probability Method
Sampling Area/frame
Mumbai Region

Statistical test : Single factor ANOVA

VII. DATA ANALYSIS

A. Quantitative Analysis:

DATA ANALYSIS & INTERPRETATION:

H0 - There is no awareness of environmental sustainability among consumers.

H1 - There is an awareness of environmental sustainability in consumers.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	65	68	1.046	0.044712
1	65	158	2.431	2.967788
2	65	142	2.185	0.402885

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	70.933	2	35.47	31.15315	1.91705E-12	3.04296402
Within Groups	218.58	192	1.138			
Total	289.52	194				

The results of the single-factor ANOVA analysis indicate a significant difference between the means of the two groups. Group A, with an average of 1.1846 and a variance of 0.1529, is statistically distinct from Group B, which has a higher average of 2.0462 and a variance of 0.7947. The ANOVA test reveals an F-statistic of 50.9143, which far exceeds the critical value of 3.9151. Furthermore, the P-value (6.38×10−116.38×10 −11) is substantially lower than the standard significance threshold of 0.05, confirming that the observed differences are not due to random chance. The within-group variability (mean square: 0.4738) is relatively low compared to the variability between groups (mean square: 24.1231), reinforcing the conclusion that the two groups differ significantly. These results suggest that the factors distinguishing the two groups have a meaningful impact on the measured outcomes.

H0 - There is a negative correlation between green marketing and purchasing decisions.

H1 - There is a positive correlation between green marketing and purchasing decisions.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2	65	74	1.138	0.1212
2	65	126	1.938	0.3712
2	65	235	3.615	1.0841
1	65	68	1.046	0.0447

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	276.13	3	92.04	227.11	7.78484E-72	2.63986279
Within Groups	103.75	256	0.405			
Total	379.89	259				

The **F-statistic** is very large (227.1095), and the **P-value** is extremely small (7.78E-72), which indicates that the differences between the groups are highly significant. Since the **P-value** is much smaller than typical significance levels (such as 0.05), you can reject the null hypothesis that all group means are equal. The significant variation between groups suggests that the factor you're testing has a large effect on the groups. The group means are not likely to be the same, and there is strong evidence that differences between the groups exist. the F-statistic (227.1095) is much greater than the critical value (2.6399), reinforcing that the group means are significantly different.

P-value (7.78484E-72): This is extremely small, indicating that the observed difference between group means is highly statistically significant. In fact, the probability of observing such extreme results by random chance is effectively zero. Thus the null hypothesis is rejected. (which states that all group means are equal)

H0 - There is a positive consumer perception towards green products.

H1 - There is a negative consumer perception towards green products.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
1	65	89	1.37	0.2365
1	65	68	1.05	0.0447
3	65	265	4.08	0.7909
1	65	133	2.05	0.7947

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	360.8	3	120	257.7	5.07989E-77	2.63986279
Within Groups	119.5	256	0.47			
Total	480.3	259				

The **F-statistic (257.7004)** is extremely large, and the **P-value (5.07989E-77)** is very small, indicating that the variation between the group means is highly significant. Since the **P-value** is far below typical significance levels we can reject the null hypothesis, which means that the means of the groups are not equal. The results suggest that the factor being tested has a significant impact on the groups, and the means of at least some of the groups are different from each other. the calculated F-statistic (257.7004) is much larger than the critical value (2.6399), reinforcing the conclusion that there are significant differences between the group means.

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VIII. SUGGESTIONS AND RECOMMENDATIONS

It is suggested that the study should not be limited to only the Mumbai region so as to get the macro level insights for better measures at national level. The study can be taken ahead to cover core psychological aspects of individual consumers. There should be an individual industry/sector wise consumer perception towards green products. Hard core research has to be conducted for considering the economic variables affecting green marketing.

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IX. CONCLUSION

Green marketing is the need of today's global market. Green products and practices will help us to save our environment and it will establish sustainable development. Companies should start following green marketing in their day-to-day production. Green marketing should not neglect the economic aspect of marketing. Marketers need to understand the implications of green marketing. If you think customers are not concerned about environmental issues or will not pay a premium for products that are more eco-responsible, think again. You must find an opportunity to enhance you product's performance and strengthen your customer's loyalty and command a higher price. Green marketing is still in its infancy and a lot of research is to be done on green marketing to fully explore its potential. Consumers' level of awareness about green products found to be high but at the same time consumers are not aware about green initiatives undertaken by various government and non-government agencies signifying need for more efforts from organizations in this regard. Internet remains leading source of information for most of the respondents and should be utilized more for reaching out to the consumers regarding green products and practices. Responses were on moderate positive level and we can conclude that consumers are not skeptic about green claims of the organizations and consumers are concerned about the present and future state of environment signifying need for green products and practices. Marketers can come up with new green products and communicate the benefits to the consumers. Due to increased awareness and concern consumer may prefer green products over conventional products to protect the environment. The consumers are concerned about the state of environment and expect the organizations to employ green practices towards the protection of environment. The results have implication for durable manufacturers especially to practice green marketing. The marketing communication regarding green practices need to focus more on the me and message. Advertising appeals using green products and practices are likely to move emotions and result in persuasion. It is important for markets to be in top-of-mind recall of consumers to gain maximum from their green brand positioning.

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A study on the impact of programme outcome attainment in bridging employability gap with reference to undergraduate programmes offered by HEIs in Mumbai suburban region

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A study on the impact of programme outcome attainment in bridging employability gap with reference to undergraduate programmes offered by HEIs in Mumbai suburban region

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***Abstract*—This study examines the impact of programme outcome attainment in bridging the employability gap among graduates from Higher Education Institutions (HEIs) in the Mumbai suburban region. Based on a survey of 100 respondents, the research evaluates the effectiveness of curriculum design, institutional policies, and industry-academia collaborations. The findings highlight critical gaps and propose strategic recommendations for enhancing employability outcomes.**

***Keywords*—Employability gap, Programme Outcome Attainment, HEIs, Industry-Academia Collaboration, Curriculum Effectiveness**

1. INTRODUCTION

The employability gap among graduates remains a pressing issue for HEIs in Mumbai. This study investigates how programme outcome attainment influences employability and explores institutional and collaborative practices aimed at addressing the gap. The objectives include evaluating curriculum effectiveness, identifying challenges, and proposing actionable strategies.

The employability gap, is defined as the disconnect between the skills and competencies of graduates and the requirements of the industries, is a critical issue facing the global education system. In Mumbai, a city that serves as a hub for various industries, higher education institutions (HEIs) play a crucial role in shaping the future workforce. However, the alignment between academic curricula and industry needs remains a persistent challenge. This research aims to explore the role of HEIs in Mumbai in addressing the employability gap, focusing on the effectiveness of the existing curriculum, institutional policies, programs, and partnerships with industries.

2. CONCEPTUAL FRAMEWORK

Programme Outcome Attainment refers to the process of evaluating and demonstrating how well the educational objectives or outcomes of a specific program are being met by students.

The Higher Education Institutions (HEIs) refers to the institutions offering undergraduate self-financing courses in Commerce & management such as BAF, BBI, BBA & BMS.

Employability gap is referring to the disparity between the skills and competencies that undergraduate students possess upon graduation and the skills and competencies that are expected or required by an employer at entry-level positions.

The employability problem in Mumbai, as in many urban areas in India, is multifaceted and arises from a combination of factors such as

Skill gap- Gap between skills that students acquire through formal education and the skills that employers in Mumbai require.

Quality of Higher Education- Quality of education is still inconsistent in many educational institutions in Mumbai which makes it difficult for graduates from lesser-known institutions to compete with those from top-tier colleges.

High competition for jobs- The number of job opportunities does not always keep pace with the number of job seekers, leading to high competition for available positions.

Economic and industry specific challenges- Certain service sectors such as IT and finance are growing in cities like Mumbai whereas certain traditional industries in Mumbai are declining. Not all graduates are equipped to transition into these emerging sectors. Even the rise of automation and AI is leading to job displacement in several industries creating more demand for new skills among employees.

Lack of Industry-Academia collaborations- Students are still not exposed to practical learnings and experiences through internships, apprenticeships and work integrated learning programs. There is a need for stronger collaborations between industry and academia to provide these exposures to students.

Addressing the employability problem in Mumbai requires a multi-pronged approach that includes updating educational curricula, enhancing industry- academia collaborations, improving skill development programs and addressing socio-economic disparities. This research aims to bridge the gap to increase job creation and provide recommendations to HEIs to ensure that graduates are equipped to meet the demands of the modern workforce.

3. RESEARCH OBJECTIVES

i. To analyze the current state of the employability gap among graduates from HEIs in Mumbai.

ii. To evaluate the impact of Programme Outcome Attainment and the effectiveness of the existing curriculum, institutional policies, programs and practices aimed at enhancing employability.

iii. To assess the role of industry-academia collaborations in bridging the employability gap.

iv. To identify challenges faced by HEIs in aligning academic programs with industry requirements.

v. To propose strategic recommendations for HEIs to enhance their role in reducing the employability gap.

4. LITERATURE REVIEW

I. The employability gap in India is a significant issue, with various studies and reports highlighting the mismatch between the skills of graduates and the requirement of employers. Various studies have proven that approximately 30% of the graduates remain unemployable not due to lack of employment opportunities but due to lack of skills. The literature review will include secondary data and primary data. Secondary data is the data that will be collected from existing research papers publishes by various researcher for their own research whereas primary data will include original data collected first-hand specifically for the purpose of addressing the research questions or objective.

II. Singh, R., & Sharma, S. (2014). "Bridging employability skills in management education: An industry-oriented approach." IUP Journal of Soft Skills*, 8(1), 7-13. This paper discusses the gap between the skills taught in management education and those required by industries, emphasizing the need for industry-oriented skill development programs. It can be used to analyze similar gaps in Mumbai's educational institutions.

III. India Skills Report (2022) Wheebox, CII, AICTE, UNDP, AIU, & Sunstone Eduversity. This annual report provides a comprehensive overview of the skills gap in India, with data that can be used to assess how well higher education institutions in Mumbai are responding to government initiatives.

IV. National Employability Report: Engineers (2021) Aspiring Minds. This report focused on the employability of engineering graduates across India, this report provides insights that can be specifically analyzed for Mumbai's context to assess the effectiveness of institutional and governmental policies. This report also states that only 45.9% of graduates were found employable across various sectors.

V. National Education Policy (NEP) 2020

The National Education Policy (NEP) 2020, introduced by the Ministry of Education, emphasizes the importance of aligning higher education outcomes with industry needs to address the employability gap. It advocates for a multidisciplinary approach to education, integration of vocational training, and a focus on skills like critical thinking, problem-solving, and digital literacy. NEP 2020 also highlights the role of industry-academia collaboration in curriculum design and practical training to ensure students are industry-ready upon graduation. The policy's framework sets a foundation for educational institutions to innovate and adapt to evolving job market demands, particularly in regions like Mumbai with a dynamic and competitive employment landscape.

VI. Report on Employabi;lity by NASSCOM & CII

NASSCOM's Future Skills Report (2020) explores the growing need for digital skills in India's workforce, emphasizing the mismatch between academic training and industry requirements. The report identifies key areas such as artificial intelligence, data analytics, and cybersecurity, where skill gaps are prevalent. It suggests that higher education institutions (HEIs) must integrate emerging technologies into their curricula to prepare graduates for future job roles.

The CII Report (2021) underscores the importance of bridging the employability gap through strategic initiatives such as internships, apprenticeships, and real-world project-based learning. It highlights the need for continuous upskilling and reskilling programs to keep pace with technological advancements and changing industry expectations. Both reports emphasize collaboration between academia and industry as a critical factor in enhancing employability outcomes.

5. RESEARCH METHODOLOGY

A survey was conducted with 100 undergraduate students, faculty members, and recruiters associated with HEIs in Mumbai suburban region. A mixed-method approach was used to gather quantitative and qualitative data.

6. FINDINGS AND ANALYSIS

6.1 Current State of Employability Gap

Survey Insight: 65% of graduates reported difficulty in securing jobs aligned with their qualifications. Recruiters emphasized a mismatch between academic outcomes and industry expectations, particularly in technical and interpersonal skills.

Analysis:

The employability gap stems from a combination of factors:

- **Inadequate Skill Development:**

While theoretical knowledge is emphasized, practical application, critical thinking, and problem-solving skills are often underdeveloped.

Graduates lack exposure to real-world scenarios, which reduces their adaptability to workplace demands.

- **Outdated Curricula:**

Many programs fail to incorporate emerging industry trends like digital transformation, AI, and data analytics.

Slow curriculum revisions leave graduates ill-equipped for rapidly evolving job roles.

- **Limited Career Guidance:**

A lack of structured career counseling and mentorship during academic programs contributes to misaligned career aspirations and skill sets.

- **Regional Challenges:**

In Mumbai, the high competition for jobs amplifies the challenges, as employers prioritize candidates with hands-on experience and industry-ready skills.

6.2 Impact of Programme Outcome Attainment

Survey Insight: 58% of respondents agreed that programme outcomes are partially aligned with employability skills.

Analysis:

- **Foundational Knowledge vs. Practical Skills:**

While academic programs ensure graduates possess theoretical foundations, they often fail to address soft skills (e.g., communication, teamwork) and technical expertise (e.g., software proficiency, industry-specific tools).

Graduates are proficient in concepts but lack the ability to apply them effectively in workplace settings.

- **Inconsistent Implementation of Programme Outcomes:**

The mapping of programme outcomes to specific skills is uneven across institutions.

Some institutions excel in technical training, while others focus on holistic development, leading to varied employability rates.

- **Assessment Gaps:**

Current assessment methods focus more on rote learning than on evaluating problem-solving abilities, creativity, or decision-making skills.

There is a need for more project-based learning and competency-based evaluations to ensure better alignment with industry expectations.

- **Feedback Mechanism:**

Institutions lack robust feedback systems to evaluate whether programme outcomes are meeting industry standards are leading to a disconnect between academic goals and job market demands.

6.3 Role of Industry-Academia Collaborations

Survey Insight: 72% of respondents recognized internships and workshops as beneficial but noted limited opportunities.

Analysis:

- **Value of Practical Exposure:**

Internships, industry projects, and workshops offer hands-on experience, enabling students to bridge the gap between academic knowledge and practical application.

Students who participate in such activities are more likely to demonstrate job readiness and adaptability.

- **Challenges in Collaboration:**

Many HEIs lack established networks with industries, resulting in fewer internship opportunities and limited exposure to current industry practices.

Smaller institutions, in particular, struggle to attract partnerships due to resource constraints or geographical limitations.

- **Need for Structured Programs:**

Industry-academia collaborations often lack structure, leading to inconsistent benefits. Programs should include clear objectives, skill mapping, and periodic evaluations to maximize impact.

- **Emerging Trends and Opportunities:**

Collaborations in areas like digital up skilling, sustainability, and artificial intelligence can address skill gaps in high-demand sectors.

Industry experts could be invited to co-develop curricula, deliver guest lectures, and mentor students, fostering a deeper understanding of workplace expectations.

- **Policy Support:**

Government incentives for industries collaborating with HEIs can encourage partnerships, particularly in Mumbai's competitive job market.

6.4 Challenges Faced by HEIs

Survey Insight: 68% of faculty cited resource constraints and lack of industry involvement as major hurdles.

Analysis:

- **Resource Constraints:**

Financial Limitations: Many HEIs, particularly smaller institutions, struggle with insufficient funding to upgrade infrastructure, adopt modern teaching tools, or provide advanced training programs.

Lack of Technological Integration: Outdated laboratory equipment, limited access to industry-relevant software, and inadequate digital resources hinder students' ability to acquire practical skills.

Shortage of Skilled Faculty: Recruiting and retaining faculty with industry experience is challenging due to budget constraints and a lack of competitive salaries.

- **Limited Industry Involvement:**

Weak Partnerships: HEIs often face challenges in establishing sustained collaborations with industries. This results in fewer opportunities for internships, guest lectures, and collaborative projects.

Disconnect in Expectations: Industries may not see immediate benefits in collaborating with HEIs, leading to minimal engagement in curriculum design or training programs.

- **Rigid Academic Structures:**

Delayed Curriculum Updates: The process of revising curricula to incorporate emerging industry trends is often slow due to bureaucratic hurdles and regulatory requirements.

Focus on Theoretical Learning: Many institutions prioritize traditional academic approaches over experiential and skill-based learning, leaving students underprepared for the job market.

- **Lack of Feedback Mechanisms:**

HEIs rarely incorporate systematic feedback from alumni, employers, or industry experts to refine their programs, resulting in outdated course content and teaching methods.

- **Student Demographics and Accessibility:**

In Mumbai's suburban regions, many students come from economically disadvantaged backgrounds. This limits their access to additional resources like certification programs or skill enhancement workshops that could improve employability.

- **Policy and Administrative Challenges:**

Regulatory Compliance: Adhering to national and state-level educational policies often diverts resources and focus from innovation in teaching and learning.

Overburdened Faculty: Faculty members are often tasked with administrative responsibilities in addition to teaching, leaving little time for industry engagement or skill development initiatives.

- **Resistance to Change:**

Institutional inertia and reluctance to adopt new pedagogical methods or technologies further exacerbate the challenges faced by HEIs.

7. STRATEGIC RECOMMENDATIONS

Survey Insight: Respondents suggested integrating skill-based training and expanding internship programs.

Proposed Strategies:

1. Revise curricula to include emerging industry trends.
2. Foster partnerships with local industries for internships and live projects.
3. Implement faculty development programs to bridge teaching-learning gaps.
4. Introduce career counseling and employability workshops for students.

8. LIMITATIONS OF THE STUDY

1. Limited Scope of Data Collection
2. Subjectivity in Programme Outcome Attainment (POA) Evaluation
3. Challenges in Measuring Employability Gap
4. Industry-Academia Collaboration Assessment
5. Institutional Challenges and Biases
6. Dynamic Nature of Industry Requirements
7. Dependence on Secondary Data and Surveys
8. Time and Resource Constraints
9. Resistance to Change in HEIs
10. Focus on Undergraduate Programs Only

9. CONCLUSION

The study underscores the importance of aligning programme outcomes with industry requirements to bridge the employability gap. HEIs must adopt a multi-faceted approach involving curriculum reforms, robust industry collaborations, and targeted skill development initiatives. Addressing these challenges will enhance graduate employability and contribute to the socio-economic development of the region.

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