Architecture and Urban Waste Management: The Case of the City of Yaounde, Cameroon

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Abstract: The management of urban waste (GDU) is a critical challenge in Sub-Saharan Africa, particularly in Yaoundé, where rapid urbanization exacerbates insufficient infrastructure, service fragmentation, and the proliferation of illegal dumps. With a recycling rate below 4% and a composition dominated by organic matter (61-65%), the current system generates significant environmental (leachate pollution, methane emissions) and socio-health impacts. Facing the objective of the Yaoundé Urban Community to reduce landfilling by 70% by 2030 through an investment of 80 billion FCFA (including a sorting center, a methanization unit, and a plastics processing unit), this study is essential. It aims to design an adapted urban waste management center by integrating architectural, urban, social, and environmental dimensions. Through a critical analysis of African models (Dakar, Nairobi, Kigali) and circular economy strategies, this work defines the optimal architectural principles (flow organization, safety) necessary to guarantee a functional, sustainable, and well-integrated infrastructure within Yaoundé's constrained urban context.

Keywords: *Urban Waste Management (UWM), Yaoundé (Cameroon), Architectural Design, Circular Economy, Waste Valorization.*

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I. INTRODUCTION

Urban waste management represents a global challenge, exacerbated by rapid urbanization and population growth, particularly in developing countries. In Sub-Saharan Africa, household waste production is expected to reach 244 million tons in 2025, with a recycling rate below 4% (ACCP, 2020), despite ambitious recovery objectives.

In Cameroon, and particularly in Yaoundé, insufficient infrastructure, irregular collection, and the proliferation of illegal dumps reflect fragmented and informal management (Monebene, 2024). Facing this situation, the Yaoundé Urban Community launched a valorization project in 2025 with 80 billion FCFA, including a sorting center, a methanization unit, and a plastics factory, aiming to reduce landfilling by 70% by 2030 (Investir au Cameroun, 2024). The General Assembly on Urban Waste emphasized the urgency of an integrated approach, involving all stakeholders and an adapted architectural design for better urban integration of facilities (MINHDU, 2025). This work aims to design an urban waste management center adapted to the specific context of Yaoundé, by integrating architectural, urban, social, and environmental dimensions. It is based on a critical analysis of management models in Sub-Saharan Africa, sustainable strategies, and local practices, to propose a functional, sustainable, and well-integrated infrastructure capable of improving waste collection, sorting, and recovery within a constrained urban environment.

II. LITERATURE REVIEW

A. Urban Waste Management (UWM)

Urban Waste Management (UWM) constitutes a fundamental issue in developing cities, requiring an integrated and sustainable approach. This literature review aims to clarify key concepts, examine the challenges specific to these urban environments, and highlight the critical environmental, economic, and social impacts of inadequate management. UWM, defined as all operations for the collection, transport, treatment, recycling, or disposal of waste generated by urban populations, aims to minimize its harmful effects on human health and the environment. The term "waste" refers to what its owner no longer wants and perceives as worthless (Kingue, 2020), while urban waste in the context of this study

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encompasses household garbage, bulky items, and market waste in Yaoundé, excluding toxic industrial waste.

➢ *Classification and Composition of Urban Waste in Yaoundé*

The composition of waste in Yaoundé is dominated by organic waste: it represents about 61 to 65% of household waste (kitchen scraps, peelings, etc.). This biodegradable fraction can reach up to 80% humidity during the rainy season, a factor that significantly complicates its recovery (Monebene, 2024). Recyclable waste includes plastics (bags, bottles), paper and cardboard (often soiled), glass (≈1 to 3%), and metals (very small share, ≈0.8%). Poor separation at the source leads to the contamination of these materials, limiting their economic potential. Furthermore, inert or bulky waste (rubble, construction debris) and special or hazardous waste (batteries, WEEE, expired medicines) remain insufficiently or marginally managed, due to the lack of structures and appropriate regulation, favoring the proliferation of illegal dumps and posing increased health risks.

➢ *Global Challenges of Urban Waste Management in Developing Cities*

Waste management in cities in developing countries is facing exponential growth in production: projections indicate a global doubling between 2010 and 2025, driven mainly by low- and middle-income countries (World Bank, 2012). This situation is exacerbated by rapid urbanization, population growth, and industrialization. The development context is characterized by insufficient coverage of collection services (where 60 to 85% of waste can remain in neighborhoods), the predominance of open dumps, a low recycling rate, and a strong dependence on the informal sector (World Bank, 2018). The challenges are mainly institutional and organizational, including lack of planning, insufficient perennial funding, absence of a strong regulatory framework, and often deficient governance (IDRC, 2020). Facing this, it is imperative to strengthen governance, integrate the informal sector, and adopt circular economy strategies to reconcile development and environmental protection (UN-Habitat, 2021).

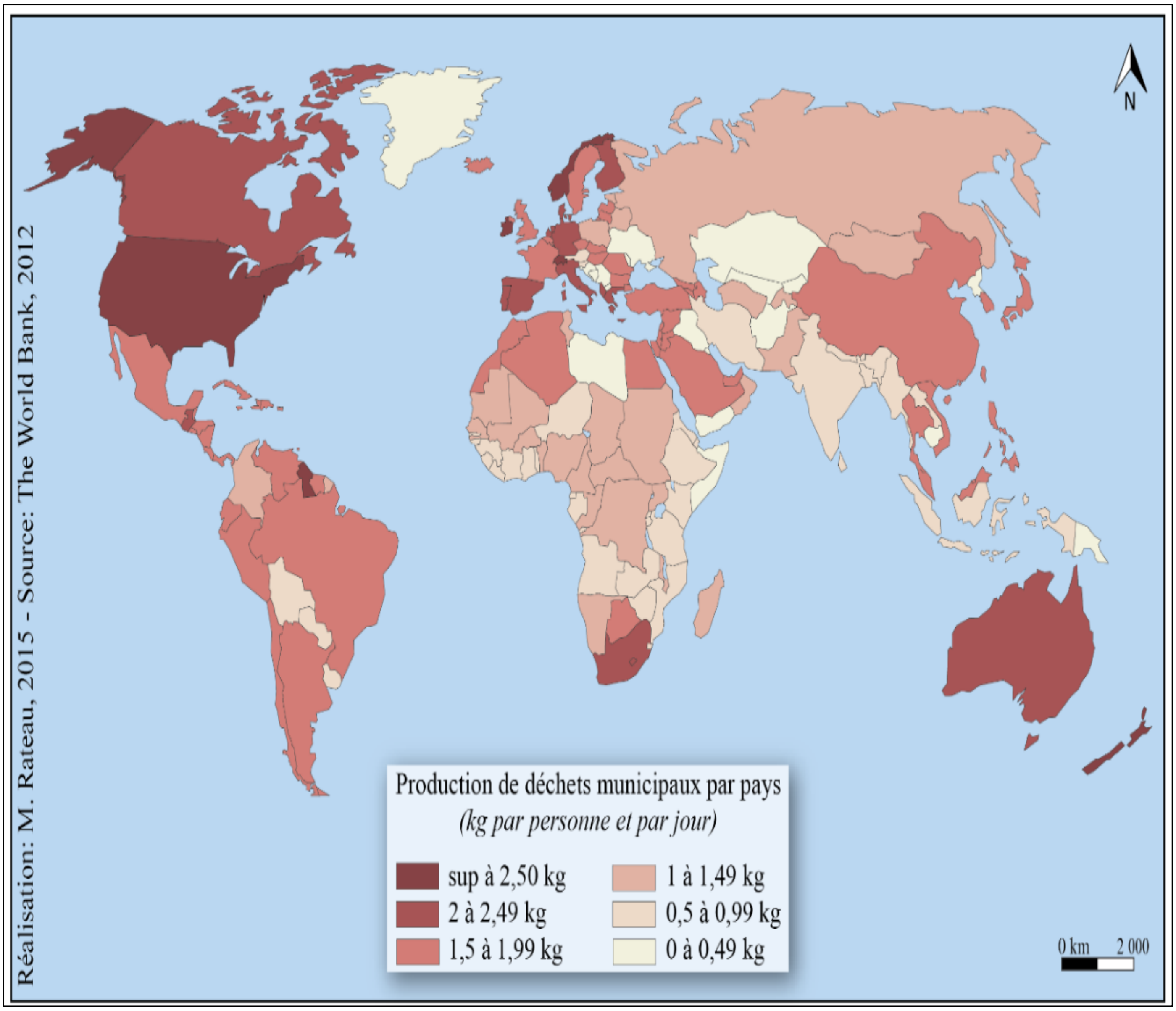

Fig 1 Global Challenges of Urban Waste Management in Developing Cities

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➢ *Environmental, Economic, and Social Impacts Linked to Urban Waste*

- *Environmental*

The disorderly establishment of dumps near residential areas causes severe soil, water, and air pollution. The mixing of plastic waste, metals, paper, and organic matter contaminates recyclable materials and aggravates environmental degradation. These sites also become breeding grounds for insects, reptiles, and rodents, increasing health risks. Furthermore, the decomposition of organic waste generates greenhouse gases, thus contributing to climate change (Monebene, 2024).

Fig 2 Image of Unsanitary Conditions in Yaoundé
Source : (Bilo'o, 2023)

Moreover, liquids from waste, if untreated, pollute rivers, groundwater tables, and harm plant and animal life (Ngnikam et al., 2012). A striking example is the Nkolfoulou landfill, which has accumulated over 2 million tons of waste. It produces about 450 m³ of polluted liquids (leachates) per day, part of which is discharged untreated into the nearby river. This pollutes surface and groundwater with harmful substances such as organic matter and heavy metals, endangering biodiversity and the health of nearby residents (Ngnikam et al., 2012).

In addition, the decomposition of organic waste produces methane, a potent greenhouse gas. Between 2007 and 2030, the cumulative methane emissions from the Nkolfoulou landfill are estimated at 1.9 million tons of CO2 equivalent, thus contributing to climate change.

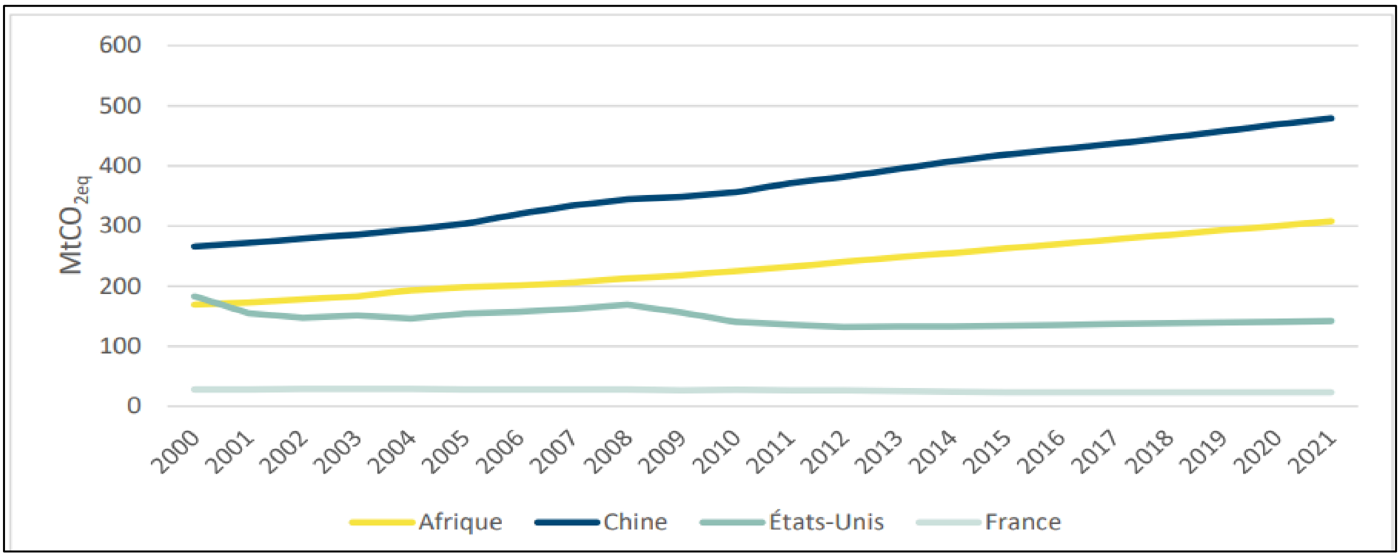

Fig 3 Greenhouse Gas Emissions from the Waste Sector in a Selection of Countries Compared to Africa.
Source : (Climate Chance, 2023)

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- *Economic and Health Impacts*

Poor waste management in Yaoundé has direct consequences on both the population and the local economy. On a human level, it limits economic opportunities and perpetuates the precariousness of the informal sector, as the contamination of waste by organic matter reduces the value of recyclable materials. With only 15% to 40% of waste officially collected, the majority of residents especially in informal settlements are exposed to unsanitary conditions, which worsens poverty and social exclusion.

In terms of economic activity, the proliferation of illegal dumping sites hinders development, degrades the urban image, and discourages investment. The potential of recycling is largely underexploited (with losses estimated in the billions of dollars across Africa) due to an inefficient collection system and the lack of source separation.

Finally, from a health perspective, the accumulation of garbage is costly: it promotes the spread of disease vectors (such as cholera and dengue), leading to significant healthcare expenses, reduced productivity, and absenteeism all of which negatively impact the local economy.

- *Social*

The piling up of waste facilitates the spread of diseases such as cholera, dengue, and other infections linked to lack of hygiene. The proximity of dumps to homes causes unpleasant odors, visual pollution, and increases the risks of accidents. The lack of information and material hinders the implementation of sorting at the source and encourages dangerous practices, such as dumping garbage in nature (Urban Waste Management and Health Safety in Cameroon, 2024; Tamo, 2013). Moreover, the lack of awareness and adequate material limits the implementation of sorting at the source and favors risky practices, such as abandoning waste in nature, which deteriorates the living environment and increases health risks (Tamo, 2013).

B. Models and Approaches to Waste Management in Sub-Saharan Africa

Firstly, this section presents the various waste management systems adopted in Sub-Saharan Africa, highlighting the engaged actors as well as the operating modes employed. Subsequently, it exposes the main technical and institutional constraints that limit the performance and sustainability of these systems, particularly in the context of booming cities. Finally, comparative case studies from several African cities provide concrete illustrations, allowing useful lessons to be drawn for improving local practices.

➢ *Waste Management Systems: Actors and Operating ModesActeurs*

- *Actors*

In Sub-Saharan Africa, waste management mobilizes a diversity of actors and relies on operating modes adapted to local contexts, often marked by specific institutional, technical, and economic constraints. According to (CoM SSA, n.d.), local authorities play a central role, as waste management is traditionally a competence devolved to local governments. They are responsible for the planning, regulation, and coordination of services, while sometimes directly ensuring the collection and treatment of waste. However, (Climate Chance, 2023) states that these authorities face financing difficulties, often covering less than 50% of the necessary investment costs, which limits the quality and coverage of services. To overcome these shortcomings, municipalities frequently rely on partnerships with private operators or local actors.

The informal sector is a key player in the recovery and recycling of waste, particularly in disadvantaged neighborhoods and areas not served by formal services. These collectors, often marginalized, contribute significantly to the recovery of recyclable materials, but their integration into official systems remains a major challenge (ACCP, 2024; IDRC, 2020). Furthermore, Non-Governmental Organizations (NGOs) and community associations play an important role in awareness-raising, social mobilization, and the implementation of innovative pilot projects, especially in informal neighborhoods where public services are insufficient (Dorier-Apprill & Meynet, 2005).

➢ *Operating Modes The Systems Generally Follow a Functional Chain Including Collection, Transport, Sorting, Treatment, and Final Disposal;*

- Collection and Transport: Firstly, collection is often fragmented, distributed among public services, private operators, and the informal sector. In fact, in several cities, this task is partially or totally privatized, like in Kampala where, according to JICA (JICA, 2021), five private operators serve the majority of urban areas. However, despite these efforts, peripheral areas and informal neighborhoods often remain poorly served, due to difficult access and persistent financial constraints.
- Sorting and Valorization: Furthermore, sorting is rarely done at the source; it is therefore mainly carried out in dedicated centers or by informal collectors. Despite its importance, as noted by (IDRC, 2020), the valorization of recyclable waste remains an unstructured activity, hindered by the absence of adequate infrastructure and incentive policies.
- Treatment and Disposal: As for treatment and final disposal, they rely mainly on landfills, whether controlled or not. This is accompanied by low recourse to modern technologies such as incineration with energy recovery. For example, in Conakry, the main landfill suffers from a crucial lack of environmental protection facilities, leading to significant health risks (JICA, 2021).

➢ *Technical and Institutional Constraints*

Urban waste management in developing cities is faced with a complex set of technical, institutional, and socio-economic constraints that limit the effectiveness of existing systems. These challenges are widely documented in scientific literature and international reports.

On the technical level, the insufficiency of adapted infrastructure is a major obstacle. According to the United Nations Environment Programme (UNEP) report summarized

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in (ADEME, 2018), rapid population growth and urbanization lead to a significant increase in municipal solid waste, while the technical capacities for its collection, treatment, and disposal remain limited. This inadequacy results in a proliferation of illegal dumps and significant emissions of greenhouse gases, particularly methane from open decomposition of organic waste, which affects the health of surrounding populations. Furthermore, difficulties in accessing rugged or landlocked areas, as in some parts of Yaoundé, complicate collection. (Monebene, 2024) demonstrates that the lack of rolling stock adapted to the urban relief, particularly the impossibility for heavy trucks to reach these areas, necessitates the use of alternative means such as wheelbarrows or tricycles, which increases costs and slows down the service.

From an institutional perspective, the governance of waste management suffers from a lack of strategic planning, insufficient funding, and often inadequate regulation. The IDRC report (2020) highlights that in several African cities, poor coordination between public and private actors, as well as the absence of clear accountability, limits the quality and coverage of services. For example, in cities like Dar es Salaam or Kinshasa, less than 25% of the waste produced is collected, and illegal dumps remain frequent (IDRC, 2023). Furthermore, the integration of the informal sector, which plays a crucial role in the recovery of recyclable waste, is often marginalized, which weakens the valorization chain.

➢ *Case Studies in African Cities*

The literature on urban waste management in Sub-Saharan Africa highlights case studies in several large cities, identifying practices, recurring challenges, and contextual innovations. We were able to list a few examples:

- *Dakar, Senegal*

In Dakar, waste management suffers from institutional instability and chronic underfunding, which limits private investment and the modernization of infrastructure. The PROMOGED program, supported by the World Bank, aims to structure a public-private partnership to develop a network of sorting and treatment centers, and to formalize the informal sector. Informal neighborhoods, which house the majority of the population, are particularly poorly served, leading to the proliferation of illegal dumps. Municipal efforts focus on improving coordination between informal collectors and public authorities, strengthening awareness, and enforcing environmental laws (Mberu et al., 2018). Research shows that synchronizing informal and municipal collections, promoting source sorting, and improving financing are essential levers for improving the situation.

- *Nairobi, Kenya*

Nairobi illustrates the importance of the informal sector in waste collection and recycling. The city suffers from a low collection rate (about 33%), massive use of the Dandora landfill (uncontrolled), and institutional fragmentation. Affluent neighborhoods benefit from private services, while informal neighborhoods rely on community organizations, which have lower operating costs and better local adaptation. According to ETH Studio Basel, the municipality's inability to coordinate the different actors leads to waste accumulation in poor neighborhoods, while the city center remains relatively clean thanks to dedicated services. (Marcussen, 2020) concludes that recent innovations include the introduction of public-private partnerships, the use of tracking technologies, and increased awareness, but weak enforcement of regulations and the absence of source sorting remain major obstacles.

- *Kigali, Rwanda*

Kigali, the capital of Rwanda, is often cited as an advanced example of urban waste management in Sub-Saharan Africa thanks to strong governance, an integrated strategy, and confirmed political will. The city has seen a significant evolution of its waste management system over the past ten years, moving from fragmented and poorly regulated management to a more structured and innovative approach. (Kabera et al., 2019; Nwanege, 2024) shows that Kigali stands out for strong governance and community involvement. The city has implemented exclusive franchises awarded by sector, renewed every three years, which guarantees high coverage (nearly 95% collection rate). Households pay a fee adapted to their means, and the service is free for the poorest. This approach, combined with a strict policy on plastics, has allowed the city to achieve results superior to the regional average, even if recycling remains limited and the elimination of illegal dumps remains a challenge. Kigali has adopted an ambitious strategy aimed at transitioning from a conventional linear system to a modern, intelligent system based on the circular economy. This transition includes the transformation of the current landfill into a resource recovery center, the total privatization of waste management activities via public-private partnerships (PPP), as well as the introduction of an integrated waste management system (IWMS) to reach an 80% recycling rate by 2024 (UN-Habitat, 2022). In 2024-2025, Kigali inaugurated its first municipal waste recovery facilities, notably at the Nduba site, with modern equipment financed by international partners (MINICT Rwanda, 2025b). Furthermore, a pilot project for intelligent waste management was launched in several neighborhoods, combining solar collection, sensors, and community involvement, as part of the Smart Cities strategy (MINICT Rwanda, 2025a; SDG Local Action, 2024).

C. Strategies and Practices for Sustainable Urban Waste Management

Urban waste management constitutes a central issue for the sustainable development of cities, which are confronted with increasing waste production and its environmental and socio-economic impacts. In this context, strategies based on the circular economy and waste recovery play a key role in transforming this challenge into an opportunity. This part focuses on evaluating these sustainable approaches as well as exploring concrete practices for urban waste recovery, in order to better understand their contributions to more effective and responsible management.

➢ *Evaluation of Sustainable Development and Circular Economy Strategies in the Waste Sector*

Sustainable development strategies in the waste sector rely on the treatment hierarchy, prioritizing prevention, source reduction, reuse, recycling, energy recovery, and, as a last

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resort, disposal. This approach aims to minimize environmental impact, preserve natural resources, and promote public health (Automate, 2024; Development & Development, 2022; What Is Sustainable Waste Management?, 2024).

- *Main Strategies Adopted*

- ✓ Source Reduction: Encouraging the design of products that generate less waste and limiting superfluous packaging. Reuse: Implementation of reuse programs to extend product life.
- ✓ Optimized Recycling: Development of sorting and treatment chains enabling materials to be reintroduced into the production cycle.
- ✓ Composting: Recovery of organic waste to produce agricultural amendments, reducing the volume of waste to be disposed of.
- ✓ Energy Recovery: Transformation of non-recyclable waste into energy (electricity, heat) via incineration or methanization, while controlling emissions.

- *The Circular Economy*

The circular economy aims to break away from the linear extract-produce-dispose model by promoting the closed loop where waste becomes a resource reused in new production cycles. The circular economy includes key principles applied to waste:

- ✓ Design for Circularity: Developing products that are easy to repair, dismantle, recycle, or recover.
- ✓ Extended Producer Responsibility: Obligation for manufacturers to manage their products at the end of their life, stimulating eco-design and material recovery.
- ✓ Valorization Loops: Encouraging selective collection, source sorting, and the creation of efficient recycling chains to maintain the value of materials in the economy for as long as possible.
- ✓ Technological Innovations: Adoption of advanced technologies (optical sorting, artificial intelligence, industrial composting, chemical recovery) to improve the efficiency and profitability of recycling.

- *Evaluation of the Effectiveness of Strategies*

The evaluation of sustainable development and circular economy strategies in the waste sector is based on several criteria:

- ✓ Environmental Performance: Reduction of greenhouse gas emissions, decrease in consumption of virgin resources, reduction in the volume of waste sent to landfill.
- ✓ Economic Performance: Creation of new value chains, reduction of management costs, development of markets for recycled materials.
- ✓ Social Acceptability: Awareness, involvement of citizens and stakeholders, improvement of working conditions in the sector.
- ✓ Resilience and Adaptability: Capacity of systems to adapt to changes in waste flows, technological innovations, and regulatory requirements.

- *Common Evaluation Tools*

- ✓ LCA, Life Cycle Assessment: Allows measurement of the overall environmental impact of different waste management options.
- ✓ MCDM, Multi-Criteria Decision Making Methods: Used to compare and prioritize alternatives based on environmental, economic, social, and technical criteria.

The integration of sustainable development and circular economy principles into waste management is now recognized as essential for achieving climate and resource preservation objectives. The most effective strategies are those that combine prevention, innovation, involvement of producers and citizens, and adaptation to local contexts. However, challenges persist, particularly the harmonization of sectors, the profitability of recycling chains, and the integration of the informal sector in developing countries.

➢ *Valorization of Urban Waste*

- *Urban Waste Valorization Chains in Yaoundé*

The valorization of urban waste aims to transform this waste into useful resources, thus reducing its environmental impact and supporting the circular economy. It is divided into three chains: organic, material, and energy, adapted to the local context. In Yaoundé, the organic chain is the most relevant, as the majority of household waste is biodegradable. Composting and vermicomposting, like the pilot project in Nkolbisson, allow the production of organic amendments intended for urban agriculture, while providing economic benefits to residents (Liegui & Tech, 2019). The material chain involves the sorting and recycling of plastics, paper, cardboard, glass, and metals. For example, the CFAO company stands out for the collection and transformation of plastics into manufactured products or construction materials, helping to reduce plastic pollution and create local jobs. Energy recovery, meanwhile, transforms non-recyclable waste into energy (heat, electricity, biogas), with pilot projects in Yaoundé exploring this path with organic waste and solid recovered fuels, despite high investment needs and rigorous technical management.

- *Role and Importance of the Sorting Center in Valorization*

The sorting center plays a key role in waste valorization. It allows the separation of flows according to their nature and potential: recyclable waste directed to material recovery, organic waste to composting or methanization, and non-recyclable waste to energy recovery. The quality of sorting, especially at the source, and the operational efficiency of the centers directly influence the overall valorization rate. Furthermore, certain rejected waste from sorting can be transformed into Solid Recovered Fuels (SRF), valorized energetically in industrial installations, thus reducing waste destined for landfilling or conventional incineration. Thus, the sorting center is a central step for optimizing the circular economy and sustainable urban waste management in Yaoundé.

D. Architecture and Layout of Waste Management Infrastructure

This section presents the architectural principles specific to sorting centers and waste management stations, highlighting the criteria for functionality, sustainability, and urban integration. Subsequently, it addresses the functional programming as well as the optimal spatial organization of these infrastructures, which are essential for ensuring effective waste flow management. Finally, it illustrates these concepts through concrete examples of sorting centers, detailing the different stages such as sorting, storage, and treatment, to offer a complete vision of the operation and challenges related to these facilities.

➢ *Architectural Principles for Sorting Centers and Management Stations*

The architectural design of urban waste sorting centers and management stations is based on essential principles aimed at ensuring their functional efficiency, safety, sustainability, and good insertion into the urban fabric.

- *Functional Organization and Optimized Flows*

A central principle is the optimization of flows: the arrangement of spaces must allow for fluid circulation of waste from its reception to its treatment and dispatch. This implies a clear separation between the reception, sorting, intermediate storage, conditioning, and dispatch areas for sorted materials. Reference documents emphasize the importance of a rational architectural plan to limit flow intersections, reduce contamination risks, and improve operational efficiency (CITEO, 2005; INRS, 2018).

✓ Example of a functional sequence: vehicle reception and weighing, unloading, sorting (manual and automated), temporary storage, conditioning, storage, dispatch.
✓ Spatial Planning: plan distinct traffic lanes for incoming and outgoing vehicles, minimize intersections, integrate sufficient maneuvering areas for heavy machinery.

The centers mainly process waste from selective household collections: packaging, paper, cardboard, plastics, metals, and glass. They are designed to efficiently separate recyclable materials using mechanical, optical, and sometimes robotic equipment. Their spatial organization prioritizes flow fluidity, safety, and sorting quality (CITEO, 2005) presents some types:

- *Safety, Health, and Environment*

Architectural standards require taking into account aspects related to operator safety and environmental protection. This includes :

✓ Fire safety: installation of alarm systems, extinguishing devices, and confinement zones to limit fire spread.
✓ Ventilation and odor management: design of efficient ventilation systems to limit olfactory nuisances and ensure indoor air quality.
✓ Wastewater management: integration of drainage devices, hydrocarbon separators, and effluent treatment systems to prevent soil and water pollution.

Indeed, the design of modern sorting centers prioritizes safety, occupational health, and environmental compliance. The technical guide from (CITEO, 2005) insists on the importance of controlling occupational risks, particularly those related to vehicle traffic, fires, noise pollution, dust, and chemical or biological risks. Measures such as flow separation, the installation of automatic detection and extinguishing systems, as well as ventilation and extraction systems are recommended.

In parallel, working conditions must be optimized by adapted ergonomics for sorting stations: conveyor height, posture, lighting, and accessibility are factors directly influencing operator performance and health. The document also addresses psychosocial aspects, emphasizing the effect of repetitive movements and the need to value the work of sorters.

On the environmental front, the High Environmental Quality (HQE) approach is proposed as a reference framework. It aims to limit the ecological impacts of the building, improve overall comfort, and promote harmonious urban integration. These principles reinforce the sustainability and acceptability of sorting centers as essential public facilities.

- *Urban Integration and Sustainability*

The architecture of sorting centers must promote their integration into the urban fabric and reduce their visual and noise impact. The recommendations include:

✓ Landscaping and buffer zones: creation of green belts, hedges, and green spaces to limit visual and acoustic nuisances.
✓ Careful façades: selection of robust materials (steel, concrete) that are also aesthetically pleasing to improve the social acceptability of these industrial facilities.
✓ Reception and information areas: integration of premises dedicated to public awareness and environmental education, fostering citizen ownership of the site. Contemporary architectural principles for sorting centers and waste management stations increasingly incorporate strong requirements for sustainability and environmental innovation. (CITEO, 2005) emphasizes the importance of adopting a comprehensive approach, combining bioclimatic design, the use of ecological materials, and the integration of modern technologies to reduce the environmental footprint of infrastructures. Recommended practices include rainwater harvesting, the installation of solar panels, green roofs, and the choice of materials with low environmental impact, in accordance with High Environmental Quality (HQE) standards.

Furthermore, the flexibility and evolvability of the spaces are highlighted as essential criteria. Sorting centers must be able to adapt to changes in the volumes and types of waste processed, as well as to technological innovations. This modularity also facilitates the management of emergency situations, such as capacity saturation or equipment failure (Rethinking The Future, 2024).

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International recommendations stress the need for a design tailored to the site's size, the nature of the waste, and the local context. They particularly advocate for one-way traffic to limit flow conflicts, clear zoning between different functions (reception, sorting, storage, maintenance, administration), and the provision for future extensions and emergency solutions (URA, 2023). These guidelines aim to ensure the efficient, secure, and sustainable operation of the facilities while anticipating future needs.

This integrated approach, combining sustainability, innovation, and adaptability, is essential to ensure the longevity of sorting centers in a constantly evolving urban context, particularly in Africa where waste volumes are increasing rapidly and technical and financial constraints are significant (Rethinking The Future, 2024).

➢ *Functional Programming and Spatial Organization of Infrastructures*

The functional programming and spatial organization of waste management infrastructures, particularly sorting centers and transfer stations, are crucial steps in ensuring their operational efficiency, safety, and integration into the urban fabric. Research agrees on the importance of rigorous planning that clearly articulates functions, optimizes flows, and anticipates future developments.

Functional programming primarily aims to precisely define needs in terms of capacity, types of waste processed, and services to be rendered. It must integrate a detailed analysis of the volumes produced, the characteristics of the waste, as well as regulatory and environmental constraints. According to (CITEO, 2005), well-executed programming allows infrastructures to be adapted to local realities while ensuring the necessary flexibility to cope with demographic and economic changes. In this regard, (Rethinking The Future, 2024) emphasizes that programming must also take into account requirements for safety, occupational health, and the management of nuisances such as odors, dust, and noise.

Spatial organization directly results from functional programming. It involves arranging the different zones of the infrastructure to optimize the movement of waste, personnel, and vehicles, while ensuring safety and environmental compliance. Documents from (URA, 2023) insist on the need for clear zoning, distinguishing reception, sorting, storage, maintenance, and administrative areas. This separation helps limit flow intersections, thereby reducing the risk of accidents and cross-contamination.

Internal traffic must be designed to ensure a unidirectional flow of waste, from reception to dispatch, with distinct lanes for incoming and outgoing vehicles. This organization facilitates flow management, reduces internal congestion, and improves productivity (CITEO, 2005). Furthermore, spatial planning must provide maneuvering areas adapted for heavy machinery, as well as temporary storage spaces to handle peak activity or interruptions in the processing chain (Rethinking The Future, 2024).

Finally, flexibility and evolvability are essential criteria in spatial programming and organization. Infrastructures must be able to adapt to future changes, such as increased waste volumes or the introduction of new sorting and recovery technologies. This modularity is also a lever for optimizing investment and operating costs (Rethinking The Future, 2024).

➢ *Some Examples and Limitations of Waste Management Centers*

The Amager Bakke (or Copenhill) Sorting and Incineration Center in Copenhagen The Amager Bakke (Copenhill) sorting and incineration center in Copenhagen stands out for its innovative architectural approach, which integrates the principles of biophilic design and a multifunctional spatial organization. This project, designed by Bjarke Ingels Group (BIG) in collaboration with the landscape architecture firm SLA, transcends its industrial function to become an urban attraction pole. (Dezeen, 2018; Vijaya Durga, 2024)

- Biophilic Architecture and Multifunctionality: The most striking aspect of Amager Bakke is its roof, transformed into an artificial ski slope, accessible to the public all year round (Dezeen, 2018). This slope is flanked by plantings, hiking trails, and a climbing wall, creating a recreational space integrated into an industrial zone. This biophilic approach aims to reconnect city dwellers with nature by incorporating natural elements into the built environment (Contributor, 2021). The design is not limited to simple aesthetics; it seeks to create a vibrant "urban ecosystem." SLA specifically tested vegetation capable of withstanding extreme conditions (wind, boiler heat) to ensure a lush and resilient natural environment on the roof (Megson, 2018).
- Spatial Organization and Flow Management: Amager Bakke's spatial organization is designed for maximum efficiency in waste treatment, while optimizing the integration of recreational functions. The building is organized vertically to maximize space, with the industrial processes of combustion and flue gas treatment located beneath the public and recreational areas. (Vijaya Durga, 2024).

Regarding its limitations: Amager Bakke is too large relative to local waste volumes, requiring the importation of waste to operate at its full capacity of 560,000 tons per year, which raises environmental concerns because some of the incinerated waste contains recyclable materials, increasing the carbon footprint. Technical failures have also caused shutdowns and additional costs. Finally, its energy production is limited in the summer due to insufficient grid capacity to absorb the surplus, forcing the plant to reduce its operating capacity (Madsen, 2019).

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➢ *Urban Solid Waste Collection Central*

Fig 4 Exterior View of Amager Bakke by Hufton + Crow.
Source: (Dezeen, 2018)

The Urban Solid Waste Collection Central (CUSWC), designed by Vaillo + Irigaray, stands out for its biomorphic approach and exemplary urban integration. The 832 m² building is conceived as an "urban stomach": it sucks in, sorts, compacts, and dispatches waste to various treatment, reuse, or recycling points.

Architecture: The center's volume is organic, evoking digestive organs, to illustrate the waste "digestion" process. The façade and roof are covered with large panels of recycled lacquered aluminum (2.5 m x 1.5 m), fixed to form a kind of swollen scale pattern. This choice of material and texture recalls the deformation caused by internal gases generated during waste processing, while ensuring material optimization and a unique aesthetic (Archilover25, 2012).

Functionality and Urban Integration: Unlike traditional industrial buildings, which are often opaque and isolated, the CUSWC is designed to coexist harmoniously with other urban functions. Its multilayer envelope offers effective acoustic insulation, essential for containing the noise of the internal machinery. The building thus becomes an urban landmark, conveying an "ecological culture" and a positive image of urban waste treatment (Archilover25, 2012; CUSWC Central Urban Solid Waste Collection | Vaillo + Irigaray Architects, 2012).

Waste Flow Management: Flow management within the CUSWC is entirely designed for efficiency, hygiene, and the reduction of environmental impact.

- Collection and Admission: Household waste is sucked from the points of origin (homes, neighborhoods) via a network of underground pipes. This pneumatic collection system avoids the circulation of traditional garbage trucks, thereby reducing noise, emissions, and urban nuisances (Archdaily, 2010).
- Sorting and Compacting: Upon arrival, the waste is separated and compacted according to its nature. Internal equipment (turbines, settlers, compacting filters) is organized in-line to ensure a continuous and fluid flow, much like the digestive system. This primary sorting minimizes the geometric volume of the waste and prepares it for dispatch to the appropriate streams (recycling, recovery, landfill).
- Temporary Storage and Dispatch: Sorted and compacted waste is temporarily stored in specific areas within the center before being evacuated by specialized trucks to treatment or recovery centers. The internal spatial organization is designed to prevent the crossing of waste flows, thus ensuring operator safety and the efficiency of sorting operations. This layout helps limit the risks of cross-contamination, optimize internal circulation, and facilitate handling, ensuring a fluid and secure process.

Urban solid waste collection centers, such as the Urban Solid Waste Collection Central, face several major limitations that hinder their effectiveness. These include the inadequacy of adapted infrastructure, which is unable to keep pace with the accelerated rate of waste production linked to rapid urbanization, frequently leading to overflowing bins,

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inadequate storage, and the proliferation of illegal dumps with detrimental impacts on public health and the environment. In parallel, significant budgetary constraints, characterized by often insufficient or poorly allocated resources, impede equipment maintenance and service expansion. Technical challenges are also numerous: collection in densely populated areas is complex, collection routes often remain inefficient, and coordination among the various institutions involved lacks fluidity, which reduces the scope of interventions. Furthermore, the lack of sufficient public awareness and active participation contributes to increased waste contamination and the absence of sorting at the source, decreasing the overall effectiveness of the collection centers. Faced with these multiple constraints, the centralized management of urban waste remains complex and requires the implementation of integrated solutions, combining infrastructure investment, actor training, reinforced citizen mobilization, and technological innovation for more efficient and sustainable collection and treatment (Archello, 2025).

Fig 5 Exterior View of Urban Solid Waste Collection Central

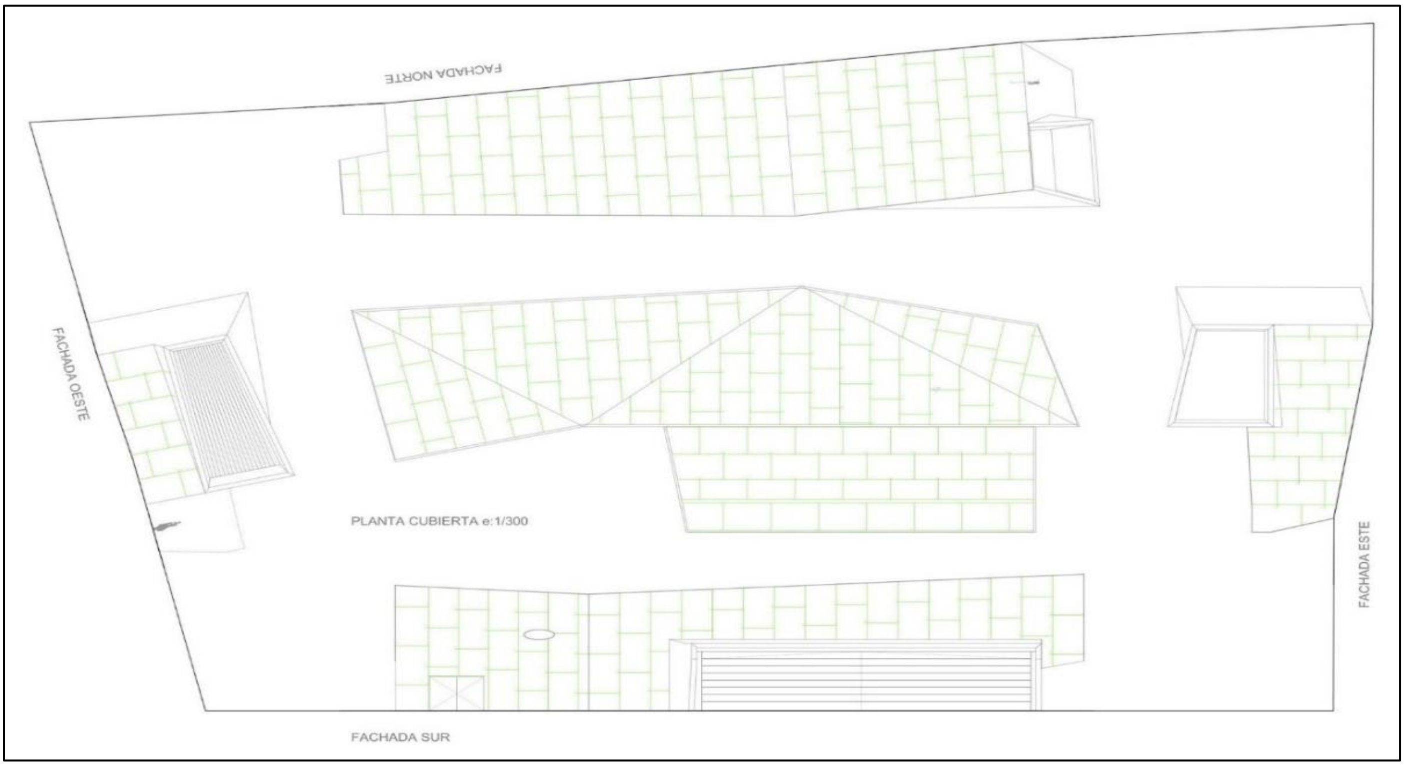

Fig 6 Plan of Urban Solid Waste Collection Central

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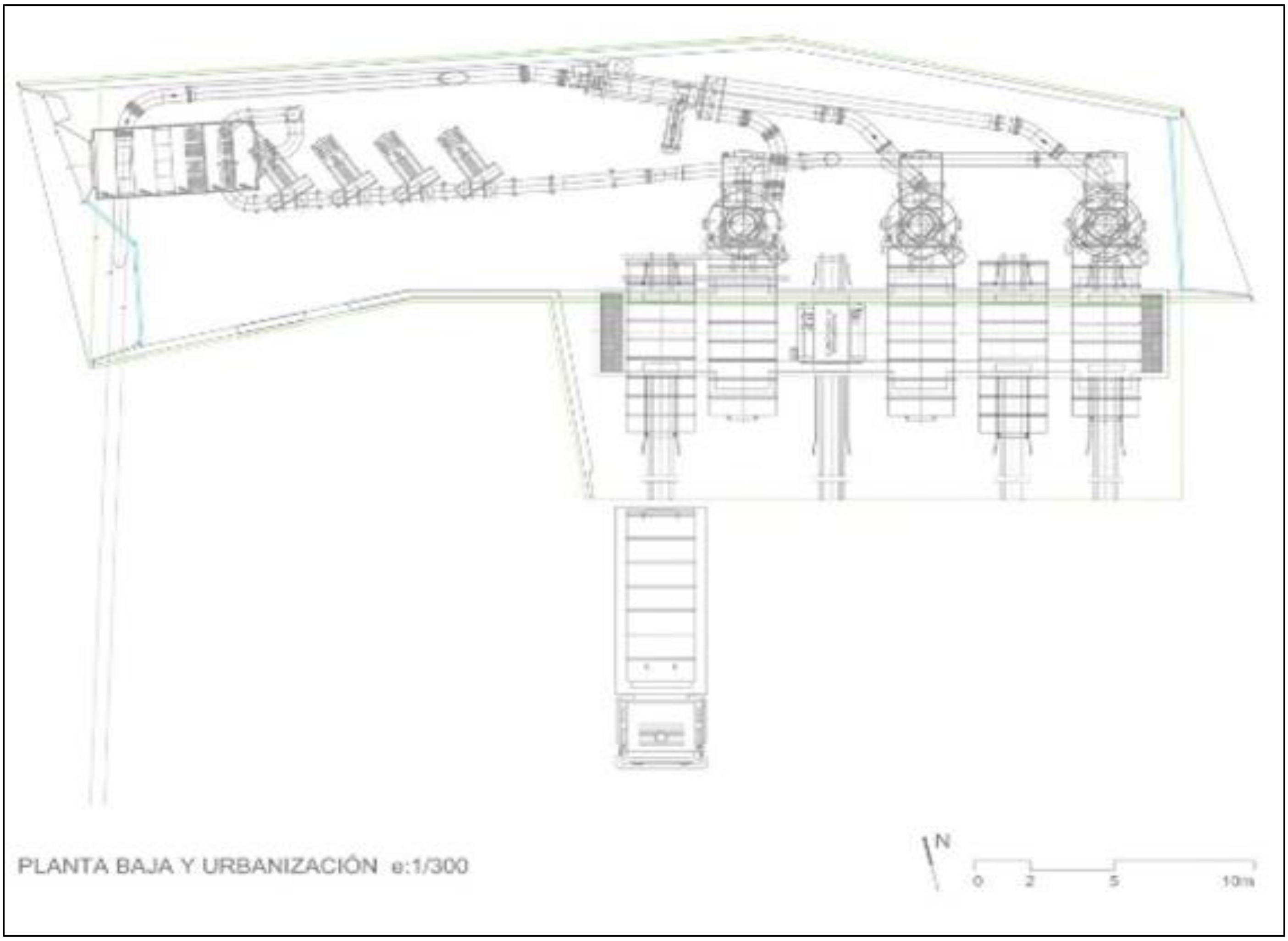

Fig 7 Urban Planning Map of Urban Solid Waste Collection Central

Fig 8 Exterior View of Urban Solid Waste Collection Central

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Fig 9 Exterior View of Urban Solid Waste Collection Central

- *Sweden: Site Zero, Motala*

Site Zero is the world's largest plastic sorting facility, capable of processing 200,000 tonnes per year. It uses a 5 km automated sorting line, equipped with over 60 machines featuring infrared sensors (NIR/VIS), lasers, deep-learning cameras, and electromagnetic systems. The waste streams are analyzed, sorted into 12 plastic categories, and then compacted into bales for recycling or energy recovery (Edo et al., 2024). This industrial building is characterized by an imposing volume and a large flat roof, designed to accommodate a photovoltaic installation covering its entire surface, which contributes to the plant's goal of carbon neutrality (HEBDO CONSTRUCTION, 2022).

Site Zero's architecture is designed to optimize large-scale plastic waste flow management. The structure integrates an automated sorting line approximately 5 kilometers long, consisting of conveyor belts that continuously transport up to 40 tons of plastic waste per hour through different sorting phases. This linear arrangement maximizes flow fluidity, avoids intersections and interruptions, and facilitates the integration of advanced sorting technologies.

Fig 10 Interior View of Site Zero, Motala.
Source: (HEBDO CONSTRUCTION, 2022b)

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Despite its technological advancements, including infrared scanners, lasers, cameras, and artificial intelligence to separate 12 different types of plastics, this facility nevertheless presents certain limitations. One of the main difficulties stems from the complexity of modern plastic packaging, often composed of multiple materials that are difficult to separate, which partially reduces recycling efficiency. Another limitation is related to the variability and contamination of the incoming waste, which can affect the quality of sorting and necessitate additional treatment or rejection. Furthermore, the economic model still relies on a market with narrow margins, where the high cost of sorting technologies and the low price of recycled materials hinder optimal profitability. Finally, despite the impressive capabilities, achieving total circularity remains a challenge in a context of overconsumption and constant plastic waste production. These limitations highlight the persistent issues in plastic recycling, even in state-of-the-art infrastructures like Site Zero. (From waste to resource: how Sweden's Site Zero transforms plastic packaging | Estiko Packaging Solutions, 2024; vietnam.vn, 2023)

Fig 11 (HEBDO CONSTRUCTION, 2022b)

The building is organized into several distinct functional zones, including:

A waste reception and weighing area, where trucks unload the mixed plastics A mechanical pre-sorting zone to eliminate contaminants and prepare the waste for fine sorting, The main automated sorting line, equipped with over 60 machines featuring infrared (NIR) sensors, lasers, smart cameras, and electromagnetic systems to separate up to 12 different types of plastics, Compartmentalized temporary storage areas for sorted materials, before their compacting and dispatch to recycling or energy recovery streams.

- *Paprec Chassieu Sorting Center, Lyon (Paris)*

The Paprec Trivalo 69 sorting center, located in Chassieu near Lyon, is one of the largest and most modern in France. Inaugurated in 2019, it covers an area of 11,900 m² and processes approximately 60,000 tons of recyclable waste per year, or nearly 20 tons per hour, covering a large part of the Lyon metropolitan area. (Paprec, 2021; Ulmann, 2024).

The industrial building was designed to accommodate a complex industrial process with a glued-laminated timber beam frame spanning 46 meters, allowing for vast spaces without obstructive columns for the circulation of waste and machinery. This structure facilitates the implementation of a linear and fluid sorting line, essential for optimizing waste flows (DEVISUBOX, 2019).

(Grand Lyon, 2024) shows that the plant is organized into several distinct functional zones: waste reception and unloading, mechanical pre-sorting, optical and manual sorting, temporary storage, compacting, and dispatch. This spatial organization clearly separates the different flows to limit intersections and improve safety and efficiency.

Waste Flow Management: Recyclable waste collected from households arrives in bulk and is dumped into reception pits. It is then transported by a 1.7 km network of conveyors to the different sorting stages. Sorting combines:

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Optical sorters using infrared recognition to separate plastics, papers, cardboard, metals, etc. Ballistic separators to separate light from heavy materials. "Max" Robot, equipped with artificial intelligence and a vision system, which intervenes on the reject line to manually extract poorly sorted items. This robot can perform up to 65 gestures per minute, doubling the capacity of an experienced human operator (Radio Scoop, 2019). Sorting is thus both automated and human-assisted, ensuring high quality of recycled materials.

Fig 12 Exterior View of Paprec Chassieu Sorting Center, Lyon (Sassi Belouni, 2025)

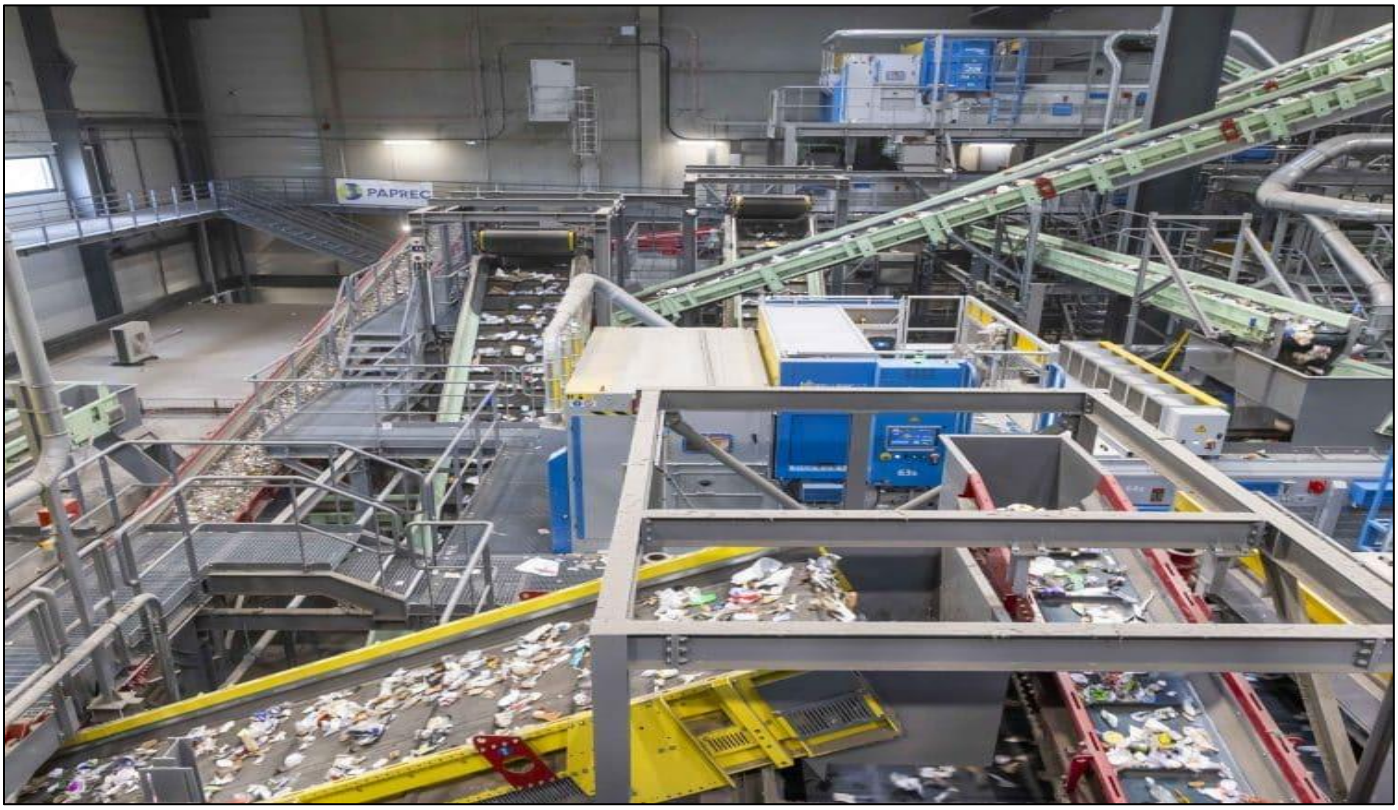

Fig 13 Interior view of Paprec Chassieu Sorting Center, Lyon (Adrien Tuffery, 2025)

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Despite its advanced equipment, notably optical sorters and an automated process that performs between 95% and 97% of operations, the center faces several limitations. Among them, the management of non-recyclable or poorly sorted waste remains a challenge, as this waste requires supplementary treatment or is destined for landfill. Furthermore, the constant evolution of sorting instructions and the increasing diversity of materials to be sorted require continuous technological adaptation, which represents a significant cost. Finally, even with a high level of automation, the role of human operators remains crucial for quality control and fine-tuning the sorting, emphasizing that the process cannot be entirely mechanized. These limitations constrain the center's ability to achieve total waste recovery and fully address the growing environmental challenges.

III. METHODOLOGY

The methodology defines the rigorous approach adopted to achieve the objectives of the thesis. It combines documentary, analytical, and descriptive approaches, integrating qualitative and quantitative tools, to build a contextualized reflection, adapted to local realities and international best practices.

➢ *Data Collection*

Data collection and analysis constitute a central stage in the methodological approach of this thesis, as they allow the design of the sorting center to be based on a detailed and contextualized understanding of urban waste management in Yaoundé. This phase mobilizes both quantitative data (volumes, flows, waste typology) and qualitative data (perceptions, practices, constraints of stakeholders), collected through a documentary review, field observations, and semi-structured interviews. The literature review provides a solid theoretical basis by identifying models, challenges, and innovations related to waste management and the architecture of sorting centers, particularly in the African context. Direct observations make it possible to grasp local dynamics, behaviors, and the physical conditions of the sites, while interviews provide insights into institutional issues, expectations, and the limits of the current system. The cross-analysis of this data, using statistical tools and interpretation grids, allows for the formulation of a global diagnosis and the definition of a relevant architectural program, adapted to the urban, social, and environmental realities of Yaoundé. This process ensures the relevance, reliability, and sustainability of the proposed solutions, by combining scientific rigor with local grounding.

➢ *Functional Specifications*

The functional specifications constitute a key step in the design of the urban waste sorting center in Yaoundé, by translating project needs into operational requirements adapted to the local context. It defines the center's missions (reception, sorting, storage, recovery), the expected performance, the constraints of operation and urban integration, while setting capacities according to waste volumes. It specifies the project intentions, the functions to be fulfilled for the different users, the working conditions, and the internal flows to be organized. Macro-zoning structures the site into major functional zones, surface tables allow for sizing and compliance, and the functional diagram visualizes the interactions between spaces, ensuring project consistency, efficiency, and evolvability.

➢ *Architectural Design*

The architectural design of the urban waste sorting center in Yaoundé is based on a structured approach aimed at translating functional, technical, and environmental needs into a coherent, sustainable, and locally adapted spatial project. It begins with a conceptual design inspired by local and international references, which guides the volumetric, aesthetic, and organizational choices of the building. This process integrates the modeling of internal flows (waste, users, vehicles), the organization of functional zones (reception, sorting, storage, offices), and adaptation to the site's topography and constraints. Digital tools such as AutoCAD, Revit, Rhino, and SketchUp are used to produce plans, sections, 3D models, and rendered images, facilitating communication with stakeholders and the evaluation of options. Particular attention is paid to the sustainable approach: natural ventilation adapted to the equatorial climate, rainwater management, integration of solar panels, use of local materials with low environmental impact, and improvement of operator working conditions. Finally, the presentation board summarizes the key elements of the project in a clear and hierarchical layout, ensuring readability, graphic coherence, and enhancement of the architectural project.

➢ *Impact Evaluation*

Impact evaluation consists of analyzing the effects of a project, program, or policy on the target group, by measuring the magnitude of the changes it causes. It makes it possible to identify transformations in the well-being of individuals attributable to a specific intervention. This process relies on establishing a causal link between the project and its results, distinguishing between direct and indirect effects. It also involves anticipating positive and negative consequences, while proposing appropriate mitigation measures. Impact evaluation is an essential tool for informing decision-making, improving the effectiveness of interventions, and ensuring responsible project management. It promotes a better understanding of social and economic dynamics, thereby contributing to the optimization of development strategies.

IV. CONCLUSION

This work has highlighted the urgency of reforming the urban waste management system in Yaoundé. Its effectiveness relies not only on investment but fundamentally on the architectural design and urban integration of the treatment facilities. The analysis confirmed that fragmentation of management, insufficient collection, and the absence of source sorting are the main obstacles to recovery, exacerbating health and environmental risks.

The success of African management models (such as Kigali) depends on strong governance, the integration of the informal sector, and the adoption of circular economy principles (material and energy recovery). The design of the proposed management center is based on these lessons,

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prioritizing a spatial and architectural organization that optimizes flows, ensures safety, and allows for maximum waste recovery (composting, methanization, recycling).

Ultimately, the design of a waste management center in Yaoundé, based on rigorous architectural principles, is the indispensable tool for achieving the goal of reducing landfilling and for transforming waste into resources, thereby sustainably improving the local living environment. The next steps should focus on a detailed impact evaluation of the project to ensure its social and environmental acceptability.

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