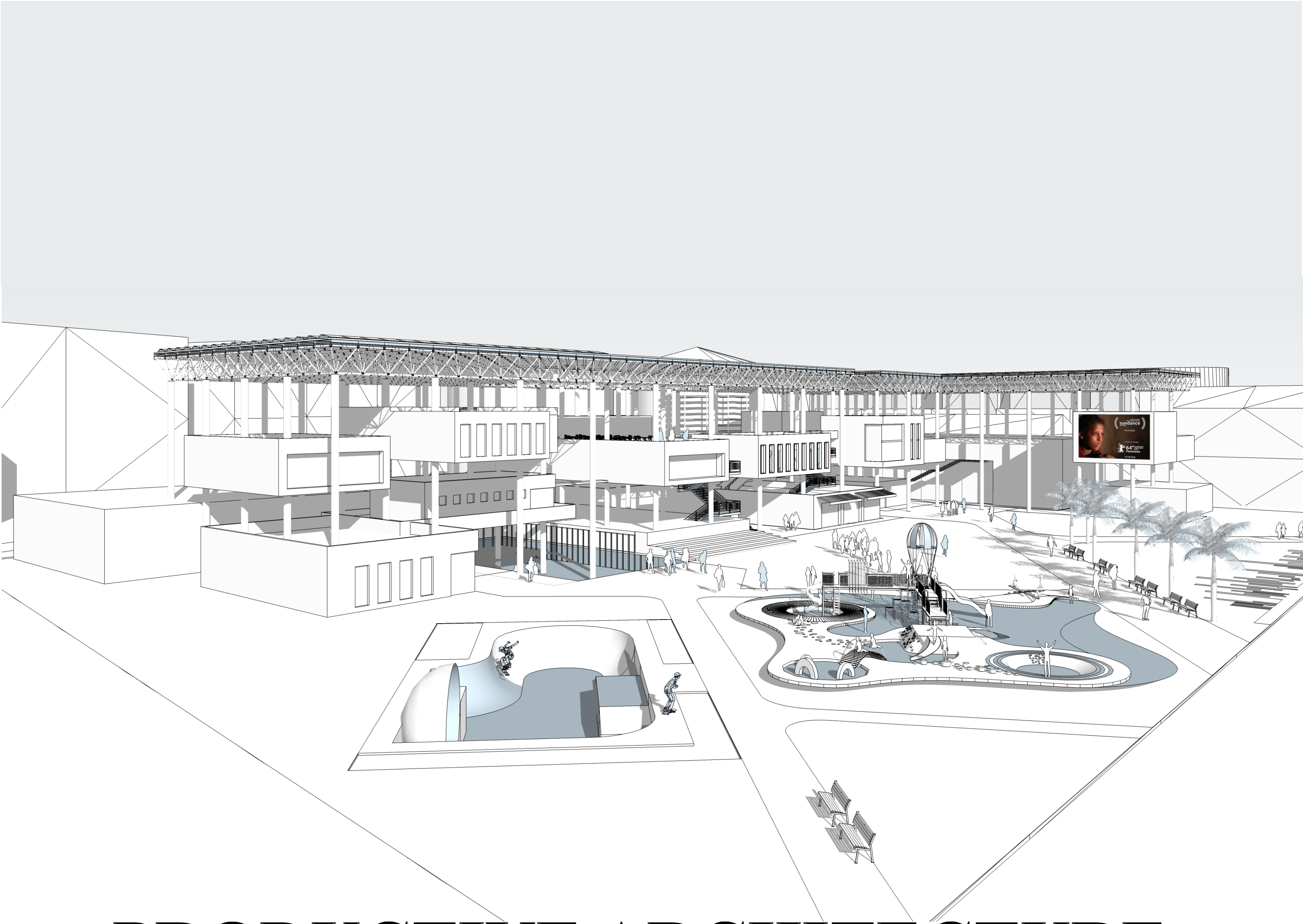

PRODUCTIVE ARCHITECTURE:

Architectural solution for decentralized solid waste mangementin the case of Addis Ababa

By: Kalkidan Debela
Advisor : Fikreselassie Kassahun

ADDIS ABABA UNIVERSITY
Addis Ababa, Ethiopia
May, 2020

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Building Construction and City Development
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PRODUCTIVE ARCHITECTURE:
Architectural solution for decentralized solid waste management in the case of Addis Ababa

By
KALKIDAN DEBELA

A THESIS
Submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE
Masters in Advanced Architectural Design
Ethiopian Institute of Architecture, Building Construction and City Development

ADDIS ABABA UNIVERSITY
Addis Ababa, Ethiopia
May, 2020

DECLARATION

This thesis entitled "PRODUCTIVE ARCHITECTURE: ARCHITECTURAL SOLUTION FOR DECENTRALIZED SOLID WASTE MANGEMENT IN THE CASE OF ADDIS ABABA" is my original work and has not been presented for a degree in MSc. In any other university, and all the sources of material used for the thesis have been duly acknowledged.

Author:

Kalkidan Debela

Signature: ________________________

Date: ____________________________

CERTIFICATION

The undersigned hereby certify that a thesis entitled "PRODUCTIVE ARCHITECTURE: ARCHITECTURAL SOLUTION FOR DECENTRALIZED SOLID WASTE MANGEMENT IN THE CASE OF ADDIS ABABA" has been read and recommended to EiABC, graduate studies for acceptance, in partial fulfillment of requirements for the degree of Master of Science in Masters for Advanced Architectural Design (MAAD)

ADVISORS:

Fikreselassie Kassahun

Signature: ________________________

Date: ____________________________

This thesis titled: "PRODUCTIVE ARCHITECTURE: ARCHITECTURAL SOLUTION FOR DECENTRALIZED SOLID WASTE MANGEMENT IN THE CASE OF ADDIS ABABA" is Submitted to Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) and the school of graduate studies of Addis Ababa University for partial fulfillment of the requirements for the degree MASTER OF SCIENCE in Masters in Advanced Architectural Design (MAAD).

AUTHOR: Kalkidan Debela

DATE: June, 2020

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Abstract

According to a recent United Nations (UN) report, Addis Ababa, the capital of Ethiopia, has a population of 4,794,000. Addis Ababa is home to 25% of Ethiopia's urban population and is one of the fastest growing cities in Africa. The rate of human consumption is rapidly transforming our planet's biomass into human-made mass, which includes more trash, and Addis Ababa is estimated to generate 2 million tons of trash a year. Each person generates about 0.45 kg of waste per day.

Addis Ababa's waste managment currently exists as a linear process: trash flows from high-density cities to sprawling landscapes of waste, which is Koshe. However, as cities grow and become more dense, critical systems of waste infrastructure must be re-evaluated. Instead of today's isolated and linear processes, urban and waste ecologies can become an interconnected and cyclical system. Current practices call for industrial processes to be pushed to the periphery of cities, thereby severing the relationship between the urban environment inhabited by humans and the one that is required to support the way humans live. If architects and designers become engaged in the conversation of waste management and other industrial processes that support the demands generated by cities, they can begin to repair the physical and mental separation of waste and public activity, while also introducing cultural, economic, and environmental value in waste infrastructure. This thesis was designed to be a provocative approach to contemplating waste and waste management.

Keywords
Waste Infrastructure, Public Engagement, Urban Design, Waste-To-Energy, Sustainable Cities, Productive Architecture

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For his mentorship and guidance: Fikreselassie Kassahun
For their collaboration, feedback, and help: My friends and family

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ACRONYMS

AA	Addis Ababa
AACA	Addis Ababa City Administration
AASWMA	Addis Ababa Solid Waste Management Agency
EEPC	Ethiopian Electric Power Corporation
EPA	Environmental protection Agency
FDRE	Federal democracy republic of Ethiopia
MRF	Material Resource Facilities
MSSE	Micro-and Small-Scale Enterprises
MSWI	Municipal solid waste incineration
MSW	Municipal solid waste
MSWM	Municipal solid waste management
SBPDA	Sanitation, Beautification, and Park Development Authority
SWM	Solid waste management
WCS	Waste collection site
WTE	Waste to Energy

PART ONE

CHAPTER ONE
INTRODUCTION

1. Introduction

1.1. Background

Since the industrial revolution, the amount of waste created has increased significantly worldwide, both in amount, as well as type and toxicity. Currently, waste management is a pressing issue in most countries around the world because it is directly related to a country's economic, social, and political status. This management challenge is more difficult for middle and lower-income countries. According to a 2016 World Bank report, Ethiopia is a low-income Sub-Saharan country with a gross domestic product (GDP) of $555 per capita, with a population of 97.1 million. (World Bank, 2016)

In most cases, governments often have insufficient capacity and/or funding to meet the growing demand for solid waste management services. (Marshall n.d.) In many cities, solid waste management represents the largest portion of the local government's budget (UN-HABITAT, 2012/2013) In developing countries, municipalities commonly spend 20-50% of their budget on solid waste management, though 30-60% of all the urban solid waste is not collected. In addition, only 50% of the population receives this service. By contrast, in high-income countries, waste collection accounts for less than 10% of the budget, which allows significant funds to be allocated to waste treatment facilities according to World Bank estimates. (ISWM n.d.)

Ethiopia has one of the fastest growing populations in Africa. Addis Ababa, which is the country's capital, also has the fastest average annual population growth rate of 2.4%. (LSECities, 2018) Due to the population and construction booms, the city is suffering from solid waste piling up and a lack of proper waste management. The piles of trash on the streets and in neighborhoods are creating a variety of types of pollution. Currently, in Addis Ababa, solid waste management primarily relies on the municipalities to address the problem, and only a few private participants are working on a small scale compared to the amount of work needed in the sector. The system used by the municipality includes open dumping in a place named Repi, which is 15 km from the city's center.

Addis Ababa's municipal solid waste (MSW) handling is being conducted in an unsustainable, inefficient, uncoordinated, and unrepresentative manner. The solid waste generation is increasing, and this trend promises is being vigorously fueled by the population boom and business expansion in terms of volume, type, and the level of hazard. Community understanding and how they relate to the SWM problem is critical.

Thus, the MSM Management (MSWM) question is critical and must be addressed at all levels, from its source to the final disposal, including elements of management and stakeholders' involvement. High and crystal clear pressure is emanating from this growing and complicated problem. There is a dire need to put legal procedures in place by introducing an appropriate and efficient way of dealing with this challenging problem. Furthermore, this requires desire, will, and resources to bring about a positive and visible change.

This thesis paper critiques Addis Ababa's current MSWM system as a necessary yet undesirable 'invisible infrastructure.' Most of the time, industry and waste treatments have been pushed to the periphery of urban environments. These are severing the relationship between the urban environment we inhabit and the environment that is required to support the way we live. The flow of trash from the city centers to the piles of landscape waste has a linear system that separates the input from the output.

1.2. Justification of the research

Ethiopia, the second-most populous country in Africa, has an estimated population of 109 million. According to a 2019 World Bank report, Ethiopia is still predominantly a rural country, and the people living in an urban area represent only 20% of the total population. The Ethiopian Central Statistics Agency projected that the urban population would triple to 42.3 million by 2037, with represents an average annual growth rate of 3.8%. According to the 2015 Ethiopia Urbanization Review, the urbanization growth rate will be even faster, reaching 5.4% a year. (World Bank, 2019)

The government planned to achieve 'a middle-income country' by 2025. From this plan, Addis Ababa has benefited from massive investment over the past decade. The city is planning massive urban renewal and redevelopment projects to improve its competitiveness as a business location and to tackle the enormous backlog in affordable housing and primary service delivery through accelerated investment in infrastructure and public housing programs. As a result of these interventions, Addis Ababa has experienced tremendous economic dynamism, attracting both domestic and foreign investments that generated job creation and other financial opportunities.

As Ethiopia develops, its cities will experience change and will be transform in terms of layout and the type of human activities, which has profound implications on the country's solid waste management. The rapid economic growth has improved the urband dwellers' standard of living, thus enabling them to change their pattern of consumption of goods. This intervention has created a higher per capita waste generation rate, rendering the existing solid waste management system ineffective, thus creating a higher risk of massive failure. (UN-Habitat, The state of Addis Ababa 2017)

1.3. Problem Statement

Ideally, the creation of all waste would be prevented. However, in most cases and for different reasons, this does not happen. If there is a waste, it is usually best to reuse it if possible, and if not, then to recycle it. What cannot be recycled could either go to energy recovery, or as a last resort, disposed of in a landfill. This general order is known as the waste hierarchy: prevention, reuse, recycling, recovery, and disposal

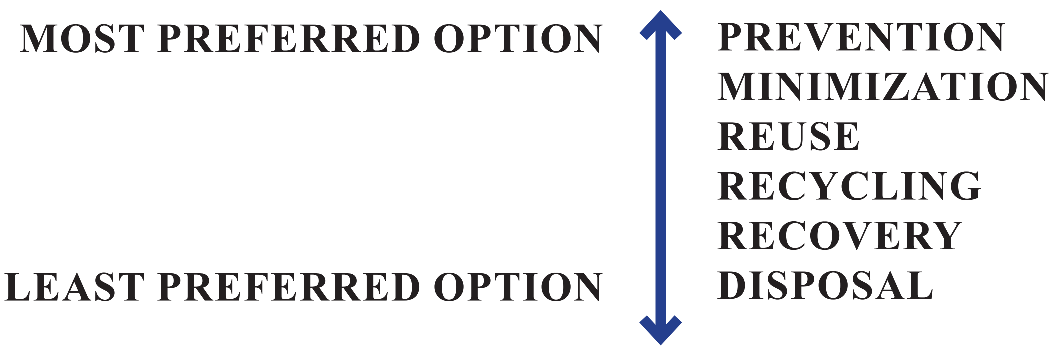


Figure 1 : Waste Hierarchy in EU with the Principle to move towards the higher tiers (Prevention being the most beneficial)
Source : (EU,2010)

In Ethiopia, except for recent activities in Addis Ababa, the solution to the waste situation is unmonitored landfills with smaller sorting operations. This action is a poor environmental solution, and there are informal plans for change, though no specific strategy has been presented or found.

Waste management is not directly associated with the field of architecture, landscape architecture (i.e., urban design), and planning. Infrastructure, such as waste management, is closely tied to the planning of cities. Most of the time, waste management operations are tucked away in the periphery or industrial area of a city that is not visible to the public eye and easily forgotten.

"Sanitation is the most important uniformed force on the street. No city can thrive without a workable solid waste management plan." [1]

Another significant issue is the relationship between waste and society. There is a substantial awareness gap in how to deal with waste and waste management. Large projects like Reppi's waste-to-energy plant are good, though they are not close enough to society's activities to create awareness. Instead of building a monocentric waste treatment plant, it would be better to decentralize treatments plant at the neighborhood level. This thesis considers case studies and investigates how to solve this kind of problem in architectural projects.

1.4. Objectives of the research and questions

1.4.1. General Objective

The general objective of this thesis is to propose a decentralized waste treatment plant that will not only be the treatment plant but also have other function for the society in Lideta sub-city, Addis Ababa, Ethiopia.

1.4.2. Specific Objectives

1. Assess solid waste management issues in Addis Ababa.

- How is waste managed in Addis Ababa?
- What is the role and competency of the responsible body in SWM?
- What are types of waste and their share, as referenced with generators?

2. Investigate for the seamless integration of SWM and productive architecture within the urban fabric.

- What are the formal/spatial attributes of waste at different spatial levels?
- What are the site selection criteria for Waste Collection Site (WCS)?
- Which spaces are de-facto garbage dumping sites?
- What are the considerations in establishing Waste Collection Site (WCS?
- What are the significance of productive architecture in SWM?

3. Propose a decentralized system that creates a strong link between the urban waste infrastructure and public hubs together through the architecture and landscape architecture to create a new center for civic engagement with waste processes.

- What is the spatial/ administrative level appropriate for project intervention?
- Who is the target group?
- What is the appropriate design approach for such kind of project?
- What are the means to secure an accessible (accessible, affordable, adequate, and available) urban waste infrastructure?

4. Investigate waste to energy technologies for decentralized waste to energy plants.

- What is the appropriate technology?
- What criteria shall govern the selection of appropriate technology?

This study thus brings solid waste management in the city of Addis Ababa to light, where the significant problem of solid waste management has been studied, and the significance of architecture and design for the seemingly invisible but undeniable waste is considered.

[1] *Abstract Title Of Thesis : The Ar Chitecture Of Waste .., https://drum.lib.umd.edu/bitstream/handle/1903/18654/Muller_umd_0117N_17288.pdf? (accessed April 04, 2020).*

1.5. The scope of the research

The research was carried out in the city of Addis Ababa, Ethiopia, and its solid waste management system was studied. The interaction of waste management and society is discussed in this thesis paper. More importantly, the study was foucsed on the involvement of architecture in waste management by proposing a decentralized waste treatment system that is closer to the city's individual neighborhoods. For this purpose, the site was located inside the city of Addis Ababa. The site was studied based on the size, population, and socio-economical characteristics based on primary and secondary data that were gathered during the study.

1.6. limitations of the research

The main limitations of the research include finding updated data regarding the amount of waste, type of waste collected, the collection system, waste dump site selection criteria, and how waste management operates in the city. Only two studies in this area were found at the SWM agency, which includes the Income Generation and Climate Protection by Valorizing Municipal Solid Wastes in Emerging Megacities in a Sustainable Way, (IGNIS) and Franch agencies. The other limitation was visitation to the Reppi waste-to-energy (WTE) plant. It was difficult to gain access, analyze, and study the plant in-depth.

1.7. Organization of the research

This study was organized into two parts and seven chapters. Chapter 1 focuses on the introduction, which includes background information related to the study, research problem, the objectives, research questions, justification, and organization, as well as the limitation of the study. This is followed by Chapter 2, which explains the methodology used, including model specification, data sources and measurement, and estimation techniques. Chapter 3 provides a review of the extensive and related empirical literature regarding solid waste management, institutional structure for solid waste management, Addis Ababa's perspectives on community involvement in the waste management decision process, waste collection, and disposal. Chapter 4 discusses the empirical results. Chapter 5 describes the contextual review of the selected site. Chapter 6 covers the site analysis and the design proposal for the chosen area, and the summary, conclusions, recommendations, and direction for future research presented in Chapter 7

The research study was designing according to the following diagram.

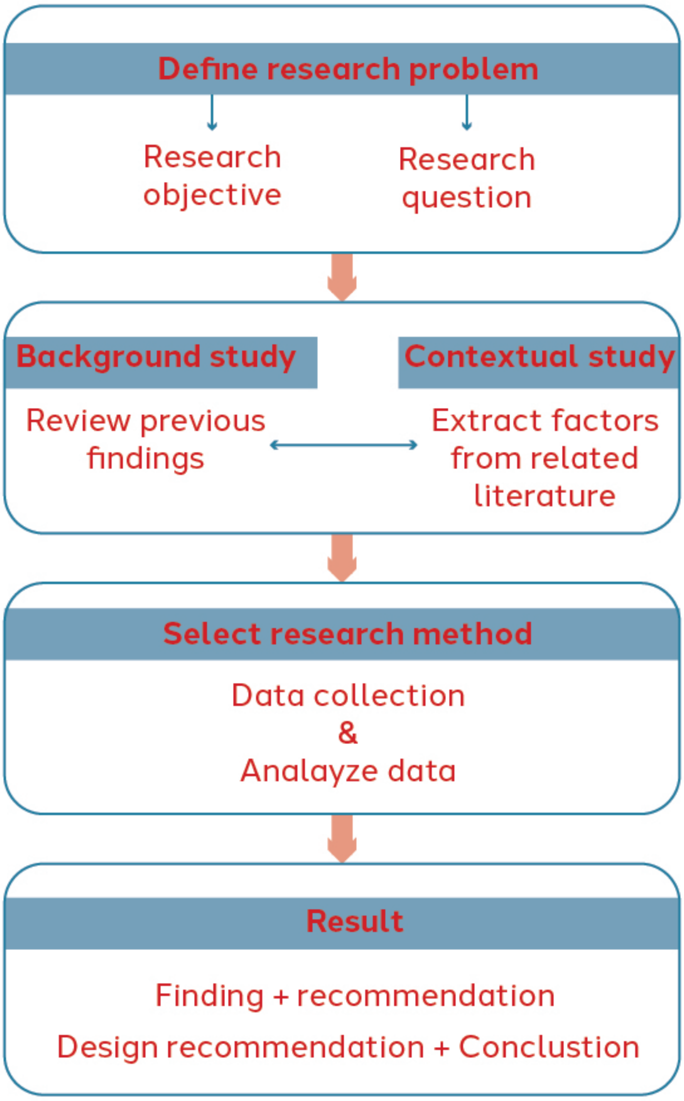


Figure 2 : Research design framework Illustraion by the author

1.8. Operational definition

Description and Working definition of keywords in the study:

1.8.1. Productive architecture

Productive architecture refers to buildings that produce positive benefits on three levels, incuding human, environmental, and economic aspects. In addition to this architectural design is also considered in human terms. This means a place that promotes health, happiness, and inspiration. In environmental terms, this also means producing a surplus of renewable energy, using no groundwater, and generating no waste. In economic terms, it is about creating real value, and in architectural terms, it is a prerequisite to good design (KIss+Cathcart,2019).

1.8.2. Sustainable Architecture

Sustainable architecture means an architecture that works to minimize the negative environmental impact of buildings. This can be done by efficiency and moderation in the use of material, energy, and development space and the ecosystem at large. It is using a conscious approach to energy and ecological conservation in the design of the built environment (Globalfootprints, 2018).

1.8.3. Solid waste (SW)

A "solid waste" is defined as any discarded material that abandoned by being disposed of, burned, or incinerated, recycled, or considered "waste-like." Solid waste can physically be a solid, liquid, semi-solid, or container of gaseous material. It includes garbage, construction debris, commercial refuse, sludge from the water supply or waste treatment plants, or air pollution control facilities, and other discarded materials. Solid waste can come from industrial, commercial, mining, or agricultural operations, and household and community activities." This thesis focus on the organic solid waste which comes out from household. (EPA n.d.)

1.8.4. Municipal solid waste (MSW)

Municipal solid waste is defined at the national level as wastes consisting of everyday items, such as furniture, clothing, product packaging, grass clippings, bottles and cans, food scraps, newspapers, appliances, consumer electronics, and batteries. These wastes come from homes and institutions, such as schools, hospitals, and commercial sources, including restaurants and small businesses. (EPA n.d.)

1.8.5. Solid waste management (SWM)

The administration of activities provides for the collection, source separation, storage, transportation, transfer, processing, treatment, and disposal of solid waste. (EPA n.d.)

1.8.6. Waste-to-Energy (WTE)

WTE is a technology that transfers waste to energy (WTE) in the form of heat, electricity, or alternative fuels, such as biogas. The technology is applied differently depending on scale and complexity. (GIZ, 2017)

CHAPTER TWO
RESEARCH METHODOLOGY

2. Research Methodology

2.1. Methodological framework

To look at the research in-depth, the study follows the major case studies and combined methodological steps. The thesis has three significant methodological steps.

First, a review of literature and practical cases on similar schemes was conducted, in which the appropriate planning and design knowledge for integrating productive architecture is explored for similar cases.

Second, a case study method was used, and the current pattern and usage of WCS and SWM (classification and quantification) are examined based on the case area.

Third, the knowledge developed through the literature review (Part 1) and the data collected from the case area (Part 2) were synthesized to assess ways for the integration of productive architecture for decentralized WTE in the built environments of the selected neighborhoods through a prototypic (sample) design and planning scheme (Part 3).

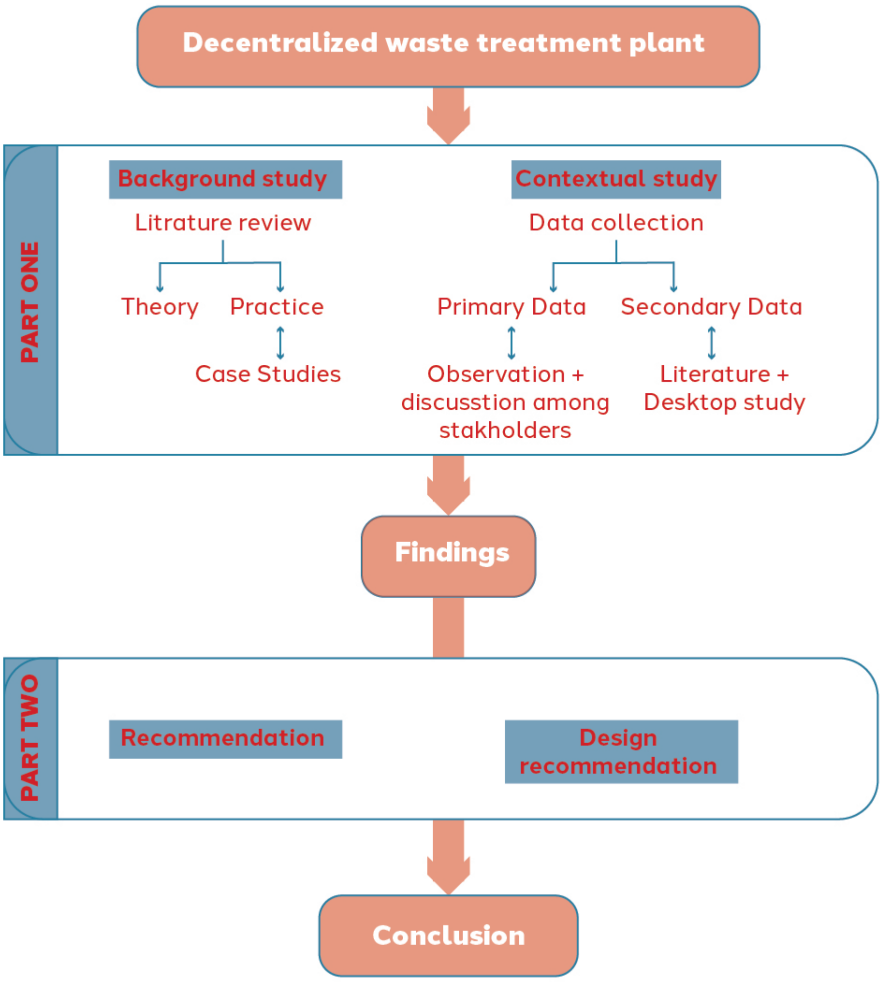


Figure 3 : Methodology framework Illustraion by the author

2.2. Types of literature review

In this section, relevant books, journals, magazines, and other reading materials related to the nature and practice of productive architecture and WTE technology are reviewed to provide a foundation of theoretical and practical knowledge.

2.2.1. Covered Theory

There are different theories about Productive architecture, solid waste, municipal solid waste, and waste to energy separately. Thus, this study starts by formulating a working definition of these key terms of the research. Mainly, theories by kiss Cathcart, Architects from their publication, and projects about productive architecture and architecture and waste (re)planned obsolescence book by Hanif Kara, Leire Asensio Viloria, and Andreas Georgoulias used as a cornerstone for this research. Supplementary theoretical exploration of waste-to-energy technologies, centralized and decentralized waste-to-energy, are mined from different literature to understand their conception in terms of their environmental contamination, planning, design, and cost.

2.2.2. WTE technologies analysis method

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) has a publication called Waste-to-Energy Options in Municipal Solid Waste Management (in 2017). In this publication, they covered many guidelines and techniques for applying WTE. The five technologies (1. Municipal Solid Waste Incineration 2. Co-processing 3. Anaerobic Digestion for Biogas Production 4. Capturing of Landfill Gas 5. Alternative Technologies: Pyrolysis and Gasification) were analyzed based on different parameters. The parameters included suitable waste, operational aspect, environmental aspect, legal aspect, economical aspect, and scale aspect. These parameters are the fundamental variables to consider before building a WTE facility.

2.2.3. Selection of Case Study on Similar Schemes (Practical Case Study) international case study

The international case study selected based on the productivity of the architecture (defined on 1.8.1.). There are three international cases selected for analysis, where the first two focused on the municipality waste-to-energy plants, and the last one is the first village in Germany to be officially recognized as a bio-energy village. The selected case studies are analyzed based on the four parameters that Kiss Cathcart Architects mentioned in their publication. The parameters are in human, environmental, economic, and architectural terms.

2.3. Selection Criteria and Method of intervention site Analysis

One of the objectives of this thesis was to propose a waste treatment plant with the community center that people can profoundly engage in and learn from the process, which will create awareness among them. Based on this, the site was selected to show the recommendation and findings of the research.

The study required a contextual tailored design with a genuine understanding of the background to test the learned knowledge through a design scheme. Thus, one case was selected in Addis Ababa for the test. The case was selected based on the following purposive criteria:

Social Housing development:- Rapid urbanization and unprecedented population growth over the past several decades have created enormous pressure on Addis Ababa's capacity to provide housing. The city government tried to fulfill this demand by implementing a condominium housing program from 2004 until now. This program initially aspired to construct 400,000 condominium housing units between the years 2006 and 2010 (UN-Habitat, 2011). However, city-wide, the program only delivered 142,802 housing units between 2006 up to 2010 (UN-Habitat, The state of Addis Ababa 2017).

This housing demand also requires electricity and other infrastructure. This mass social housing program has a potential for using waste to produce electricity and gas for the neighborhood to become more self-sustainable, and it may even contribute to the national grid. However, the neighborhood planning did not consider the waste as a potential for use to produce electricity or gas for housing.

Lideta Condominium site: - The condominium site was inaugurated and transferred to the beneficiary in 2013 (Meles 2013). In total, there are 20,330 condo housings—the location was selected because of the character of its land use and activity of the surrounding. Based on the Local Development Plan (LDP) of the site and its environs, develop as a high mixed residential area (see 6.1.2.). Condominium housing also has a different variety of levels, such as G+4, G+7, and G+12. It is also mixed with shops, restaurants, and other activities. It also offers the potential of finding waste material, such as old car parts and other different tools from the site and the surrounding area, especially "Menalesh Tera."

Figure 4 : Lideta Condominium Neighborhood satellite map from Google map

2.3.1. Design of Data Collection Techniques and Analysis Layout

Quantitative and qualitative methods were used to analyze the collected data from primary and secondary data sources. The tools used for primary data collection are personal observations, open-ended interviews with participants related to the issue, discussions, site visits, and use of photographs and questionnaires. Moreover, relevant documents from Addis Ababa Solid Waste Management Agency (AASWMA), IGNIS, and the French Development Agency (FDA) were used as secondary resources.

Observation
The observation is done by adapting Jan Gehl's several observation techniques. *"Tweaking observations into a system provides interesting information about the interaction of public life and public space."*[2]. Behavioral mapping, counting, and trace measures used to study both stationary and dynamic activities as well as the physical setting of the WCS, SWM, and public interaction to these spaces.

Table 1 : Some of the selected Observation Techniques

Techniques	Description
Mapping	Activates, People, Places for staying and much more is plotted in as symbols on a plan of an area to make the number and type of activities and where they take place.
Photographing	Taking pictures to document the interaction of urban life and form.
Looking for traces	Registering traces such as walking trials, dirt patches on grass and other that gives the observer information about the city life.
Keeping a diary	Registering details and nuances about the interaction between public life and space, noting observations that is categorized for identifying redundant activates.
Test walks	Taking a test walk while observing the surrounding life to notice problems and potentials for city life on a given route.

Source : Gehl, 2007

[2] *Gehl, 2013*

CHAPTER THREE
LITERATURE REVIEW

3. Literature review

3.1. Methods for Municipal Solid Waste Management

Solid waste management is a very complex process that involves a set of processes, including collection, sorting and segregation, transportation, and finally, disposes of waste in sanitary landfill sites. SWM also includes generation of the waste as this is the stage from where the management must begin. There is a need to reduce the production of waste at this very first stage. Knowing the amount and composition of solid waste generated is necessary for all management planning.

The different types of methods for solid waste management include landfills, sanitary landfills, incineration plants, composting, segregation at the source, reduction of waste using the 3 Rs (Reduce-Reuse-Recycle) method, and converting waste to energy.

3.1.1. Waste Reduction and Reuse

Waste reduction, waste reuse, and recycling, which are known as "3Rs" or reduce, reuse, and recycle are effective methods for solid waste management. This method provides many environmental benefits that reduce or prevent greenhouse gas emissions, reduce the release of pollutants, conserve resources, save energy, and reduce the demand for waste treatment technology and landfill space. Therefore, adopting and incorporating this method as part of the waste management plan is highly advisable.

Waste reduction and reuse methods of prevention are beneficial to get rid of waste production at the source and reduce the demands for large scale treatment and disposal facilities. These methods of waste prevention require a high degree of public participation. Example include manufacturing products with less packaging, encouraging customers to bring their reusable bags for packaging, encouraging the public to choose reusable products, such as cloth napkins and glass containers, backyard composting and sharing, donating any unwanted items rather than discarding them. To get the public aware, training and educational programs need to undertake to educate the public about their role in the process. In addition to public participation, the types and amount of packaging used by manufacturers and avoiding plastic bags and the reuse of shopping bags should be regulated and controlled by the government.

3.1.2. Recycling

Recycling means using items from the waste and as raw material for new products. Recycling has three phases, including collected and sorted recyclable wastes, which are following by using them to create a raw material. After this, the raw material is used to manufacture new products. There are also two ways of sorting trashes, either at the source (i.e., within the house and office) or at recycling centers. The pre-sorting at the source requires public participation, which may not be forthcoming if there are no obvious direct benefits to be derived by consumers. The evidence found that the urban poor and low-income societies are the main recyclers, re-users, and source reducers of their solid household waste. (Murad and Siwar, 2007)

To adopt a system of selective collection and transportation by the local authority would be expensive. However, collecting and transporting the general mix recyclable waste by the municipality and then sorting and recovery of the recyclable materials can be done at a suitable site. This option has the disadvantages of eliminating being dependent on the public and ensuring that the recycling occurs. The quality and amount of recyclable materials are also often compromised during this process.

3.1.3. Composting

Composting is a biological process that treats organic waste under controlled conditions to convert it into manure/compost. This compost is used as a soil conditioner in agricultural fields. The composting process provides many benefits, such as its relative low cost and its avoidance of landfill disposal. No land requirement for landfill finished compost applied to soils is also an important method to reduce greenhouse gas emissions emitted from landfills. It enhances related recycling and incineration activities. In developing countries, more than 50% of the city's municipal solid waste is composted because of the presence of organic or compostable material in the composition structure.

"The process of composting can be applied either by the open windrow method or in an enclosed mechanical facility. Windrows are long, low mounds of refuse. They are turned or mixed every few days to provide air for the microbes digesting the organics. Depending on moisture conditions, it may take five to eight weeks for complete digestion of the waste. The enclosed or mechanical composting systems employ one or more closed tanks or digesters equipped with rotating vanes that mix and ventilate the shredded waste. Complete digestion of the waste takes about one week." [3]

Table 2 : Type and Source of Waste

	Source/type	Composition
Municipal Solid Waste (MSW)	Residential	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g. bulky items, consumer electronics, white goods, batteries, oil, tires), household hazardous wastes, e-waste.
	Industrial	Housekeeping wastes, packaging, food wastes, wood, steel, concrete, bricks, ashes, hazardous wastes.
	Commercial & institutional	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes, e-waste.
	Construction & demolition	Wood, steel, concrete, soil, bricks, tiles, glass, plastics, insulation, hazardous waste.
	Municipal Services	Street sweepings, landscape & tree trimmings, sludge, wastes from recreational areas.
	Process Waste	Scrap materials, off-specification products, slag, tailings, top-soil, waste rock, process water & chemicals.
	Medical Waste	Infectious wastes (bandages, gloves, cultures, swabs, blood & bodily fluids), hazardous wastes (sharps, instruments, chemicals), radioactive wastes, pharmaceutical wastes.
	Agricultural Waste	Spoiled food wastes, rice husks, cotton stalks, coconut shells, pesticides, animal excreta, soiled water, silage effluent, plastic, scrap machinery, veterinary medicines.

Source : Hoornweg & Bhada-Tata (2012) ; ETC/SCP (2013)

3.1.4. Incineration

Incineration is the process of burning waste in a large enclosed chamber. In this process, all types of wastes are burned except the recyclable materials. It is separated from the rest of the wastes. From this process, in the end, ash is left behind. There are two types of ash produce at the end of the process, namely normal ash and fly ash. Fly ash is creating when some of the ashes blow out with the hot air. Disposing of this ash is a problem because both the fly ash and the normal ash have dangerous toxins, such as dioxins and heavy metals. Because of the toxins, at present, incineration is a last resort and is used mainly for treating infectious hazardous waste.

3.1.5. Landfill

Historically, the most common environmentally and economically acceptable waste disposal method has been landfilling. Landfills are a significant component for integrated waste management strategies besides waste

[3] *Hoornweg, D., & Bhada, P. (2012). WHAT A WASTE A Global Review of Solid Waste Management.*

reduction, recycling, and transformation technology of solid waste disposal. Most urban areas use the landfill method. However, in a metropolitan area, there is a large population and a large amount of waste generated, which requires a communal disposal lcoation. Unlike an open dump, it is a pit that dug in the ground. The garbage dump and the hole is covered, thus preventing the breeding of flies and rats. After the landfill is full, the area is covered with a thick layer of mud, and the site can, after that, be developed as a parking lot or a park.

However, landfills have many problems. Wastes containing various hazardous components dumped in landfills, and when water seeps through them, it gets contaminated and, in turn, pollutes the surrounding area. This contamination of groundwater and soil through landfills is known as leaching. (10 Effective Ways To Control The Solid Waste n.d.)

3.2. Waste management in Addis Ababa context

Addis Ababa began as a small settlement near spring water located at the center of the city named Filweha about 100 years ago. Emperor Minilik and his wife Taytu built their palace near the spring water, and all the warlords and their followers settled around them. The settlement continued expanding, and Addis Ababa has become one of the largest cities in Africa, with the physical area has leaped from 33 km2 in 1920 to 527 km2 in 2003. (CSA 2009; Camilla 2012)

There has never been a sufficient waste management system capable of addressing the multi-directional waste problem in the city. There are many reasons for the poor urban infrastructure and service in Addis Ababa. For many years, the need for a waste management system has not been recognized by the administrators. Neither has there been any waste management expertise. In the beginning, the administrators were not concerned with the matter as the number of habitats was relatively low, and the waste generated was not grave in both amount and type. Therefore, disposing of waste at a distant site was an easy solution. However, with the fast expansion of the city, the distant place has become somebody's back yard.

None the rulers have given waste management the amount of attention it needs. Waste management was never considered a pressing matter as the country has been going through numerous international and civil wars, and there were always more pressing matters to address. Disregarding the waste issue can also be observed among the people. Getting the waste out of the site has been a well-embedded approach for a long time. The trash has been piling up and has been slowly and silently causing damage. Unfortunately, when the true magnitude of the problem was recognized, the damage had already been done.

The locales have become accustomed to dumping waste on streets, open fields, and rivers. There are still squatter settlements, and the government has not been able to control them. Enormous construction is in progress, and it will take time before the proper infrastructure is in place.

After the Federal Democratic Republic of Ethiopia (FDRE) came to power, the first organization that took responsibility for waste management was the City Health Bureau under the Department of Environmental Health Care. As there were already sufficient responsibilities for the bureau, a proper waste service was not put in place. This problem was solved when the FDRE introduced structural reform to delegate responsibilities to lower units in 2003. When decentralization was implemented, the waste management responsibility came under the Sanitation, Beautification, and Park Development Authority (SBPDA). As part of the reform, waste management departments have been organized on sub-city and Kebele (i.e., the smallest administrative unit in the FDRE) level.

The primary responsibilities of the SBPDA were organizing and administering waste management in sub-cities and regulating policies concerning solid waste. The sub-cities were responsible for collecting and transporting waste within their area. Lastly, reporting daily waste operations and primary collection fell under the responsibility of the Kebeles. The structure of the authority was slightly changed when the business process re-engineering program was introduced to all the government offices to enhance service delivery.

The SBPDA was renamed the Solid Waste Management Agency and Landfill Project Office. The change that took place in the operation was that the Department of Park and Cemetery separated from SBPDA as an independent agency. As a result, the responsibility scope of the agency narrowed.

The operation of waste management has two major stages. The first stage of the process occurs individuals and informal workers collect waste and deliver it to the collection tank at a common collection site. The second stage occurs when the government trucks come to empty the tanks and dump the waste at a dumpsite. This has been the process for many years. However, in 2003, the Addis Ababa city administration adopted and implemented The Micro-and Small-Scale Enterprise's program to alleviate unemployment and poverty with micro-credit loans and business training.

As a result, the task for the primary collection of waste from households and industrial institutions was assigned to enterprises working under the sector. When the government implemented this program, it did not recruit the already existing informal collectors.

For reasons that are unclear, implementation took place that disregarded the existing actors. The task was simply taken over from the informal actors by employees organized under micro- and small-scale enterprises in the government. The households and industrial institutions are instructed by their Kebele not to pay the informal collectors. This has created more unemployment and has not alleviated the problem.

After the election in 2005, the activities of the micro- and small-scale enterprises have been decreasing. The micro-and small-scale enterprises constructed for the pre-collection are again collected under the administration of the Kebele. The MSSEs were no longer independent and allowed to function on their own, and the manner of payment has changed so that the households and institutions pay service charges with water bills directly to the Kebeles. Hence, the system has gone back to its former centralized trend.

Most of the development projects implemented in Ethiopia have been following a trend where a new idea or method was acted on only when it was introduced and then abandoned and presumably reverted back to the old method.

To support this claim, Seleshi Demissie (Gash Abera Molla), an artist and one of the very few environmental activists in the county became involved. In 2001, he set up a project to engage the unemployed youth to work on the disposal of solid waste and beautification of the city's natural areas. The project was quite influential. Most of the young generation in the entire city collaborated to implement it. The entire city mobilized towards proper management of solid waste. The phenomenon was vast enough to attract international media. However, after some time, the mobilized society has wholly abandoned the project objectives and reverted back to the old ways.

Overall, the solid waste management problem in Addis Ababa has its roots in the way the city was established and the developmental route it took. The random settlements that have established make efficient solid waste management nearly impossible.

The disregard for active solid waste management by both the government and the people also plays a significant role. Looking at the history of the government approach, one can envision a good strategy; nevertheless, the implementation should be conducted based on research to match the real circumstances of the city. Moreover, to reap the benefits of changes that are implemented, the enforcement of the changes should be sustained.

3.2.1. The primary sources of waste

According to the Addis Ababa Solid Waste Management Agency (AASWMA), in 2018, the contribution to the total generation of waste by the different sources was estimated to be around 76% from households, 9% from commercial operation and institutional operations, 5% from industrial sources, 6% from streets and public areas, 3% from hotels, and 1% from hospitals. Based on the total waste generated in the city, the following important characteristics are known:
Waste generation: **0.45 kg/day/person**
Total waste generated per day: **3,200 tons/day**
The density of waste: **264 kg/m3 per day (IGNIS 2016)**

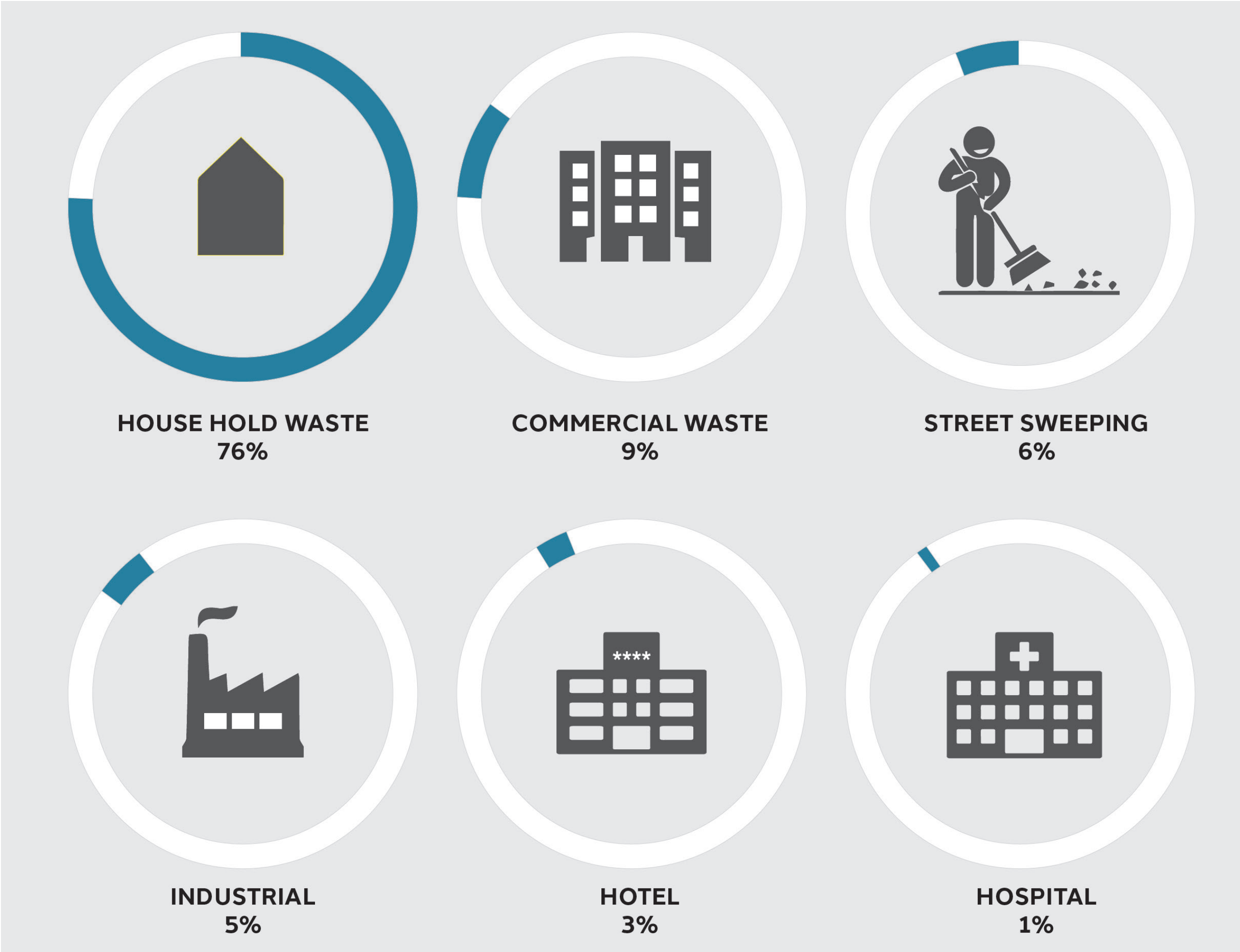


Figure 5 : Addis Ababa's source of solid waste in Percentage
Source : (AASWMA, 2018/2019) Illustration by the author

Taking the repartition of the population's level into account, in 2013, household waste generated by the population of the ten sub-cities was estimated to be 320,000 tonnes per year, and the global generation rate in the AACA was estimated to be 0.28 kg/capita. The repartition of waste generated by sub-city is presented below:

The repartition of waste generated by sub-city presented below:

Table 3 : House hold waste generation in Addis Ababa Sub cities

Sub cities	Population (2007)	Area (km2)	2013 (projections)	Density 2013 (inhabitant/ha)	House hold waste generation (2013)
Addis ketema	271,644	8,98	289,286	322,2	30,019
Akaki Kaliti	195,273	126,13	205,345	16,3	19,686
Arada	225,999	11,56	239,286	207,3	25,282
Bole	328,900	120,93	350,029	29,0	41,950
Gullele	284,865	32,73	303,166	92,7	29,180
Kirkos	235,441	16,26	250,615	154,2	26,843
Kolfe Keranio	546,219	65,1	485,854	74,7	47,606
lideta	214,769	12,4	228,501	184,3	22,168
NifasSilk Lafto	335,740	63,59	358,286	56,4	37,585
Yeka	337,575	82,3	392,702	47,8	38,185
Total	2,738,248	540	3,103,374	57,5	318,504

Source : Addis Ababa City Governement - Ethio-French Cooperation, 2013

3.2.2. Waste density

By the research of Addis Ababa city government and agency Francaise de-development, the two waste characterizations made in 2013, in the wet and dry season, show that the density of waste varies from 0.11 to 0.34 during the year and depending from socioeconomics area. The average is around 0.18 in the dry season and 0.20 in the wet season. It's globally due to the proportion of organic waste in the bin, and the moisture content of waste related to the seasons. (Addis Ababa city goverment-Ethio-French cooperation, 2013)

3.2.3. Waste sizing

The two sizes 20-100 mm and over 100 mm are roughly equivalent (between 40-50%) and homogeneous across all social classes. The fine particles (<20 mm) represent less than 10% of the waste's wet weight. It is composed mainly of fermented organic matter. (Addis Ababa city goverment-Ethio-French cooperation, 2013)

3.2.4. Composition

Since households generate the most waste, it can be deduced that the content would mostly organic. The few available research studies support this. To observe waste composition in Addis Ababa, the research data below is from the IGNIS project between 2008 and 2014, which surveyed only households. The data is the only representative data of the composition of waste from households. To conclude, exact data that provides a precise figure of the current waste composition in Addis Ababa is not available.

Table 4 : Solid Waste Composition in Addis Ababa

Waste Type	Composition Percent
Organic	64.8%
Paper and Cardboard	5.3%
Plastic	5.2%
Glass	2.1%
Textile	4.0%
Charcoal	2.1%
House Hold Hazard	0.4%
Metals	1.2%
Fines	7.8%
Inert Metals	1.7%
Sanitary Products	3.6%
Wood	0.9%
Miscellaneous	0.9%
Total	100 %

Source : AASWMA, 2018/2019

3.2.5. Collection

Under the Addis Ababa City Administration (AACA), there is an agency, the Addis Ababa Solid Waste Management Agency (AASWMA). This agency is responsible for waste collection, transportation, and disposal, as well as street sweeping related to generation by households, commercials, and institutional sources. The collection of waste was delegated to sub-cities which empowered themselves to Woreda offices. Woreda offices are responsible for control, billing, awareness, and street sweeping. (AASWMA, 2018/2019).

Figure 6: Solid Waste collection and transportation system in Addis Ababa
Source : (AASWMA, 2018/2019) Illustration by the author

The formal waste management sector is the responsibility of the AACA. The institutional organization includes three levels of services for the first collection, the secondary collection, and operation of the Koshe Reppi landfill.

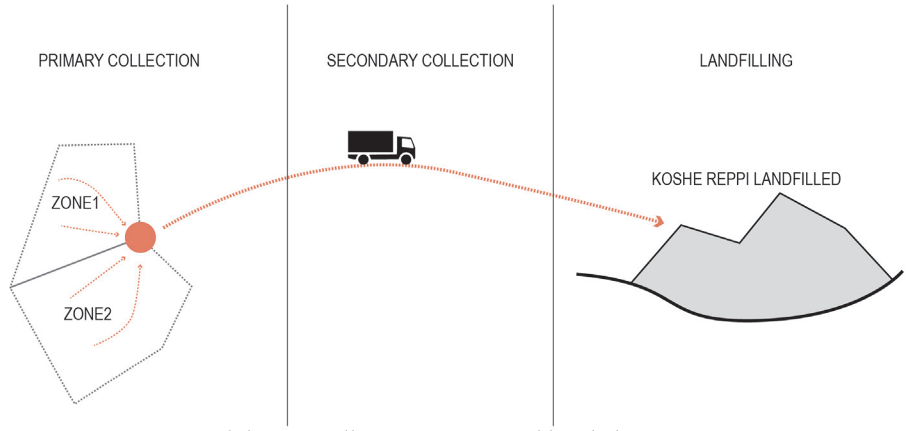


Figure 7 : Current Solid Waste collection system in Addis Ababa
Source : (AASWMA, 2018/2019) Illustration by the author

In parallel, an informal management system takes place in the city, as shown in the following figure.

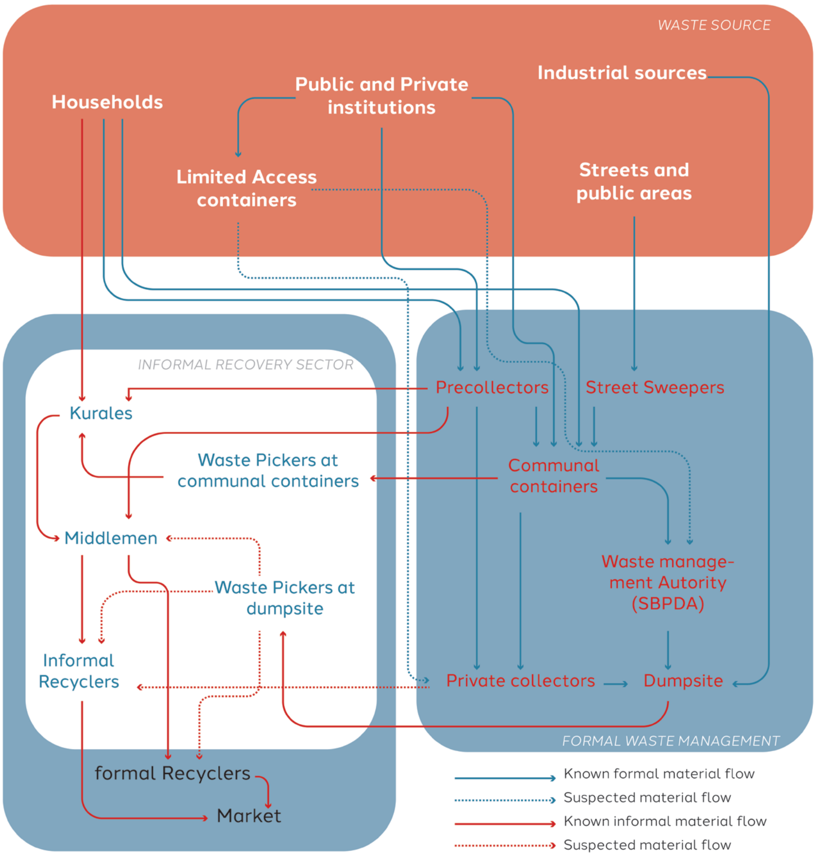


Figure 8 : Waste managment system in Addis Ababa

Source : Addis Ababa City Governement - Ethio-French Cooperation, 2013 Illustration by the author

3.2.6. Landfilled waste disposal – “Koshe Reppi.”

The dump site is located in the southwestern part of the city, in Koshe Reppi, in the Kolfe Keranio sub-city, in Woreda 23/Kebele 16, about 13 kilometers away from the city center. (Coordinates: 8°58, 57’N and 38°41, 78’E. The land was established for waste disposal in 1964. The total area is 30.5 ha, of which the waste deposit occupies approximately 26 ha.

The total area is 30.5 ha, of which the waste deposit occupies 26 ha.

Figure 9`: Location map

Figure 10: Koshe Landfill area

Figure 11 : Site area of Koshe Reppi Landfill

Source : Google map Illustration by the author

In March 2017, a waste collapse accident occurred at the Reppi disposal site, killing more than 130 people. Currently, the disposal site is still in service. Heavy equipment is in operation, but it is an open dumping site. There is no measuring facility on site.

3.2.7. Sendafa Landfill

The new sanitary landfill is located in the territory of the city of Sendafa, more precisely at Chebi Weregenu, 10 km north-east from Addis Ababa city.

According to the design report of the Sendafa Landfill, the expected life span of the landfill is approximately 20 years. The landfill was opened on January 20. Currently, the landfill site is not in service because of the people around that area were against this proposal, and now the issue is under discussion with the government officials.

Figure 12: Site area of Sendafa Landfill

Source : Google map Illustration by the author

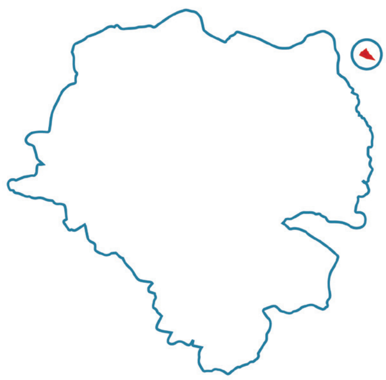


Figure 13 : Location map

3.2.8. Reppi Waste-to-Energy plant

Currently, at the Reppi or "Koshe" site, a new WTE plant was constructed and activated in 2018. The owner of the project is the Ethiopian Electric Power Corporation (EEPC) and was designed by Cambridge Industries, a United Kingdom-based firm, which cost 120 million USD to construct. (Cambridge Industries Ltd, CNEEC n.d.)

The plant was designed to produce 50 megawatts of clean energy through controlled combustion. However, currently, because of the output and the intended design, it is not that much, so the client (EEPC) is complaining to the Cambridge industry to fix the issues. This confusion resulted in temporary shutdown of the plant. The Reppi WTE plant is the first in Ethiopia as it produces green energy within city limits from municipal solid waste. AASWMA has planned for 85% of waste from the total to go to the Reppi WTE plant. (AASWMA 2018/2019)

It will also be the first baseload power in the country, providing electricity 24 hours a day for over 330 days per year. The facility will be a modern waste disposal system, eliminating over 1,000 tons of waste every day. It will operate with two lines running at a nominal design throughput of 41 tons per hour (tph) on a 24-hour basis for a design net calorific value (NCV). Waste is combusted at a minimum temperature of 850 oC with the released heat being used to generate superheated steam. The steam is then fed to a condensing turbine generator to produce electricity. (Cambridge Industries Ltd, CNEEC n.d.)

Figure 14 : Location maap

Figure 15: reppi WTE plant

Figure 16 : Reppi Waste to energy plant

Source : Google map Illustration by the author

3.2.9. Identification of Waste Management Actors

The major actors include:

- Households
- Non-residential waste generators
- Cleansing Management Agency (CMA)
- Recycling and Disposal Project Office (RDPO)
- Waste management offices at sub-city and Woreda level
- Pre-collector groups
- Private collection enterprises
- Itinerant waste buyers (known as Kurales)
- Waste pickers at the dumpsite
- The informal secondary resource market

3.3. Waste-to-Energy

3.3.1. Preconditions for waste to energy

Several preconditions must be considered before building the WTE plant. Some of the main conditions include the following:

1. Characteristics of municipal waste: Mixed municipal solid waste by its nature is different in every city. This diversity considered in any technology assessment.

2. Legal Framework and Environmental Impacts: Many countries do not have a legal framework for WTE, and it is weak or even does not exist; it includes design, approval operation, and monitoring.(GIZ,2017) An applicable legal framework has ensued, and its enforcement must be in the process of development before any WTE plant can be considered, built, and operated.

3. Financial and Institutional Aspects of WTE Plants: Most WTE plant projects are expensive, and this might be a financial risk for a municipality unless the decision-makers assess the costs and the financial impacts and implications.

3.3.2. Waste-to-Energy technology options

In this unit, an overview of following five WTE technologies at the municipal scale is provided (see Figure 17): incineration, co-processing, anaerobic digestion (AD), and landfill gas (LFG) and pyrolysis/

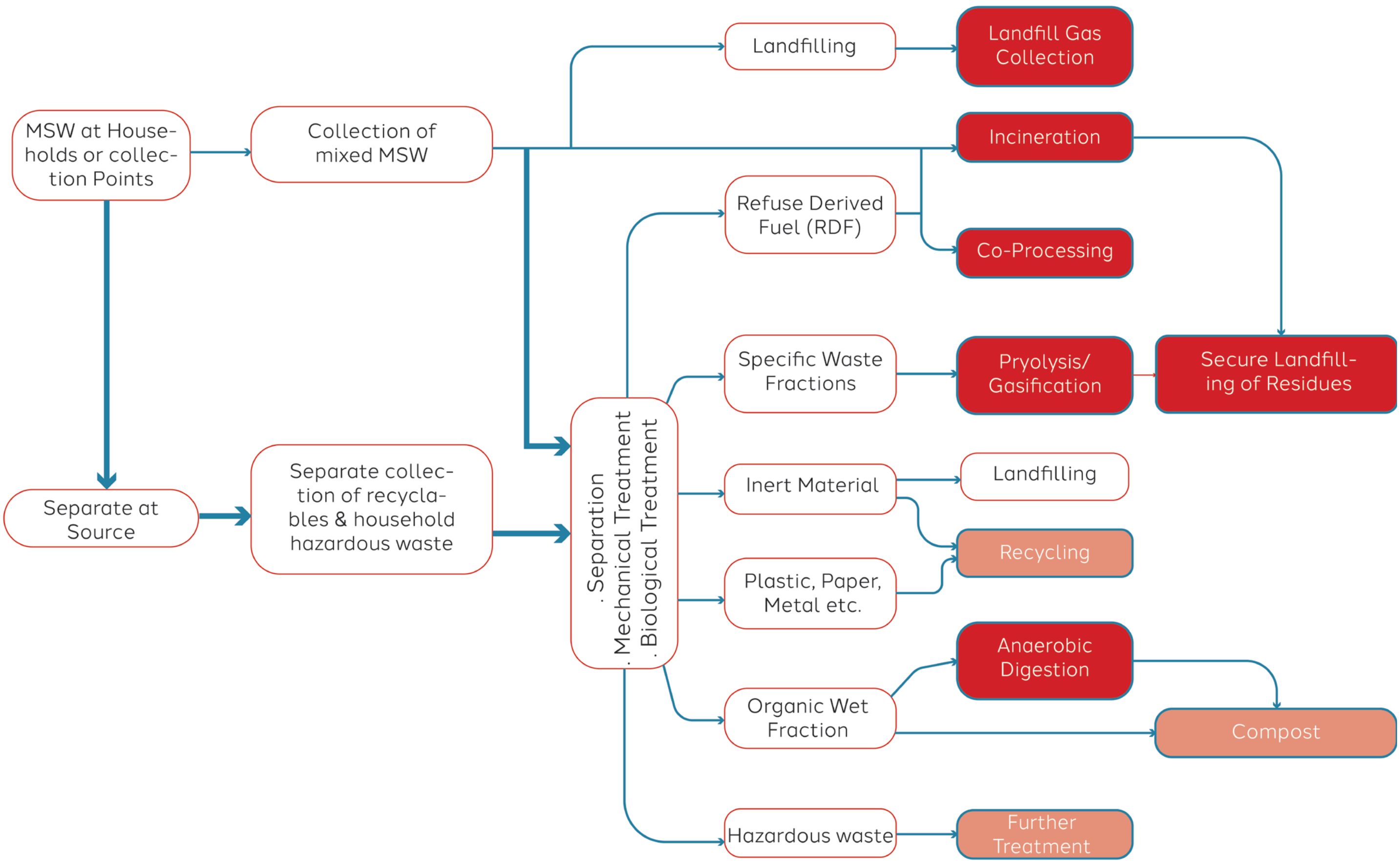
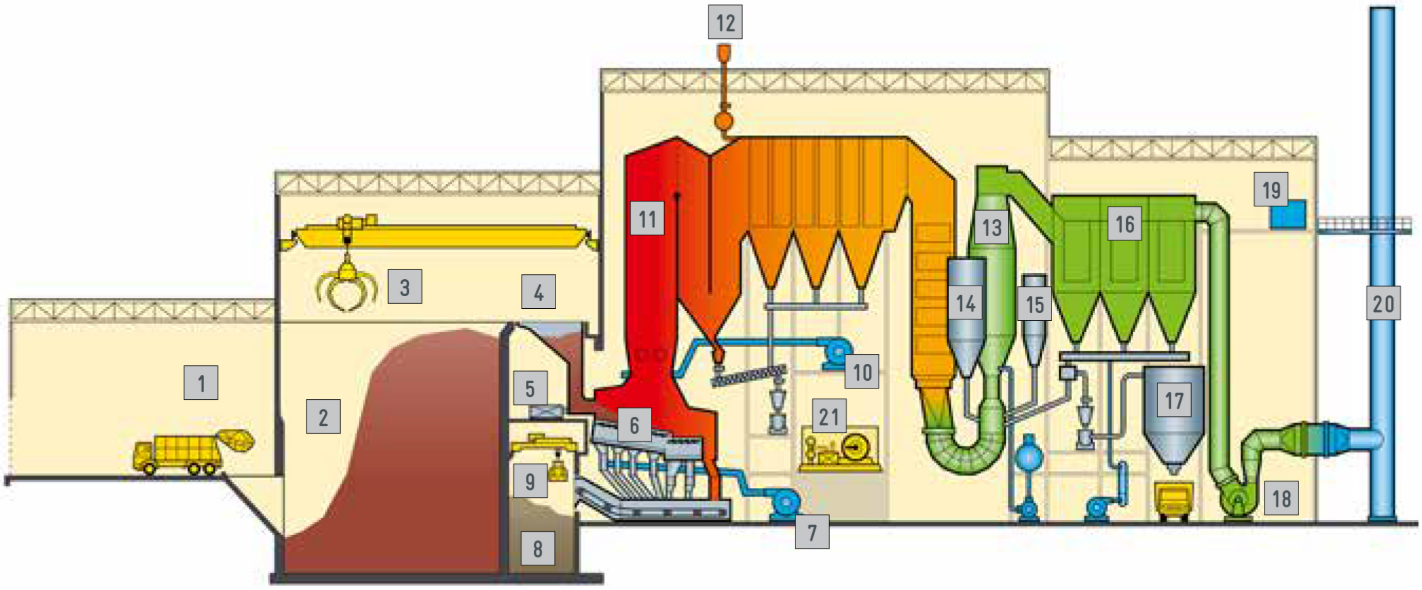


Figure 17: Over view of MSW material flow, its different utilization and treatment option

Source : GIZ ,2017

1. Municipal Solid Waste Incineration



WASTE DELIVERY

1 Tipping hall
2 Waste bunker
3 Waste crane
4 Waste feeding chute

INCINERATION

5 Ram feeder
6 Incineration grate
7 Primary air fan
8 Bottom ash bunker
9 Bottom ash crane
10 Secondary air fan
11 Steam boiler
12 Boiler safety valve

FLUE GAS CLEANING

13 Flue gas reactor
14 Hydrated lime
15 Activated carbon
16 Bag filter
17 Residue silo (fly ash)
18 ID fan
19 Emissions Monitoring System (CEMS)
20 Stack

ENERGY RECOVERY

21 Steam turbine / generator

Figure 18 : Components of a MSW incineration plant with flue gas cleaning
Source : GIZ ,2017

SUITABLE WASTES: Mixed and largely untreated domestic waste and industrial and commercial wastes.

OPERATIONAL ASPECTS: The operation of highly complex MSWI requires well-developed technical and management skills, include the location of MSWI sited in industrial parks, with short distances to waste sources.

ENVIRONMENTAL ASPECTS: The volume reduction of waste by incineration helps to save scarce and valuable space for landfills and protect the environment. It has process noise and vibration.

LEGAL ASPECTS: If comprehensive and legally binding standards are not available, these should first be developed and should follow the application of internationally recognized standards.

ECONOMIC ASPECTS: This technology requires a large capital investment, supported by the long term financial planning, and reuquires significant resources to maintain and secure the continuous operation of the plant.

SCALE ASPECTS: It is for extensive scale waste treatments.

2. Co-processing

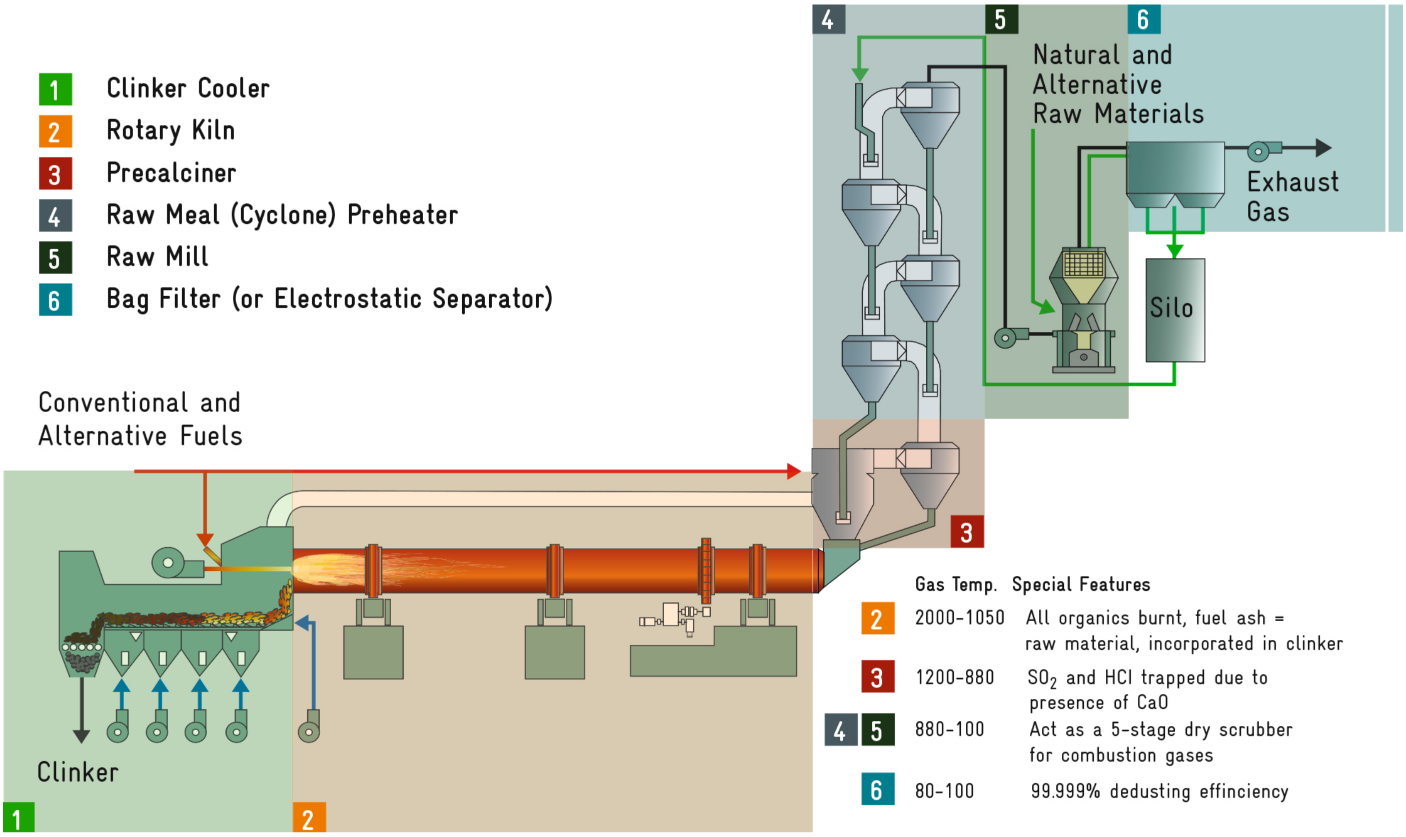


Figure 19 : Components of a cement kiln form the type pre-calciner and its special characteristics

Source : GIZ ,2017

SUITABLE WASTE: -characteristics and the type of industry where it is applied—commercial or industrial process wastes.

OPERATIONAL ASPECTS: Operational personnel adequately trained according to the specific needs and the nature of the wastes or RDF.

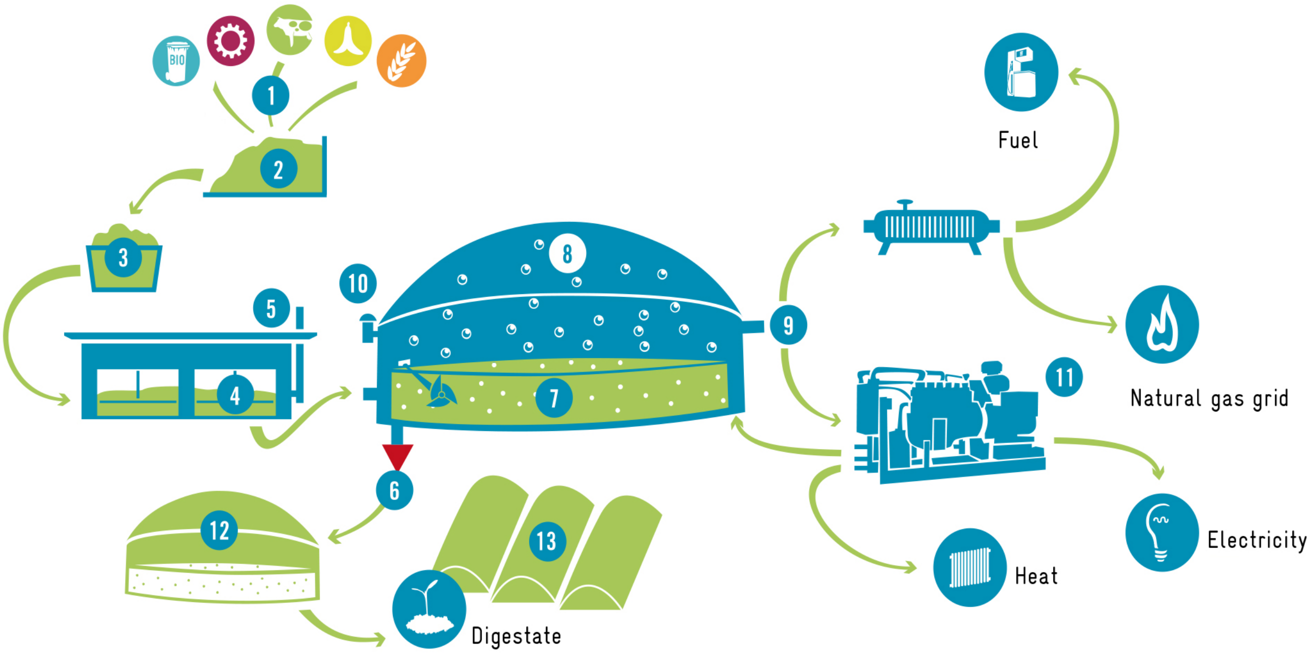
ENVIRONMENTAL ASPECTS: Potential emissions from cement kilns include dust, nitrogen oxides (NOx) and carbon oxides (CO, CO2), sulfur dioxide (SO2) as well as dioxins and furans, volatile organic compounds, hydrogen fluoride (HF), hydrogen chloride (HCI) and heavy metals.

LEGAL ASPECTS: The existence of appropriate regulation represents a precondition for successfully applying co-processing in cement kilns. Rules and regulations for co-processing should be part of the ecological and waste legislation.

ECONOMIC ASPECTS: The main objective of a cement plant operator investing in co-processing is to reduce fuel and raw material costs.

SCALE ASPECTS: It is a plug into a cement factory.

3. Anaerobic Digestion for Biogas Production



1 Different feedstocks
2 Reception and waste storage
3 Feedstock preparation, processing, sorting and cleaning
4 Enclosed building for putrescible waste preparation
5 Biofilter to reduce smells and organic compounds
6 Sanitation Unit
7 Digester
8 Gas Storage
9 Gas cleaning system
10 Safety Equipment (pressure relief devices, safety valves, gas flares etc.)
11 Combined heat and power unit
12 Digestate storage
13 Digestate Upgrading

Figure 20 : Components and end-uses of an anaerobic digestion plant
Source : GIZ ,2017

SUITABLE WASTE: AD is the only ideal for processing organic matter, i.e., biomass.

OPERATIONAL ASPECTS: Compare to other technologies it's easy to operate and mentaine.

ENVIRONMENTAL ASPECTS: The conversion of organic waste to biogas can be associated with several ecological benefits.

LEGAL ASPECTS: For large-scale AD implementation in urban contexts, additional statutory regulations have to apply, including safety regulations and concerns about odors nuisance.

ECONOMIC ASPECTS: AD has multiple economic benefits, from organic waste energy, heat and fertilizer can be produced.

SCALE ASPECTS: It can be on a small or large scale. AD has multiple economic benefits, from organic waste energy, heat and fertilizer can be produced.

4. Capturing of Landfill Gas

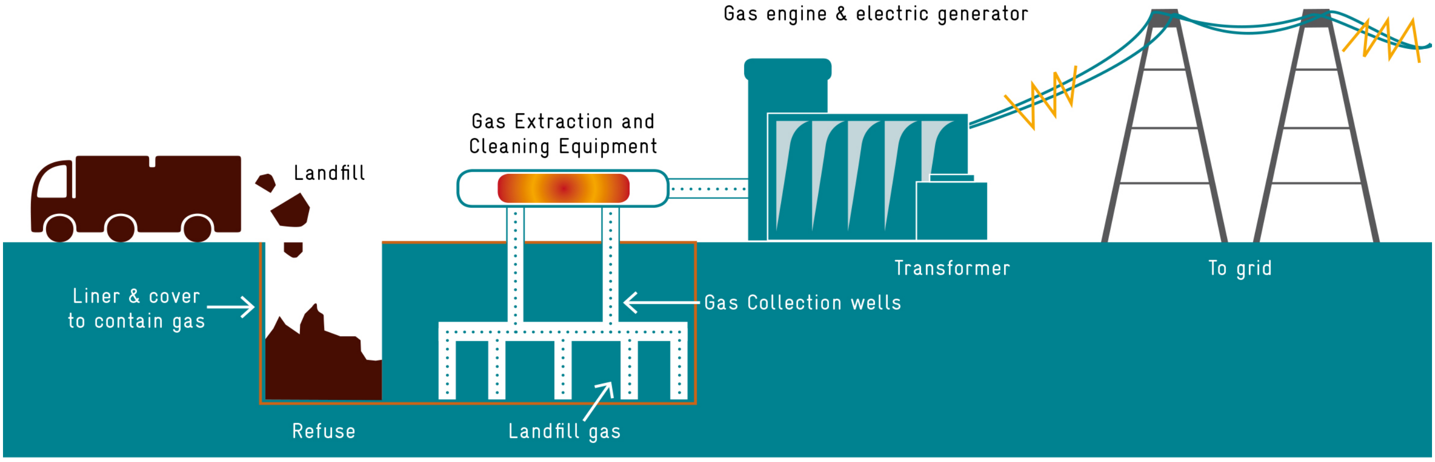


Figure 21 : Components of landfill gas capturing system with electricity production
Source : GIZ ,2017

SUITABLE WASTE: LFG capture projects require a high content of reactive organic waste in the body of the landfill. The high content of mineral waste or slow-digesting organics (e.g., wood) reduces the yield.

OPERATIONAL ASPECTS: The operators must ensure that there is no significant risk of gas migrating out of the landfill through the subsurface or accumulating outside the landfill in a mixture that could be explosive or cause asphyxiation.

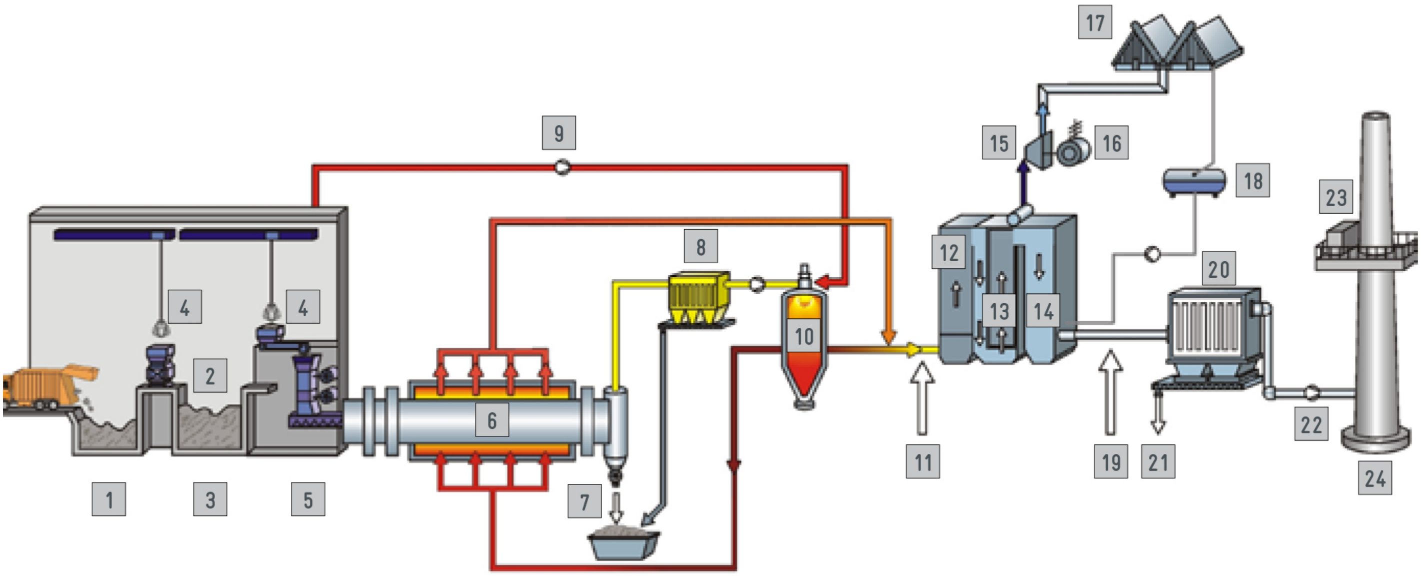
ENVIRONMENTAL ASPECTS: The collection and combustion of methane from LFG contribute to the mitigation of greenhouse gas and other toxic emissions**.**

LEGAL ASPECTS: In most countries and cases, no laws exist on landfill gas collection. This technology needs appropriate legal conditions to support its development through local waste legislation on how to operate and plan sanitary landfill sites.

ECONOMIC ASPECTS: In the scheme of the Clean Development Mechanism (CDM), many LFG capturing projects with power generation realized in developing countries.

SCALE ASPECTS: It is for large scale waste treatments.

5. Alternative Technologies: Pyrolysis and Gasification



1 Coarse Refuse Bunker	9 Combustion air fan	17 Condensor
2 Rotary Shears	10 Combustion Chamber	18 Feed Water Tank
3 Fine Refuse Bunker	11 Selective non-catalytic reduction	19 Additive Metering Hopper
4 Overhead Crane	12 Evaporator	20 Fibrous Filter
5 Feeding System	13 Superheater	21 Filter Dust Discharging
6 Pyrolysis Kiln	14 Economiser	22 Induced Draught Ventilator
7 Discharging System	15 Turbine	23 Emissions Monitoring System
8 Hot Gas Filter	16 Generator	24 Stack

Figure 22: Components of pyrolysis plant for specific solid waste treatment

Source : GIZ ,2017

SUITABLE WASTE: The suitable waste for this clinical technology waste, contaminated soil, or mono hazardous industrial/commercial waste. It not recommended for either mixed municipal waste.

OPERATIONAL ASPECTS: Pyrolysis or gasification, is difficult to handle stand-alone technologies. Operation requires a good understanding of the composition of the incoming waste and process knowledge.

ENVIRONMENTAL ASPECTS: It Recoveries the material value of the organic fraction, e.g., as methanol; Increased electrical generation using gas engines or gas turbines; Production of char or coke which used as fuel in power or cement plants.

LEGAL ASPECTS: In most developing countries, environmental legislation does not consider the application of pyrolysis and gasification as waste to energy technology, but it needs a rule and regulation for this technology.

ECONOMIC ASPECTS: Due to high operation and maintenance costs, the economics of AT considered acceptable, but the process products (gas, coke) should have a good market value.

SCALE ASPECTS: It is for large scale waste treatments.

3.4. Productive Architecture

The term and idea of sustainability have continuously shifted and metamorphosed, with more knowledge acquired through the years of increasing concern about global warming and concern for the planet. Sustainability is not only linked to the environment, but it includes the world of design, though on a larger scale than conventional buildings, to produce energy from waste, from our environment to cities and eventually the world. The definitions and tenets of sustainability often vary greatly, and everyone has a different understanding and definition of sustainability and what it encompasses.

There is a robust initial thought that sustainability first and foremost is related to buildings or that sustainability means reducing our carbon footprint. However, no one mentions eliminating that footprint. It also provokes the ideas of designing buildings that are carbon neutral, along with the issues of the reuse of materials, the locality of products used, and energy content.

It is no surprise that there is no one common idea behind sustainability as it is represented in textbook and the different ways it is taught. For architects, this is sometimes is a closed sphere. In most sustainable design methodology textbooks, sustainable design defines saving energy, recycling buildings, and creating community as a means to reduce dependence on automobiles, reduce material use, maximizing longevity, and making the buildings healthy. Problems arise due to the broadness of the final subject, in what ways do define a building as healthy? The book fails in truly addressing sustainability; it only delves into sustainable design and fails to define the difference between sustainability and sustainable design. Programs such as LEED are greenwashing for designers. LEED proves we have become complacent with our impending future environment because it makes designers feel as though they have done their part, even though they have just placed a band-aid and stamp on a building to make ourselves feel better about the damage we have done and will continue to inhibit.

"The Shape of Green: Aesthetics, Ecology, and Design, a book written by Lance Hosey define sustainability in regards to shape as "Sustainability should have style but not become a style. What designers need is not an ecological aesthetic. In essence, it is an aesthetics of ecology, a set of principles and mechanics for making the design more responsive and responsible, environmentally, socially, and economically." [4]

Hosey supports his definition with examples of the Smart Car and the Prius and touches upon three significant factors that make up sustainability; environment, society, and economics. To design sustainably, we must consider these three factors.

The way we build and use buildings affects everything we do. The built environment affects the natural ecosystem almost as much as it affects the human one. The majority of energy use, carbon, and other emissions use significant amounts of water and generate large amounts of waste that are needed by buildings and infrastructures.

To create an ecological design, we must consider aspects other than sustainable. Designing buildings without the surrounding built-up area will not give a full picture of sustainability. Achieving a full ecological design by making one building sustainable might be very complicated. Nowadays, different approaches have been introduced, one of which is called productive architecture. This approach was introduced by Kiss Cathcart Architects. It means that providing human, economic, and environmental benefits also promotes health, happiness, and inspiration. The buildings must be environmentally friendly, produce surplus renewable energy, and not generate waste that pollutes soil and groundwater.

"Sustainable means no negative impacts – a system that can continue forever. Green means something better: systems that do more good than harm. We have chosen the word Productive to represent our aspirations, because it means positive impact, like Green, but also includes human and economic productivity." [5]

Productive architecture includes the belief that ecological architecture must also be economical. The other working principle to achieve productive architecture is integration and multi-functionality.

[4] *Lance Hosey, The Shape of Green: Aesthetics, Ecology, and Design (Washington DC: Island Press, 2012), 28.*
[5] *(KIss+Cathcart, 2019)*

"An essential part of the high-performance design is multifunction, where one element of design serves more than one purpose. Integrated design much-discussed but the rarely-implemented process. Where all disciplines, systems, and components of buildings considered together because the performance of one considered as part of the performance of the whole, and vice versa."[6]

Integrating the landscape is also one of the principles to achieve productive architecture. By 2030, urban areas will be inhabited by 60% of the global population (UN, 2016).While cities offer opportunities for living with a low ecological footprint, they suffer environmental problems, such as pollution, noise, and remoteness from nature. Integrating plants into the urban fabric improves these qualities of life issues while offering many innovative opportunities for 'green' architecture.

The following section presents a summary of selected international case studies that show the productive architecture approach on the WTE plants will present.

3.4. International case studies

3.4.1. ARC, Copenhill/ Amager Bakke, Copenhagen, Denmark

Figure 23: Amager Bakke waste to energy plant
Source : www. Archdaily. com

Project Information

Client: Amagerforbraending
Collaborators: Realities United (smoke ring generator), AKT (facade & structural consulting), Topotek 1/ manmade land (landscape)
Size: Building 95,000 m2, landscape 90,000 m2, and roof + ski slope 32,000 m2 facade area: 74,000 m2 administrative + visitor center floor area: 6,500 m2
The building measures: 200 m in length, 70 m in width, 124 m in height, including the stack.
Partner in charge: Bjarke Ingels, David Zahle
Project leader: Brian Yang
Team: Jelena Vucic, Alina Tamosiunaite, Armor Gutierrez, Maciej Zawadzki, Jakob Lange, Andreas Klok Pedersen, Daniel Selensky, Gül Ertekin, Xing Xiong, Sunming Lee, Long Zuo

[6] *(KIss+Cathcart, 2019)*

HUMAN TERM

This WTE plant will give several uses for the people of Copenhagen, including heat, electricity, and water from their waste. In addition to the technological merits, the architecture of the plant includes a roof-wide artificial ski slope open to the public.

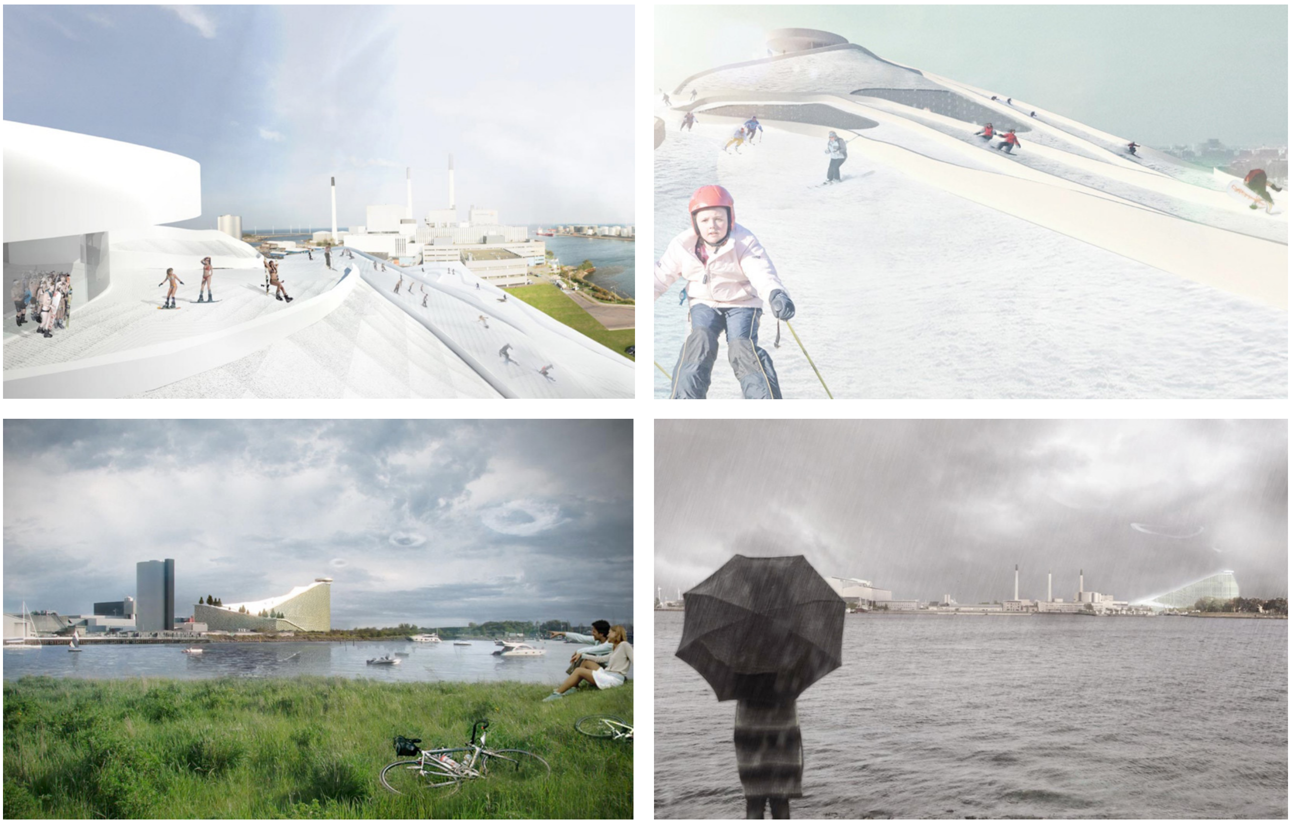


Figure 24: Amager Bakke waste to energy plant different view and human activity
Source : www. Archdaily. com

ENVIRONMENTAL TERM

The plant utilizes more than 100% of the fuel's energy content, and it has a 28% electrical efficiency rate, reduces sulfur emissions by 99.5%, and minimizes NOx emissions to a tenth, compared to the other plants in Copenhagen. The NOx-reduction was enabled due to a flue gas cleaning technology, selective catalytic reduction (SCR), which we will install in cooperation with the catalyst manufacturer Haldor Topsøe. This is the first installation of SCR in a Danish WTE plant. Hence, ski enthusiasts need not worry about the air quality at the slope on the operating plant.

Figure 25 : Amager Bakke waste to energy plant projected laser light on smoke ring illustrating, in pie chart form, the quota of fossil CO2
Source : www. Archdaily. com

ECONOMY TERM

The plant take 400,000 tons of waste a year and in result:
It produce energy which is 99% energ efficiency,
It produce heat for 160,000 households.
For 62,500 households it produce electricity.
in addition to all thouse it produce 100 million litres of spare water which is recovered through flue gas condensation.
90% reuse of metals from waste amounting to 10,000 tonnes of metal a year.
100,000 tonnes of bottom ash reused as road material which saves large amounts of gravel.

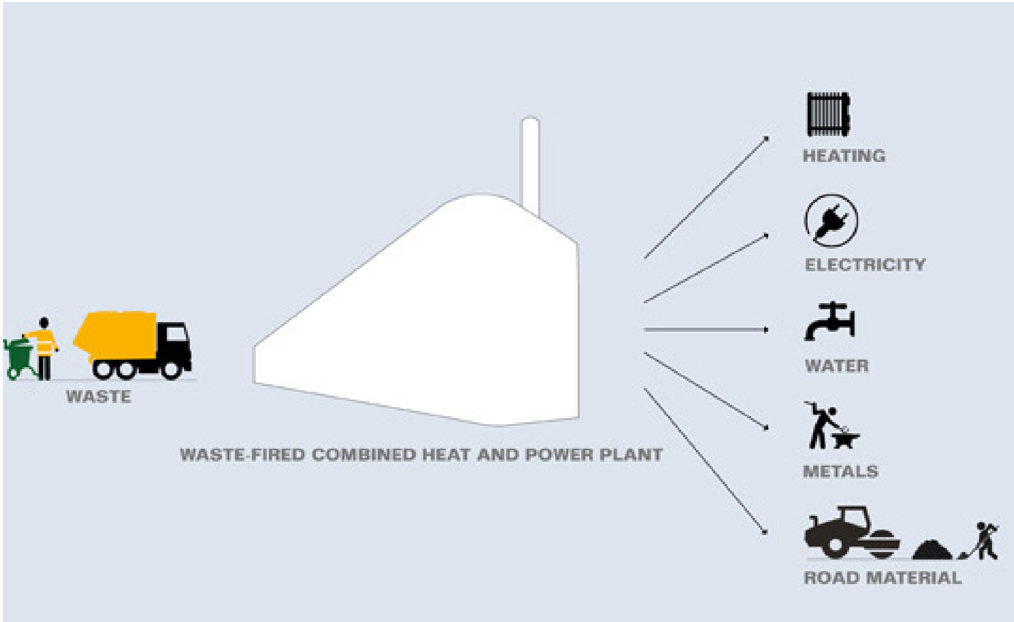


Figure 26 : Amager Bakke waste to energy plant different outputs
Source : www. Archdaily. com

ARCHITECTURAL TERM

The plant considers the local context: situated on an edge condition – factories on one side, housing on the other; the city of Copenhagen on one hand, the water and island of amager on the other – the location receives very few visitors simply by the lack of identity and purpose the site possesses.

Figure 27 : Amager Bakke waste to energy plant Interior spaces

Source : www. Archdaily. com

The design of a factory-ski slope hybrid aims to mobilize the architecture and intensify the relationship between the building and the city, creating a destination in and of itself.

By integrating the height of the smokestack into the overall form of the architecture, an artificial slope is created. Public connection is created by pushing down one corner of the building, associating the street with the roof line/ski run. Measuring a total distance of over 1,500 m, three different pistes are made from the geometry of the roof scape.

Two large ‘sky light’ apertures in the roof also provide a transparent look into the inner workings of the waste treatment plant.

With the intention of raising awareness for sustainable energy, the design proposal includes a modification to the smokestack that will release smoke rings into the sky. Activated whenever one ton of fossil CO2 is released, the signal will serve a communicative function and remind the viewer of the impact of consumption.

FAÇADE

The façade covers 26,000m2 and it made of two layers:

1. A base layer of 1.5 tonnes sections, measuring 10m x 2.5m, and
2. A second brick layer, which serve as a visual element only.

Figure 28: Amager Bakke waste to energy plant Facade detail

Source : www. Archdaily. com

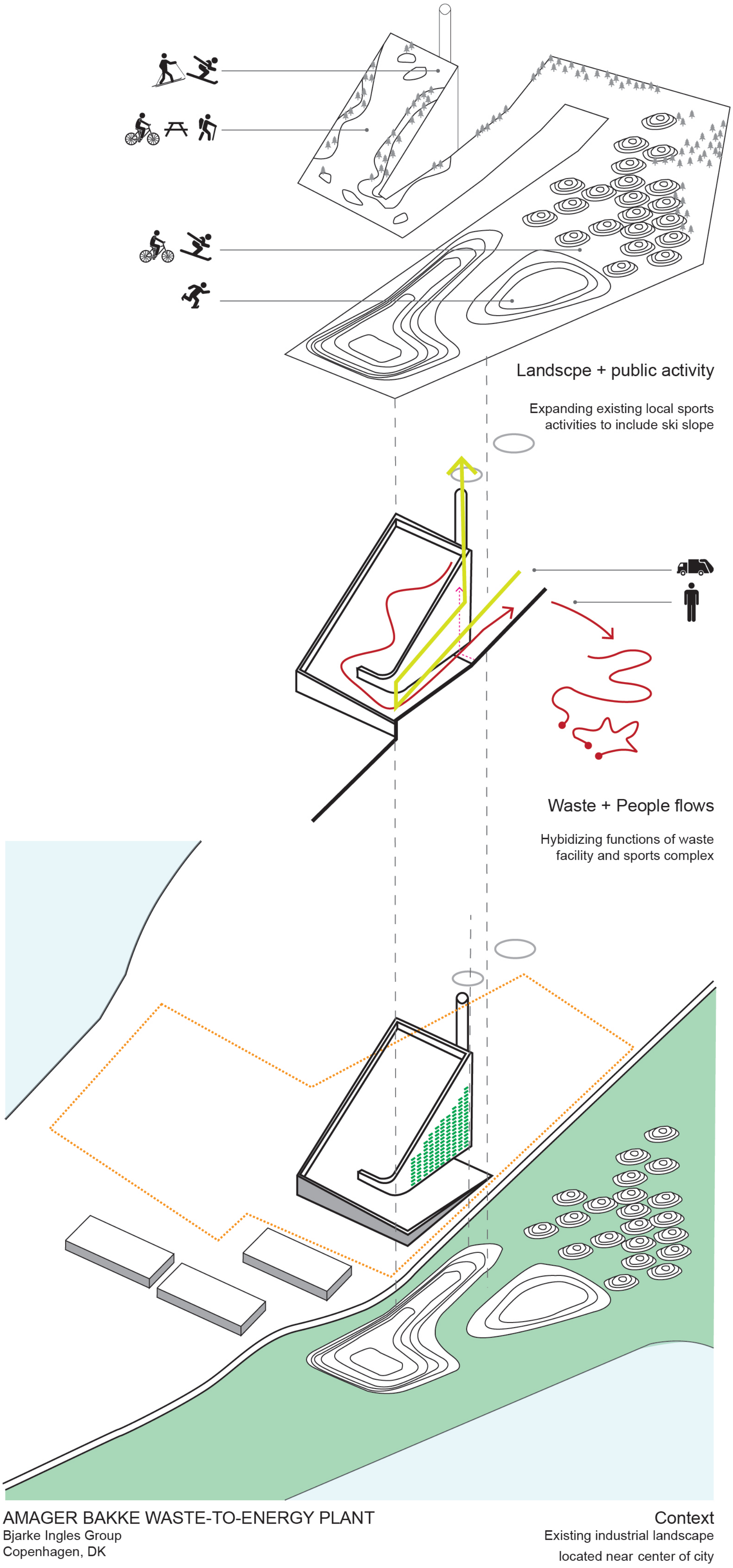


Figure 29 : Amager Bakke waste to energy plant People and waste flow diagram

3.4.1. ECO PARK

Figure 30 : ECO PARK waste to energy plant

Source : www. Archdaily. com

Project info:

Architect: Abalos & Herreros
Location: Barcelona, Spain
Engineer: Obiol, Moya y Asociados/ PGI Group
Clinte: Ajuntament de Barcelona
Completion Date: 2004
Setting: Industrial and Recreational Surroundings
Site Area: 179,000 sqm
Building Area: 12,000 sqm
Waste Throughput: 260,000 tons per year
Energy Generation: 164,580 MWh per year

HUMAN TERM

This waste to energy plant will give several uses for the people of Barcelona. Beside generating energy it serve as a city eco park.

FIgure 31 : ECO PARK waste to energy plant
Source : www. Archdaily. com

ENVIRONMENTAL TERM

In the final bend of the city, whence it had relegated the most polluting services and installations, next to a rundown area, it is now thought to create one of Barcelona’s most extensive natural public spaces. And, simultaneously, to install a number of services for energy supply, waste recollection and treatment, water storage, collectors, gas mains, etc., Plus extending the former incinerator so as to include a recycling plant and an eco-park, all this converted into an emblematic political operation, an expression of the sensitivity towards environmental issues and cultural admixtures that gives content to the urban intervention into which this project is inserted (Forum, 2004).

ECONOMY TERM

The plant gives an income to the city adminitiration by seling the electric and hit to the city.

ARCHITECTURAL TERM

The strategy for the projected complex starts from actualization of the techniques of pintorescism, the construction of new multiple and intricate experiences in which the natural components –sea, wind, sun, beach, lawn, dunes, mountains, plantations- are used as a material of construction and the different artificial components create geographic accidents, articulated by circulation and stay system which crosses the complex and links it to the city, the Mediterranean and the pre-existing industrial landscape.

Figure 32: ECO PARK waste to energy plantroof park
Source : www. Archdaily. com

The resulting conglomerate is the construction of a crossbred landscape that we consider an expression of cultural complexity which today is required by the notions of nature and public

In the remotest point from the sea, next to the Carrer Taulat, the entrance to the complex is created by a valley that is the result of the construction of an artificial mountain and landing. The mountain protects the complex from the traffic noise of the coastal ring road. Its interior contains various technical systems and climbing on top of it, it permits contemplating simultaneously the park, the sea, and the city. The landing contains the recycling installations involving the former incinerator and connecting the whole with a single building made out of blue polycarbonate which emerges polarizing all the looks, materializing the first layer that filters the more aggressive industrial sight from the park.

The complex is built with a screwed steel structure creating a big air-conditioned hall. A system of galleries for guided visits is superposed. A service building which contains offices, environmental lecture room and an exhibition center in which the energy producing process is explained, complements the installation.

Not only the program – associated with recycling and new ecological sensibilities – but also by the constructive design – implemented recyclable industrial materials, minimized details, green roofs, energetic auto-sufficiency – and the parallel program – exhibition center, aula, viewing platform … – turn the project into a public investigation about sensibility and its “politic” use of the infrastructures.

It is a singular proposal, an observatory which through its program –industrial, tertiary and cultural- permits to establish bridges between cultural and landscaping contexts, between natural and artificial, making the surrounding territory comprehensible: a privileged point, the most extroverted element of the garden from where the city looks at itself.

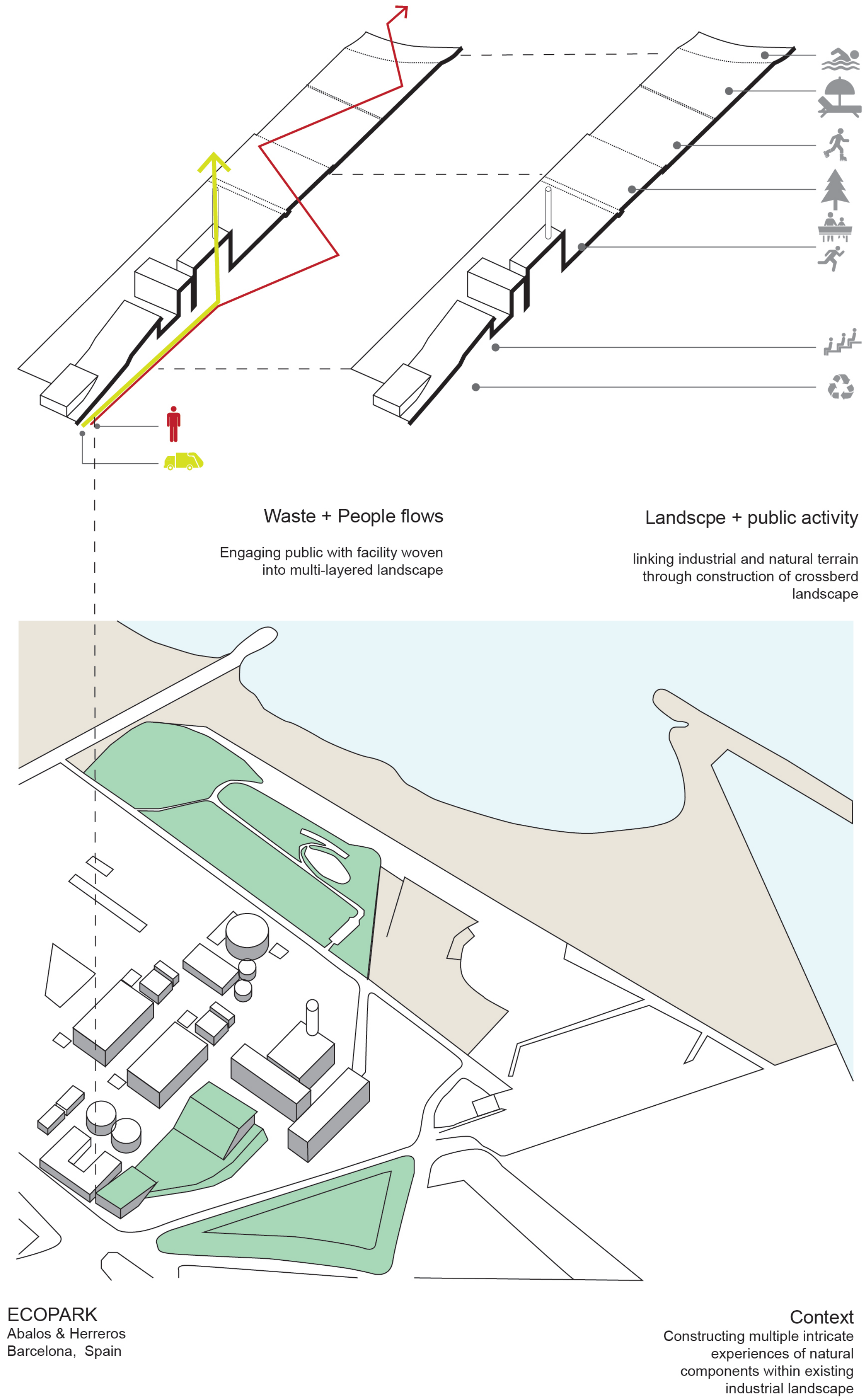


Figure 33: ECOPARK waste to energy plant People and waste flow diagram

3.4.3. Germany's Bio-energy Village

Figure 34: Jühnde, Germany Bio-energy Village
Source : www. Archdaily. com

The first village in Germany to be officially recognized as a bioenergy village was Jühnde, in the state of Lower Saxony. In 2005, a cooperative within this village of 780 inhabitants and 450 cows built a biogas production facility fueled by silage plants and manure. The gas from this plant is burned in a communally owned cogeneration plant that provides electricity and heat to buildings in the village. Eventually a wood chip-fired boiler was added to the district heating system to provide supplemental heat.

HUMAN TERM

At least 50% of the community's energy needs (electricity and heat) are supplied by locally produced bioenergy (typically silage plants and/or wood chips)
Local citizens are actively involved in developing the ideas and making the decisions
The biomass used as a resource is owned at least partially by the villagers, and is grown and harvested locally, in a sustainable manner
Other renewable energy sources may supplement the generation of power and heat from biomass
Energy efficiency and energy conservation measures are regularly considered and implemented
Value is created locally, and the benefits extend regionally

ENVIRONMENTAL TERM & ECONOMY TERM

Every year, thousands of visitors descend on Jühnde to be educated and inspired. These days the town produces over twice as much electricity as it consumes. The citizens are now participating in an electro-mobility pilot project that is exploring ways to use the excess power to serve local transportation needs.

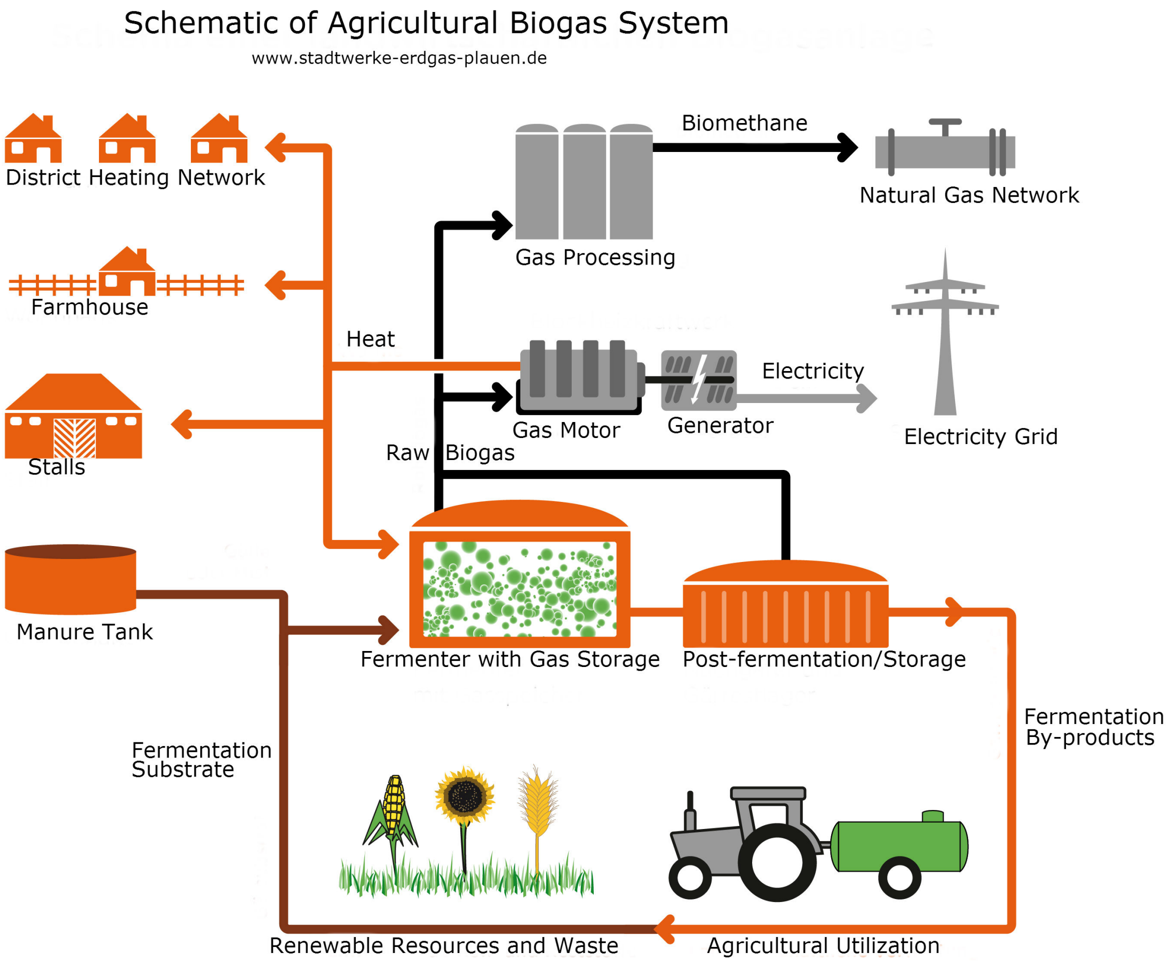


Figure 35: Jühnde, Germany Bio-energy Village system

Source :

Figure 36: Jühnde, Germany Bio-energy Village Plant photo

Source :

CHAPTER FOUR
FINDINGS & DISCUSSION

4. Findings & discussion

4.1. SWM in Addis Ababa

In general, awareness of the environment is quite low in Ethiopia. Both the benefit of taking care of the environment and the harm of neglecting the environment are not known. The people have fallen into the habit of dumping waste in the rivers, fields, drains, and ditches, largely because this is the only known approach to dealing with waste. The harmful impact of such disposal is not widely known or understood. The concept of taking responsibility for the city in the same manner that they take care of their homes is missing in society.

The society has not yet perceived the holistic image of the city and the country. Each individual is a stakeholder in the well-being of one another and the country as a whole. Both correct and incorrect actions of a given individual will affect everyone else since the environment is a system where everyone connected in a chain. Moreover, the idea of using waste as a potential resource is not familiar. Waste is known to be rubbish and useless. The well-imbedded approach is to simply get it out of sight. Changing such a habit in a manner that leads people to be responsible for disposing of waste in an environmentally-friendly manner and viewing waste as a resource is challenging, largely because habits are hard to break.

The IGNIS research and project did revolutionary work in the waste management sector in Addis Ababa. The findings and observations are dependable because they were based on reliable data and practical implementation of projects. The data collection method developed for this project can be used in the future and for other related projects. This thesis paper took many data from the IGNIS paper.

From the data found in previous research, the type of the Addis's waste is organic waste generated at the household level. Currently, all the waste is disposed of in the Koshe or Reppi landfill area. Dumping food waste or organic waste to landfill generates methane, which is a particularly potent greenhouse gas that causes climate change. A solution to waste management challenges is to develop programs that decentralize waste management, where the garbage is taken care of locally in or close to residential areas.

4.2. Productive architecture and SWM

The issue of waste is not commonly associated with the field of architecture, though it shapes the place we inhabit. Most of the industrial buildings are taken to the periphery and not associated with society. The built environment that contains the activities of waste management often removed from the public eye. Moreover, there is a lack of environmental and economic motivations, and it is hard for the public to understand and embrace advances in technology for WTE functions.

The building can be more productive and multifunctional for society so that it can be used to shape our cities, especially if it is based on Kiss Cathcart Architects' definition of productive architecture (i.e., building that produces positive benefits on human, environmental, and economic levels).

Primarily industrial and factory buildings should get more attention, and since they occupy a massive amount of land and money, the building designs need to be "regenerative", meaning that we must contribute to biodiversity with our designs. This approach creates systems that can co-evolve with us, generate mutual benefits, and create an overall expression of life.

4.3. Anaerobic Digestion Technology

Based on the literature review about the existing technology, anaerobic digestion (AD) is appropriate for the case of Addis Ababa. AD technology has many benefits and addresses a broader range of stakeholders, from the small local community, farmers up to the government. It is considered to be the optimum method for handling food waste in an environmentally-friendly way.

4.3.1. AD Benefits

Food-waste anaerobic digestion: This provides diversion to keep it out of landfills: most municipalities are investing in changing the technologies to minimize landfills to achieve recycling and sustainability targets. There may also be a reduced availability of landfill space and a need to eek-out existing landfill capacity to last as long as possible (Biogasman 2018).

Climate change mitigation: Diverting food waste from landfills to anaerobic digestion/biogas facilitates is the most effective way of capturing methane. Methane lost into the atmosphere and has less significant greenhouse gas emissions causing climate change (Biogasman 2018).

Production of clean and renewable transport fuel: Food waste is a high-calorie waste. AD makes more biogas per unit weight than almost any other biomass feedstock. There is a growing demand for biogas, which used as an energy source. Especially in urban areas, there is an urgent need to reduce air pollution from transport vehicles. Methane (Biogas) burns clean, producing very low air pollution abd methane is used to power transportation vehicles, especially in substantial air-pollution cities (Biogasman 2018).

Economic benefits: Running AD facilities can produce good profits under the right regulatory regimes. These include reduced energy costs due to the production of on-site power and tipping fees for accepting food waste. Many nations have introductions, and it should be possible, where there is a landfill tax, to attract food waste as a profitable gate fee, just below the gate fee cost of landfilling (Biogasman 2018).

Farm soil quality improvements: AD results in the output of a liquid and fibrous fertilizer (digest). This fertilizer is used on the land and can be instrumental in restoring the micro-structure of soil and recycling vital nutrients, such as phosphorus. The use of chemical fertilizers on farmland tends to degrade soil quality. In many countries, soil quality has become dangerously low. Especially in our country, the demand for fertilizer is high, and it is one of Ethiopia's most imported products. Many predict that soil quality over vast areas will soon cease to support crop productivity within the foreseeable future unless soil improvement is achieved (Biogasman 2018).

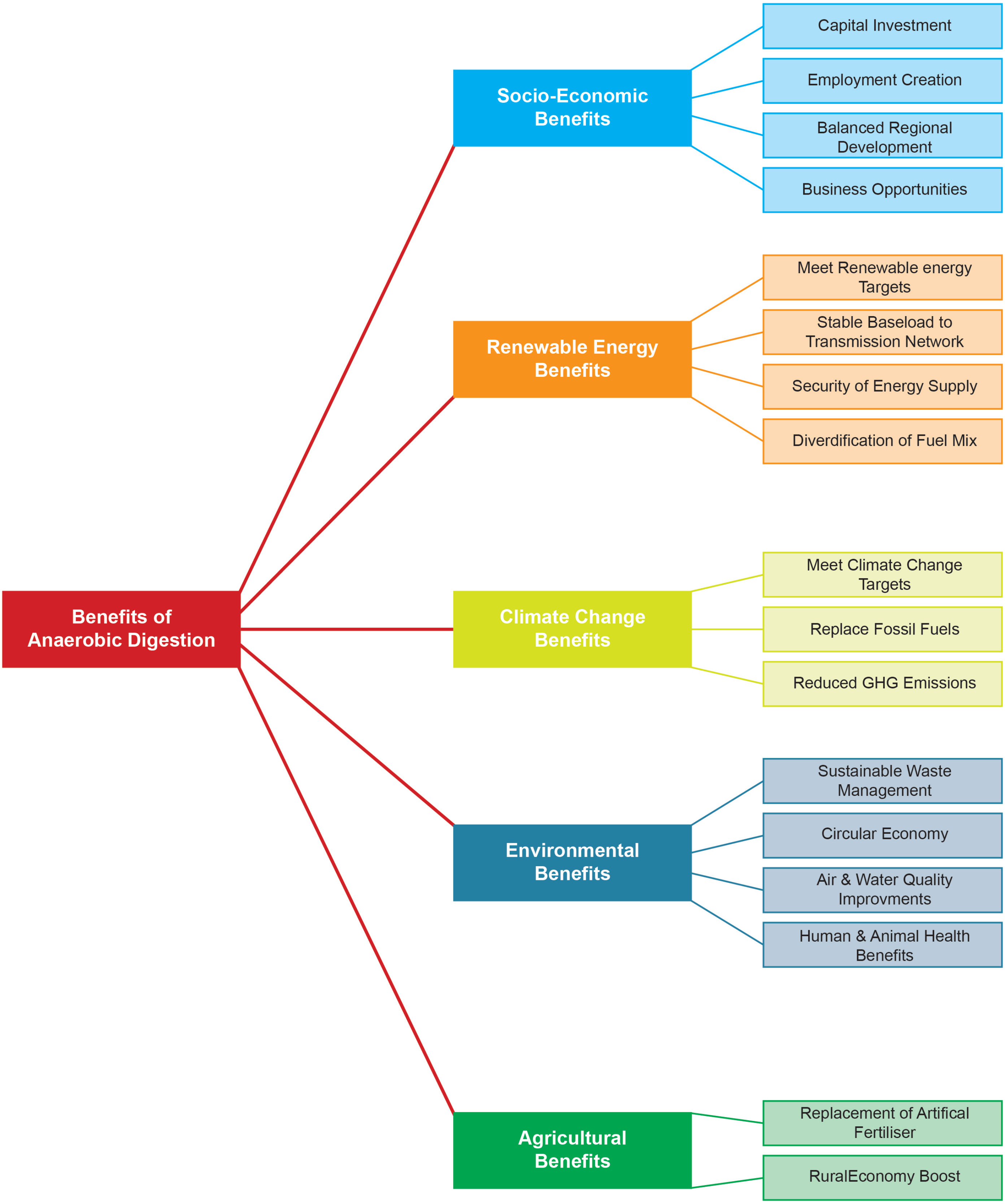


Figure 37: Benefits of AD Illustration by the author

4.3.2 Scale of an AD plant

The scale of an AD plant different based on the feedstock and the different technology choices. The size and production of energy production stated in table 5 below. On the table 6 mainly see the significant difference between small and large scale AD.

Table 5 : Size and application of AD plant

Size	Approximate tonnage	Approximate energy production	Typical application
Small	Up to 7,500	25-250 kw(e)	Household or farm
Medium	7,500 – 30,000	250kw – 1mw(e)	Farm or manufacturing facilities production digestible waste
Large	30,000 or more	>1mw (e)	Centralized, mixed feedstock sources(municipal, commercial & industrial)

Source : Global Methane Initiative, 2016

Table 6 : Different between Small and large scale AD

Small-scale AD	Large-Scale AD
On-site waste management	Municipal sources of feedstock
Low to no transport cost	Feedstock delivered to site as a source of income
Rural locations	Centralized facilities
Can attract higher subsidies	Subsidies may be available
Can offer simple design and maintenance	More complex design and maintenance

Source : Global Methane Initiative, 2016

4.3.3 Suitable site selection

The location of the plant will be determined predominantly by capacity, feedstock availability, and planned output use.

- Small-scale AD plant facilities are generally suitable for rural development areas (e.g., farms)
- Large-scale, centralized AD plant facilities are more suited to commercial/industrial urban areas
- Facilities co-located with existing infrastructure (e.g., heat users, other waste treatment facilities)

4.3.4 Feedstock

AD plant can treat a wide range of organic materials, but it is essential to understand the feedstock available for the digester.
Key issues to consider:

- Source – From where is it coming?
- Composition –what is it made of?
- Variability –how variable is it?
- Contaminants and rejects –will it contain contaminants that will harm the AD process?
- Storage –how will it be stored?

- Seasonal fluctuation -will the feedstock vary through the year?

4.3.4.1. Feedstock composition

Feedstock varies in composition and should be carefully selected:
- Variable composition
- Bacteria require nutrients

Composition includes:
- Dry solids (DS)
- Volatile solids (VS)
- C: N (carbon to nitrogen ratio)

Feedstock can cause damage to AD plant equipment. There are components not suitable for an AD treatment plant. Those include
- Inorganic wastes (e.g., glass, plastics, metals and sand), wastes like wood and bones, Soil
- Disinfectant, pesticides, and antibiotics in feedstock

4.3.5 AD process configuration

There are several different process configurations around which AD systems designed. Factors to be considered when making design decisions include whether the process is 'batch' or 'continuous' feed, whether it is a 'dry' or 'wet' system, whether it is a 'single stage' or 'multi-stage' process and whether the anaerobic digester operated at 'mesophilic' or 'thermophilic' temperatures.34

For AD plant process, a series of technologies are employed:
- Pre-treatment
- Digestion processes
- Digestion storage
- Biogas storage
- Biogas clean-up/up-grading

Pre-treatment of Feedstock

Pre-treatment is necessary to ensure process efficiency, maximize product yield, and reduce operating costs. It used to homogenize the feedstock and to remove non-biodegradable materials.

Pre-treatment method has different types:

Physical: thermal, electrochemical, mechanical, ultrasound,
Chemical: oxidative, alkali, acid
Biological: microbiological, enzymatic
Combined process: extrusion, thermochemical

Pre-treatment can be a significant step in an AD process. The requirements vary depending on the feedstock:

- Contaminants must be separates; for example, through screening, trommels, and magnets
- The feedstock usually macerated to create the right consistency
- A pasteurization stage required for particular feedstock.

Table 7 : Different between Small and large scale AD

Feedstock	Pre-treatments
Separated food waste	De-packaging may be required depending on contamination levels
Manures/slurries	Minimal pre-treatment required, usually used with other feedstock.
Commercial & industrial wastes	De-packaging is required to remove plastics and metals. Often highly contaminated so screening is also required. Effluents require minimal pre-treatment.
Energy crops	Screening to remove stones, cutting or shredded. Silage is usually pre-shredded.

Source : Global Methane Initiative, 2016

AD processes characterized by the following:

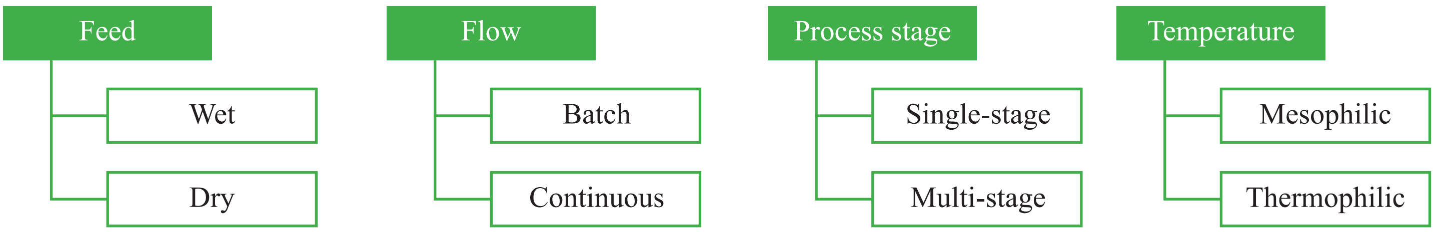


Figure 25: AD process type

Digestion Process: Feed

Wet
- <15% dry solids
- Waste macerated before processing
- Examples include food waste, manure, and slurry

Dry
- Higher dry solid content 15-40%
- No water addition
- Less mechanical treatment
- Examples include green wastes and energy crops

Digestion Process: flow

Batch
- The digestion process, or a stage of the digestion process, is allowed to start and finish in a single vessel.
- Once complete, the vessel emptied, and the process restarted with new feedstock.
- A series of vessels may be used to overcome peaks and troughs inflows of feedstock and gas production.

Continuous

- Feedstock flows through the plant continuously.
- Avoids the need to empty digesters and restart the process –a labor-intensive and time-consuming process.
- Biogas generation tends to be more consistent, although biogas generation rates may be lower than for batch processes.

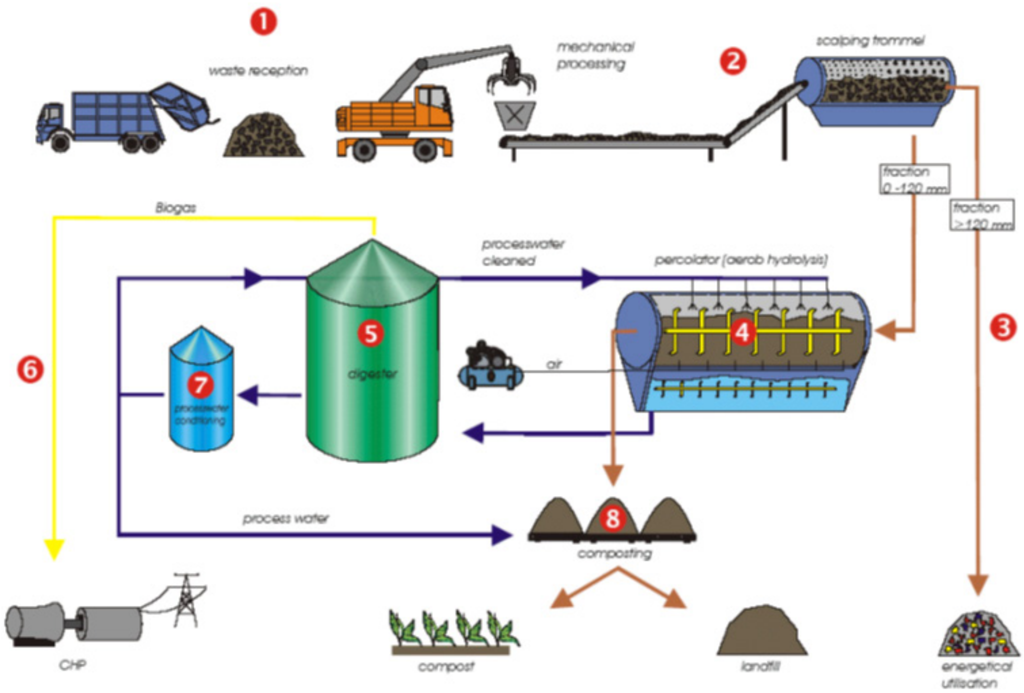


Figure 38: AD process
Source: Global Methane Initiative, 2016

Digestion Process: Process stages

Single-stage process
Digestion occurs in a single reactor
The plant design is more straightforward and more economical
Produces less biogas
Feedstock takes longer to digest

Multi-stage Process
Two or more reactors to optimize the process
Helps to degrade feedstock further
Extracts more biogas
Common Digester Types for treating MSW

Table 8 : Digester type and type of feedstock with typical scale

Digester type	Typical Scale	Typical Feedstock
Continuous, flow solids, single-stage	Large and small	Slurries, effluents (e.g. from the dairy processing)
Continuous, high solids, single-stage	Large	Green waste, food waste
Continuous, low solids, multi-stage	Large	Food waste
Batch, low solids, single-stage	Small	Slurries, effluents, food wastes

Source : Global Methane Initiative, 2016

4.3.6. Affordability

Costs are variable and specific to the project. As with many waste technologies, there are economies of scale. Costs are dependent on:

Feedstock
Pre-treatment
Configuration
Output treatment
Location

Economic Considerations for AD Projects
Accurately predicting costs and revenues remains challenging due to few projects operating in developing countries.

- Local factors vary (e.g., tipping fees, labor costs, site conditions)

Costs to consider:

- Predevelopment: siting, permitting, planning and design, and environmental impact assessment
- Construction: infrastructure, buildings/reactors, equipment, and labor
- Operations: maintenance, manager training, labor, materials, water and energy, wastewater disposal, solids disposal, and other fees
- Costs savings possible if incorporated with existing waste management facilities (e.g., co-located at a landfill)
- Economies of scale apply
- Maximizing all revenues is critical (energy, tipping fees, secondary products, and incentives)

Typical Technology costs

Table 9 : Technology cost comparison

	Capital	Operational
Thermophilic	$$$	$$$
Mesophilic	$	$
Wet	$	$$$
Dry	$$$	$
Continuous	$$$	$
Batch	$$$	$
Single stage	$	$
Multi stage	$$$	$$$

Source : Global Methane Initiative, 2016

Operational Expenses
As with capital costs, operational expenses (OPEX) are varied and depend on the scale, location, system configuration, and product utilization. Typical costs include:

Utilities
Staff costs
Effluent disposal
Mobile plant hire/running costs (e.g., front loaders)
Permit/license fees
Insurance

Consumables
Disposal of rejects
Health & safety (e.g., signage)
Facilities (office, telephone)
Digestate transport costs
Gas cleaning/upgrading
Life-cycle –maintenance

Partnerships and Stakeholders

Developing an AD project in partnership with relevant stakeholders can help ensure the success of the project:

- Feedstock producers –farmers, food manufacturers, local authorities/municipalities
- Landowners
- Local communities
- Energy companies
- Heat users –leisure centers, hospitals
- Investors –banks, private investors

4.3.7. Environmental Issues

To build and operate an AD facility, the designer has to consider environmental legislation. An environmental permit(s) may be required from the relevant regulatory body.

An Environmental Permit sets out rules must follow to prevent damage to the environment and human health.

Potential environmental impacts
- Odor–feedstock can cause odorous emissions; these can be managed through an odor management plan and suitable control and abatement techniques (e.g., inside storage)
- Water emissions –runoff from wastes stored outside, the site must be bounded to prevent leaks in the event of tank failures
- Bioaerosols–can be emitted from storage areas
- Air emissions from burning biogas (compared to fossil fuels)
- Proximity to sensitive receptors
- Potential litter if waste is contaminated

Potential environmental benefits
- Reduces reliance on fossil fuels
- Diverts waste from landfill
- Reduces GHG emissions
- Provides a valuable fertilizer/soil improver
- Reduces reliance on chemical fertilizers and associated production emissions
- Can reduce odor intensity of waste
- Reduces pathogens
- Reduces weed seeds

4.3.8. Critica

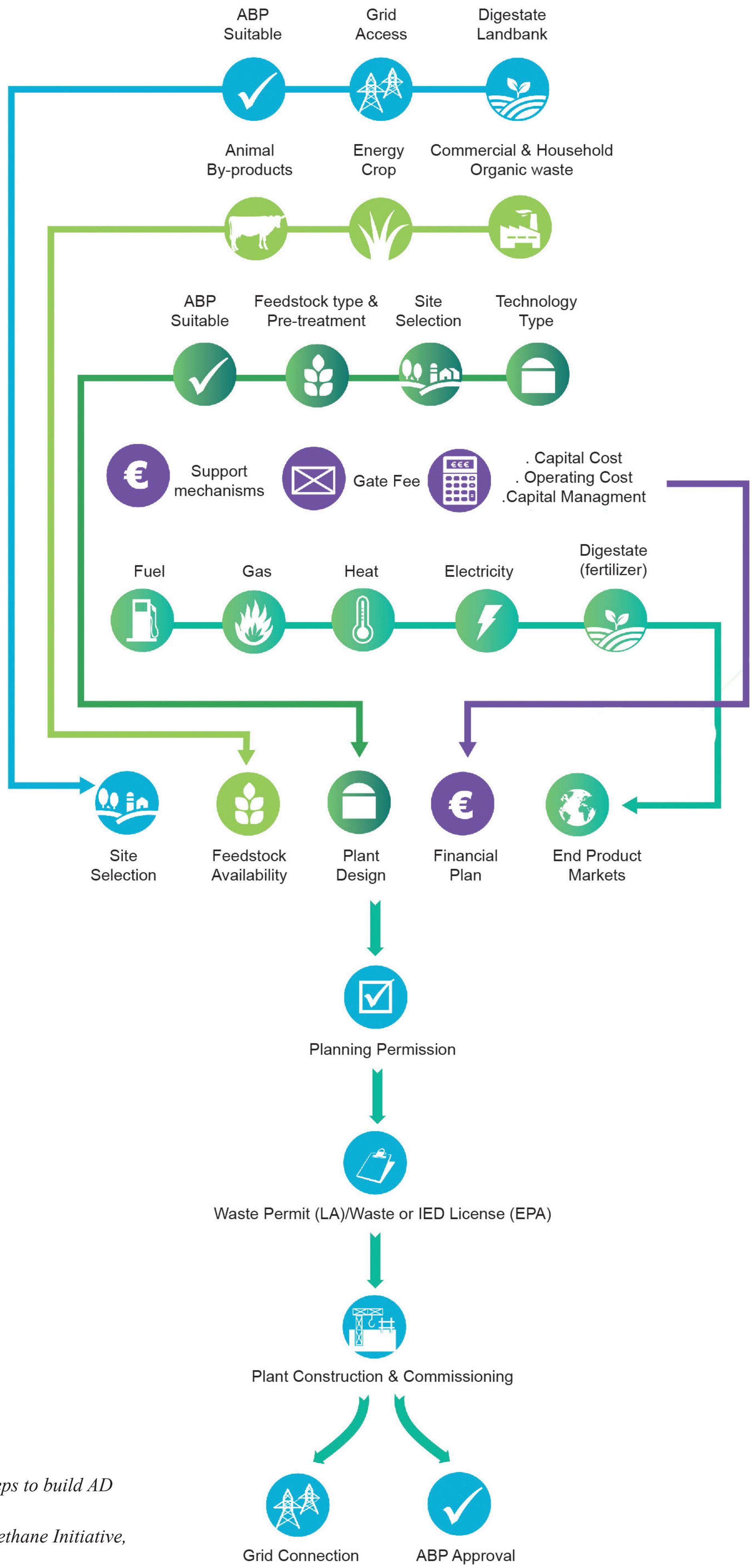


Figure39: Key steps to build AD plant

Source: Global Methane Initiative, 2016

PART TWO

CHAPTER FIVE
RECOMMENDATION

5. Recommendation

5.1. Improved Solid Waste Management

- The present solid waste management system, with its low rates of collection and treatment of wastes, could be greatly enhanced by a complete overhaul. Segregation of waste at the source with adequate storage capacity in the area of waste generation should be considered. This can achieve with the involvement of all relevant stakeholders, such as the waste generating entities or communities, informal waste pickers, recyclers, local municipality officials, and private agencies.

- Given the performance of anaerobic digestion, the plant is mostly influenced by the appropriateness of feedstock material and its homogeneity, while appropriate segregation and pre-treatment should carry out. Laws and norms regarding SWM are already in place, though their implementation is inadequate. Appropriate monitoring mechanisms have to be implemented.

5.2. Market Formation

- A steady market for biogas and manure obtained from anerobic digestion (AD) should be established so that projects are economically feasible. Biogas generated from such operations can be consumed by the institutions that set up AD plants in their areas, such as social housing, commercial areas, large hotels, and office complexes. Appropriate incentives and rewards should be put forward by the municipal authorities for setting up decentralized AD units for organic waste treatment. For projects on a large scale, generating higher quantities of biogas and manure, arrangements for procuring this output by state oil and gas and fertilizer companies should be established.

- Entrepreneurial activity in the biomethanation sector is limited due to the need for initial funding and capital assistance.

5.3. Awareness Generation

- Awareness of AD technology as a sustainable option for decentralized waste management and energy generation in urban areas generally includes using other practices, such as composting for organic waste treatment, which are more relevant. Use of this technology by the municipalities, NGOs, and others operating in the field of SWM is particularly important, and awareness levels among the general public can also increase. Programs for spreading understanding regarding the applications of biogas of AD technology should be formulated.

5.4. Technology development

- Technologies for medium- and large-scale anaerobic digestion still have significant room for improvement because most technologies and engineering infrastructure in this field are imported. These are expensive and difficult to adapt to Ethiopian conditions. Thus, a lot more research needs to be carried out in this field to develop and innovate sustainable technologies for various types of organic waste. For this, a specialized cell that can keep track and monitor various technologies for their productivity, coordinate the work of research institutions, facilitate industry-academia coordination, and support demonstration projects can be set up.

In general, in Addis Ababa, the system of waste processing currently exists as a linear process. In essence, trash flows from high density cities to sprawling landscapes of waste, which is Koshe. However, as cities grow and become more densely populated, critical systems of waste infrastructure must be re-evaluated. Instead of today's isolated and linear processes, urban and waste ecologies can become an interconnected and cyclical systems. Current practices call for industrial processes to be pushed to the periphery of cities, thereby severing the relationship between the urban environment that humans inhabit and the one that is required to support the way humans live. If architects and designers become engaged in the conversation of waste management and other industrial processes that support the demands of the city, they can begin to repair the physical and mental separation of waste and public activity while introducing cultural, economic, and environmental value in waste infrastructure.

CHAPTER SIX
INTERVENTION SITE & DESIGN PROPOSAL

6. Intervention site

6.1. Lideta Sub-city

Lideta is one of the ten sub-cities of Addis Ababa. As of 2011, its population was 214,769. It has 9.18km2 (Addis Ababa City Government, 2017).

Figure 40 : Location map of Lideta sub-city

The sub-city has a different character of land use. Most of the area covered with old residential and different scales of condominium housings. It also includes the new CBD(commercial business district)area of the city. In addition to those, there are different factories and three big-scale hospitals (This number based on the author observes, there might be other factories and hospitals inside the sub-city. Could not get exact data from the sub-city administration).

The sub-city has 10 Woredas. Moreover, there are three waste collection and sorting area. Woreda 1, 2, 3 in one place, Woreda 4,8,10 to in one place and Woreda 5,6,7,9 to in one place. According to the data from the sub-city database last year (2018), the amount of waste collected is 128,247.08 meter cubic or 33,857,229.1 kilograms—the waste collected by the small and micro-enterprise groups. Moreover, sort and gather in the assigned waste collection area. After that, the waste goes to the koshe or Reppi landfill. Currently, the sub-city is building a new waste collection building in Woreda 03, which will replace the other three old waste collection areas.

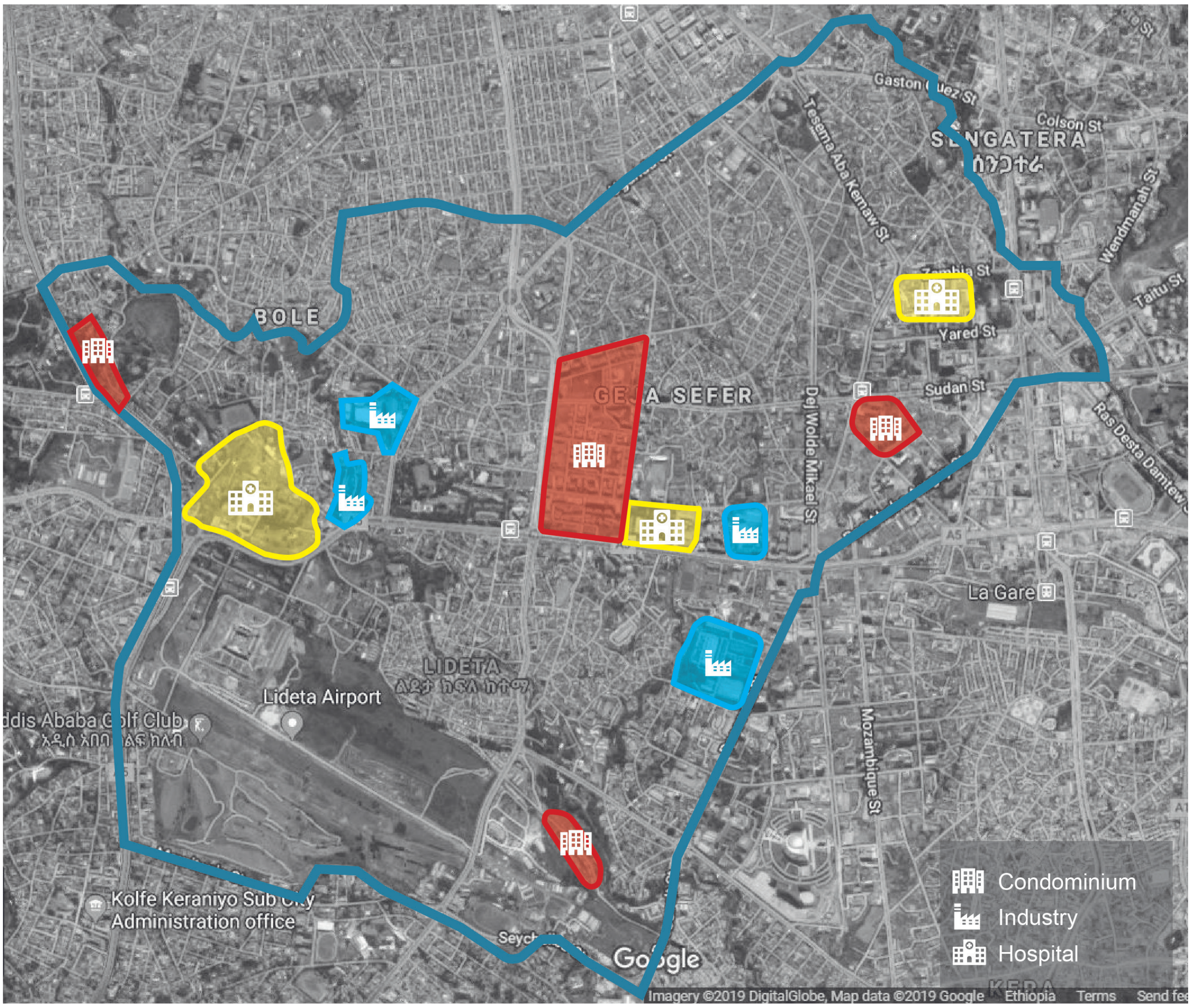


Figure 41: Different land use of the sub-city Illustration by the author

The proposal can serve for Lideta sub-city. Moreover, can be a prototype in different Sub cities. Especially on the condominium sites, this project will be implemented. Most condominium sites do not have such kind of facilities, which is very important for the communities. Based on the 2007 CSA data in this Lideta sub city 214,769 people live.

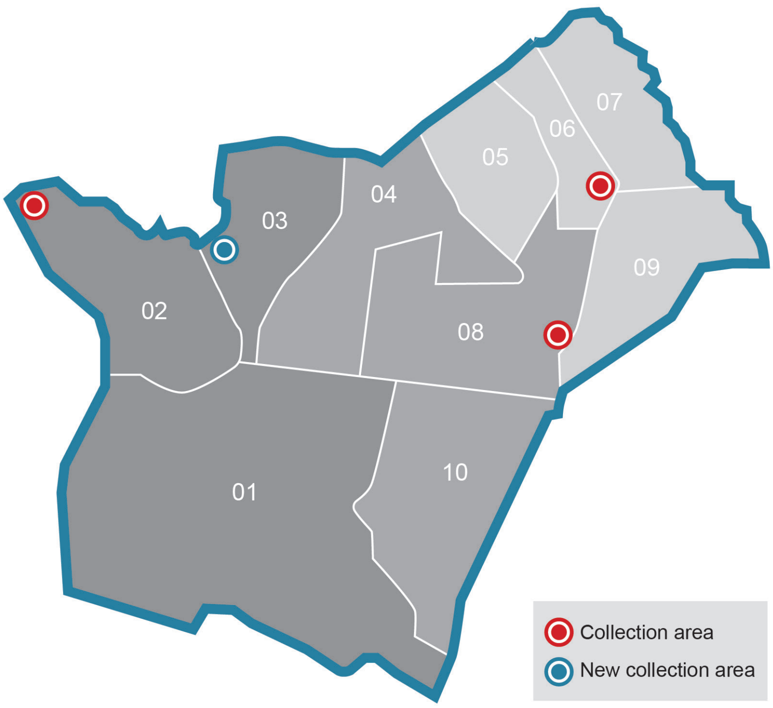


Figure 42 : Map of Lideta sub-city Woredas and waste collection area
Figure 43 : Photo of waste collection area Photographe by the author

From the observation, In the neighborhood of Lideta condominium, the Waste damping place looks like an afterthought design. As shown in figure 44, the locations area is very random and unorganized. The wastes are not separated; everything dumped together.

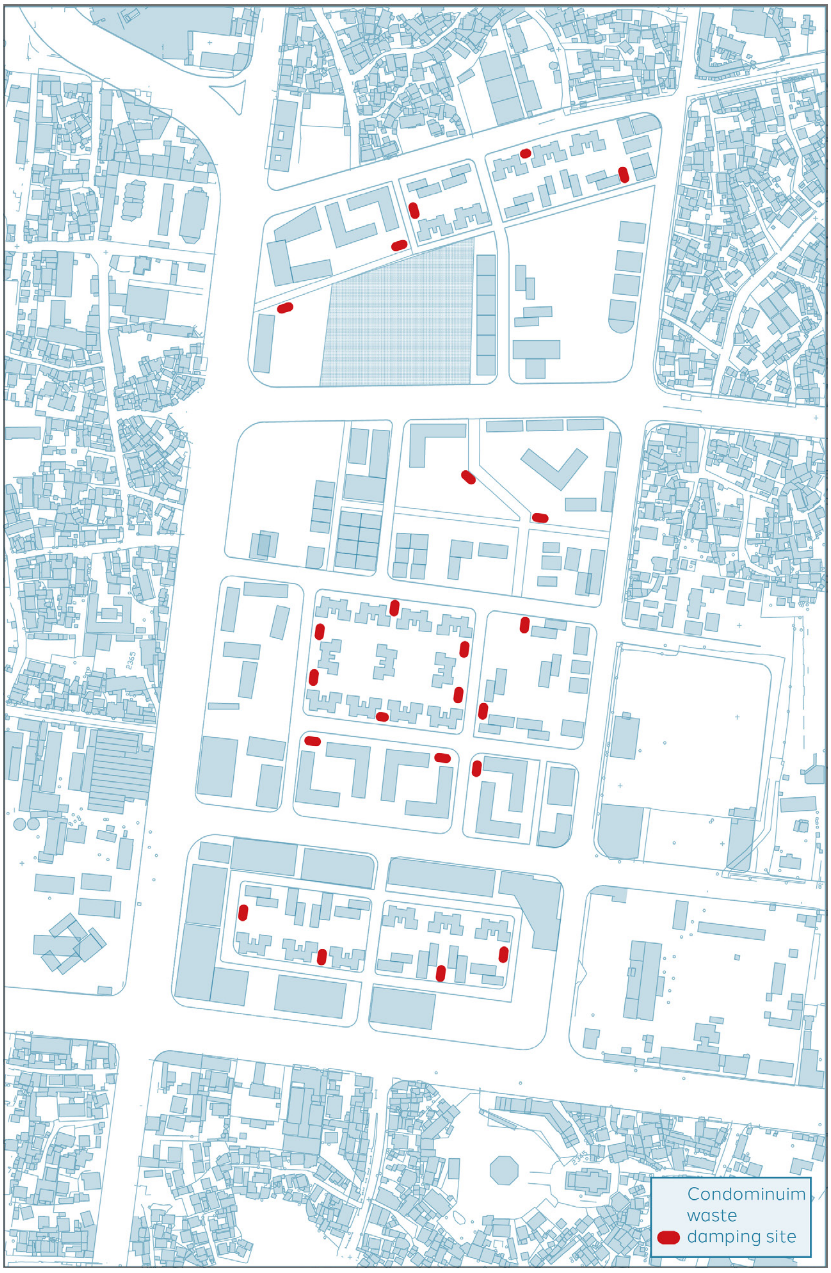


Figure 44 : Map of Selected case study area and waste collection area
Figure 45: Photo of waste collection area Photographe by the author

6.2. Site analysis

6.2.1. Figure-ground

In the figure-ground onside, Figure 46, the site and surrounding area mixed with the planned neighborhood and unplanned (slum) neighborhood. The dimension of the block varies from mixed-used building to condominium housing to row houses. There are also other blocks under construction and to be built in the future. When all those finish, the site will be relatively dense compared to the exciting situation. For the future, the destine of the slum (unplanned) area will transformed into a high mixed residential area, which means like the exiting planned area.

The chosen site (see in figure 46 on red) is currently serves as Lideta Woreda Park. The park is underutilized, and adding this facility will enhance it. The other thing On this condominium development waste is not take under consideration, and this project will be an exemplary to other similar projects.

Figure 46: Figure-Ground Map of Selected area

Figure 47 : Lideta Woreda Park Photographe by the author

6.2.2. Zoning

The zoning or land use of the site context, seen in Figure 48, allocates as high dense mixed resident area. There is several blocks for administration and service. The other significant portion is near to the site CBD (Commercial Business District) area, which is high rise buildings. The site is surround by social housing or condominium buildings and some other apartment and mixed-use buildings.

6.2.3. Major landmarks

This diagram, Figure 49, identifies the major landmarks near the site. The Supreme Court and EIABC campus, Lideta church, Balcha Hospital, small scale garages, and shops used spare parts, and Menalesh Tera is the main landmark for the site.

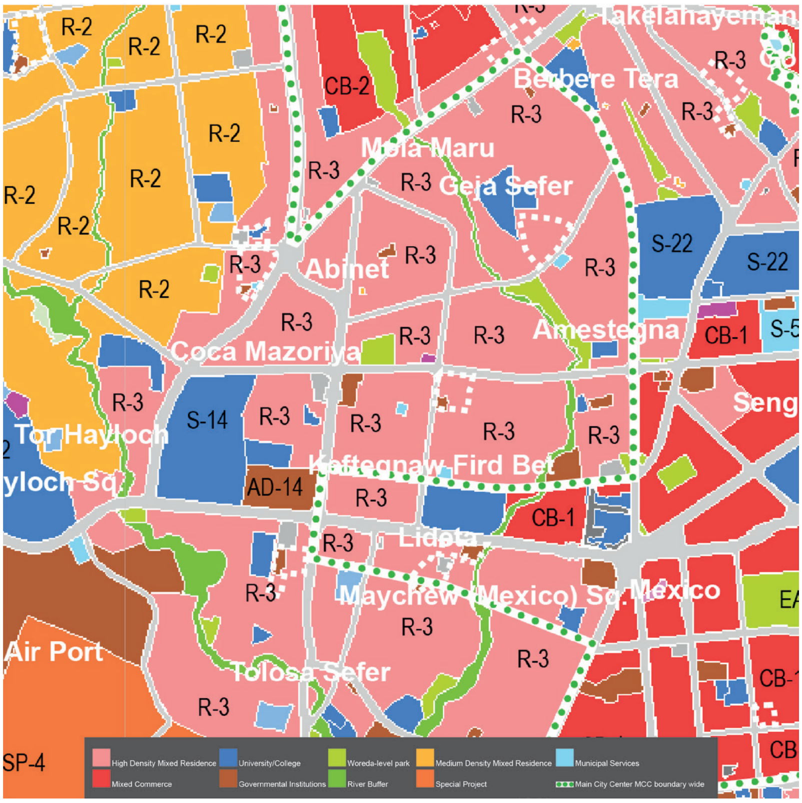


Figure 48: Land use of the selected area

Source: Addis Ababa a city structural plan, 2017-2027)

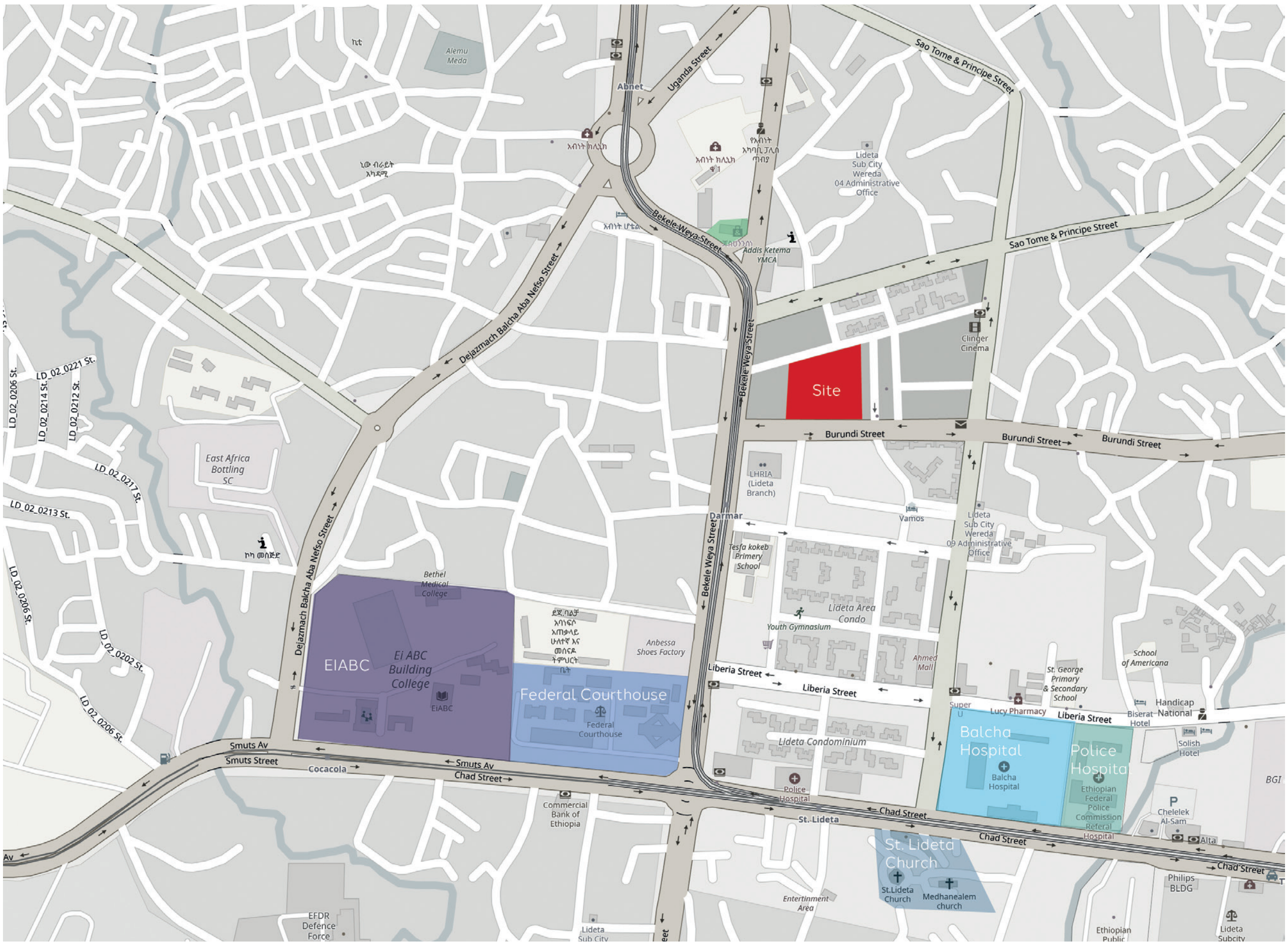


Figure 49: Major landmark near to the site
Source: Openstreet map, illustration by the author

6.2.4. Site access & Size

This site access & size diagram, Figure 50, shows both the access of pedestrian and vehicular, to the site as well as the scale of the site. The street on the left side of the site has train access, which takes to Merkato, Sebatega, Atekelt term, and Piassa and also bus and taxi roots, which will take to Merkato to pass. The street in front of the site is a primary road that will take to Mexico and on the other direction to Merkato.

The scale of the site is 13,765 square meters. Which currently is a Woreda park. The scale of the site is large compared to the location and surroundings. However, for the intended project, the site is not significant.

6.2.5. Environmental consideration

The site is located in the middle of a residential area, so the Odor–feedstock can cause odorous emissions; these can be managed through an odor management plan and suitable control and abatement techniques (e.g., inside storage). The other environmental consideration is the climatic condition of Addis Ababa.

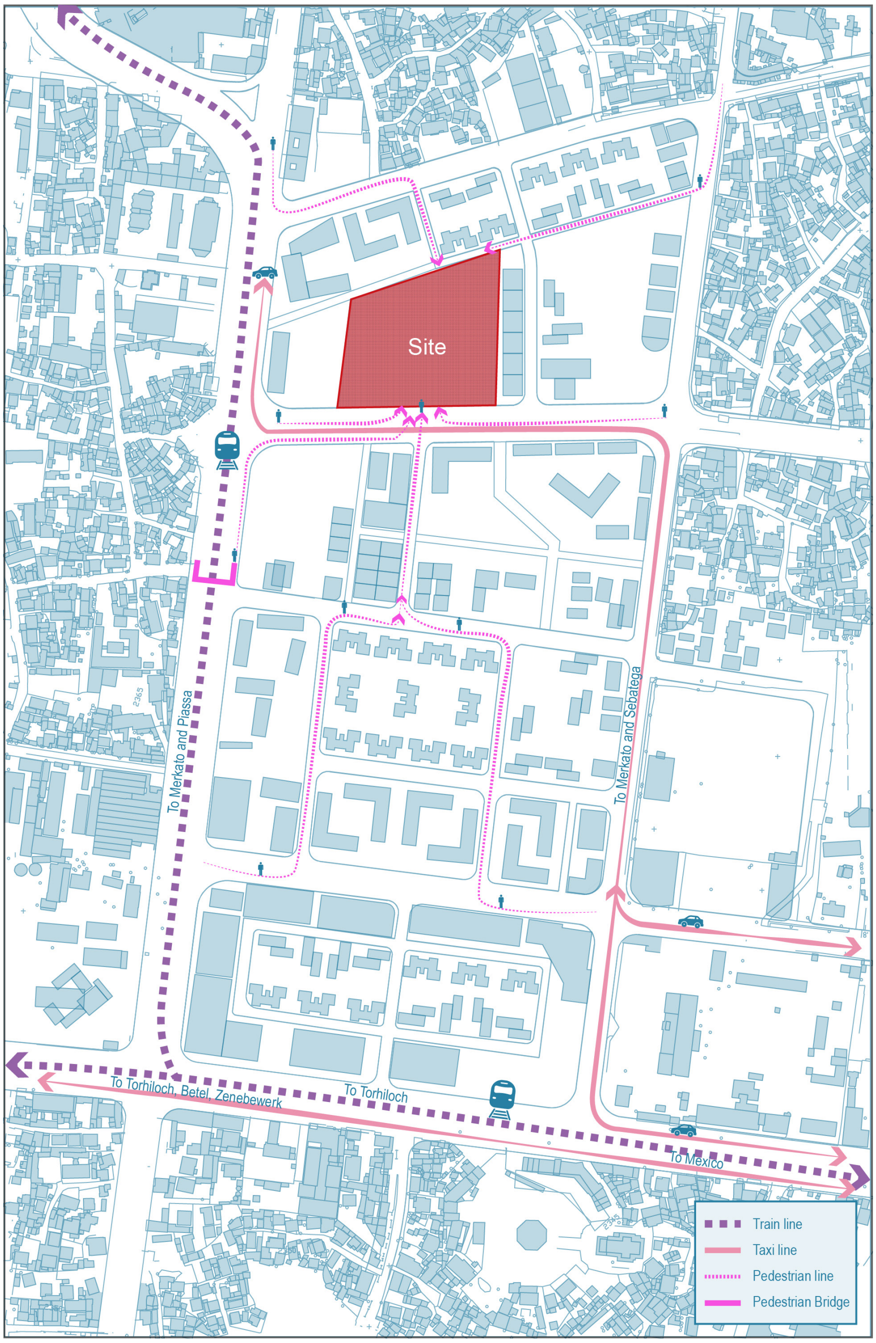


Figure 50 : Site access Map of Selected area

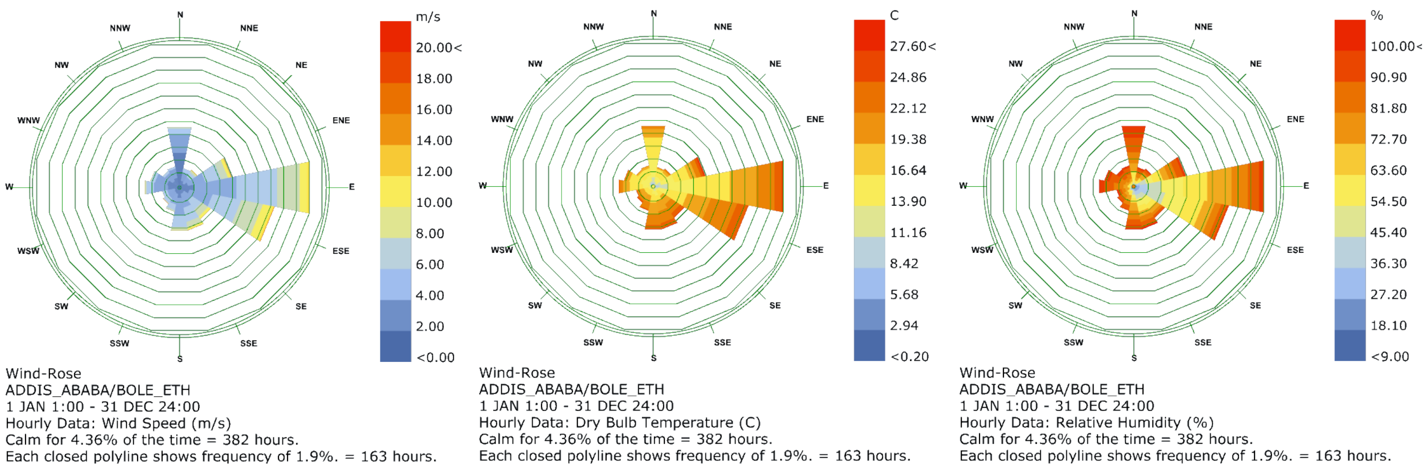


Figure 51 : Addis Ababa's Wind , dry bulb tempreture and humidity analysis graph

6.3. Program

Waste-to-energy facilities

6.3.1. Process

The breakdown of the organic material begins here, and it involves four stages of chemical processes which convert the matter into usable biogases:

1. Hydrolysis
The first stage sees the breakdown of complicated matter, such as carbohydrates and proteins, broken down into sugars and amino acids. These usually are long-chain chemical compounds, but Hydrolysis breaks them down into single molecules.

2. Acidogenesis
In the second stage, microorganisms break down the single molecules of sugar and amino acids even further into ethanol and fatty acids, as well as producing carbon dioxide and hydrogen sulphide as by-products.

3. Acetogenesis
In the third stage, the ethanol and fatty acids are converted into hydrogen, carbon dioxide, and acetic acid.

4. Methanogenesis
In the fourth and final stage, microorganisms convert the remaining hydrogen and acetic acid into methane and more carbon dioxide.

At the end of the process, we have our methane biogas. As well as producing biogas that can be supplied to the grid or converted into biofuel, anaerobic digestion also provides digestate, a nutrient-rich fertilizer, as a by-product of the process.

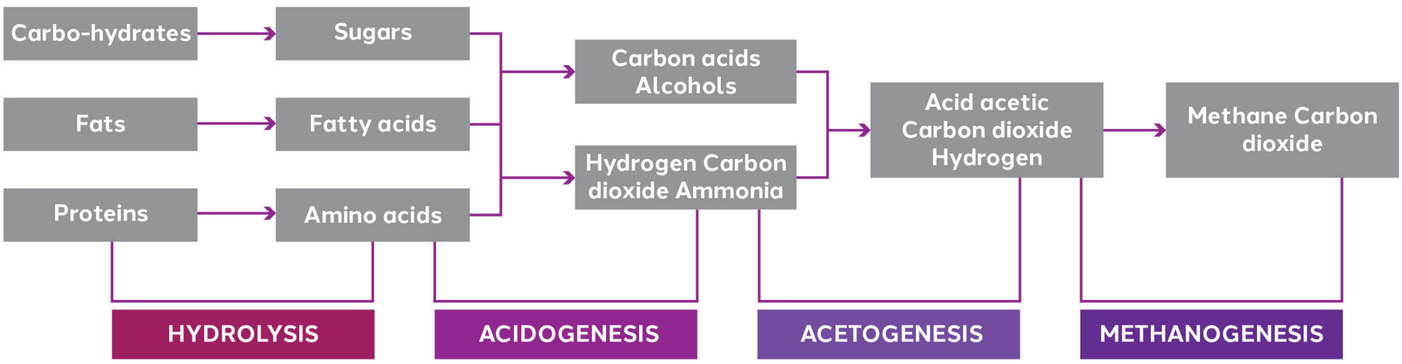


Figure 52: Chemical process of AD

6.3.2. Layout

The arrangement of the rooms for this process follows a linear logic along the sequence of events from tipping floor to storage pit to the blender to separated waste, first digester, the second digester, then CHP unit to produce electricity and heat and the rest of the waste will be composted for fertilizer.

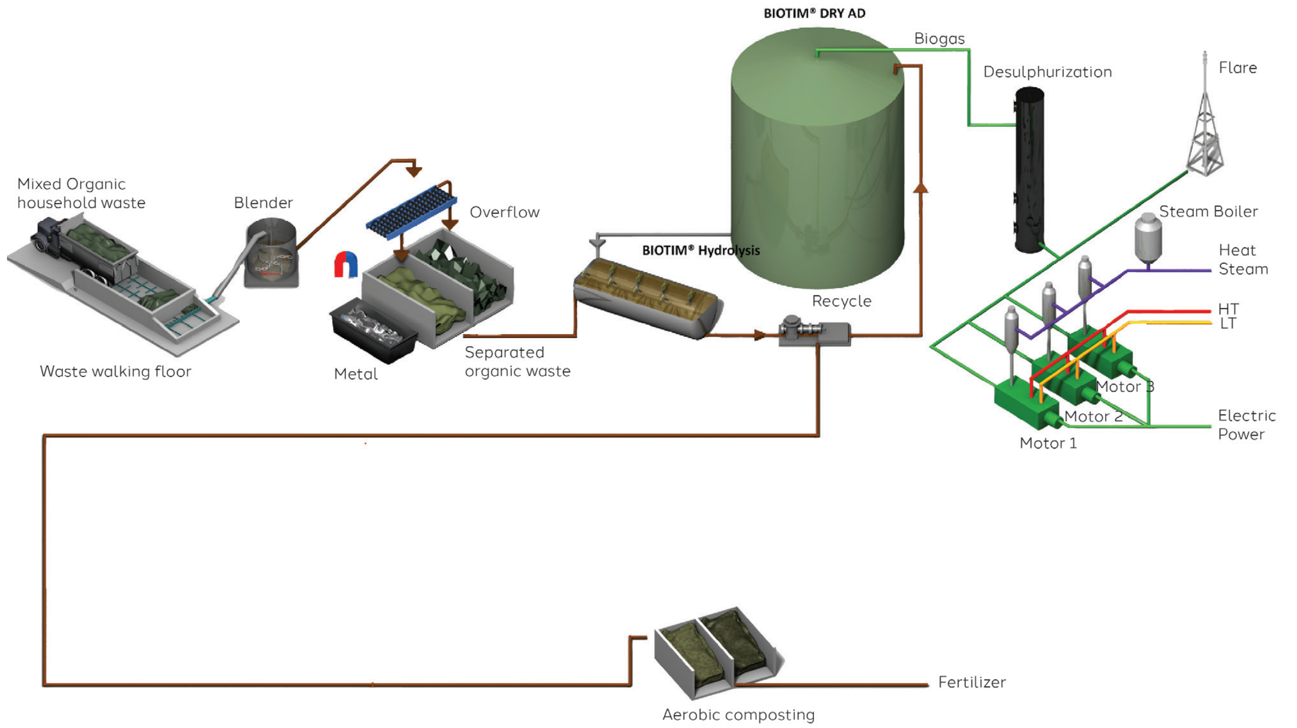
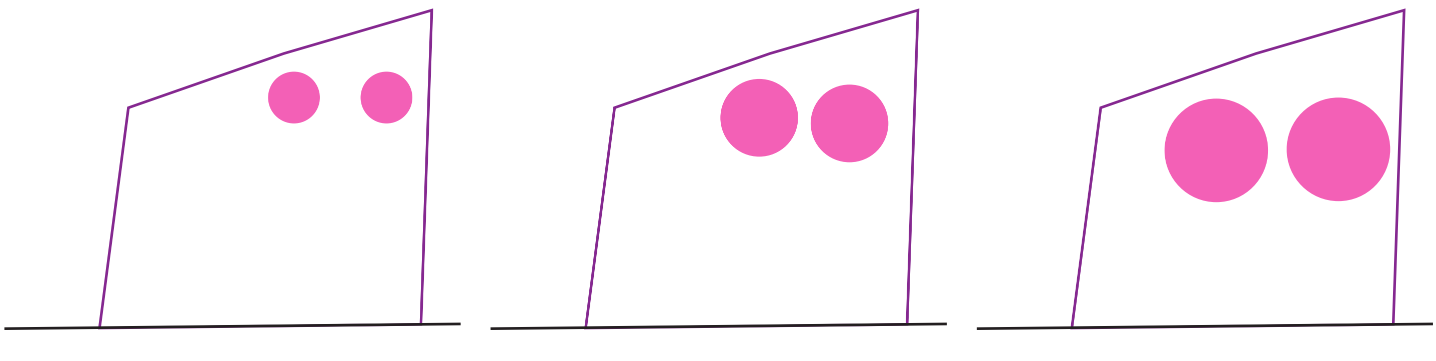


Figure 53: AD plant layout

6.3.3. Scale Relative to Site

To understand the relationship between program and site, three AD plants from findings were selected ranging in scale and capacity and placed on the site. Figure 54 shows a comparison of these three facilities.



Small scale (up to 7,500 tonnage *Medium scale (7,500 - 30,000 tonnage)* *Large scale (30,000 tonnage and more)*

Figure 54: comparison of the three scale digester plant

6.3.5. Public component

The goal of this thesis is to design the community center for the public to engage with trash in a new way. By adding a public component to this Waste-to-Energy plant, the project seeks to act as a didactic element for the community and the city to understand the technology and benefits of WTE. By exposing and promoting people to have positive interactions with trash in new ways, they can begin to value garbage as a source of energy and a source of generating public space. This will attempt to promote garbage as a valuable resource that can be incorporated into the functioning of the city, not just a harmful end product that needs to be sent away to a landfill.

Table 10 : Technology cost comparison

Room Name	Qt.	Net Area	Total Area	Adjacencies	Remarks
BIOMASS COMBUSTION/GASIFICATION FACILITY					
Loading/Receiving dock	4	37 m2	148m2		Loading/receiving from truck/rail
Staging	1	93m2	93m2	Loading	Temp. storage from loading docks
Processing plant	1	929m2	929m2	Staging	Storage/processing capabilities for +/- 1000 tons biomass/day
Storage/feed-in	1	7,432m2	7,432m2	Processing plant	Hydraulic ram delivers biomass to gasifier
Gasifier	3	372m2	1,116m2	Storage	(3) gasifiers to produce 35 megawatts electricity/day
Boiler house area	3	372m2	1,116m2	Gasifier	(1)boiler/gasifier for waste steam conversion
Pollutant removal	3			Boiler	Wet scrubbing unit (1) /Gasifier
Ash Collection hopper	3			Pollutant removal	(1)/Gasifier, ash to be used as fertilizer
Sub total			**10,834m2**		
ENERGY STORAGE					
Fule cell	3	46m2	138m2		Actual size of each unite: 224” x84”x81”: can be located outside, hydrogen precautions for this space
Flywheel	15	2m2	30m2		8000 Ib.per unit, each provides 100kw for 15 minutes
Sub total			**168m2**		
CO-OP ADMINISTRATION					
Reception/waiting area	1	18m2	18m2	Elevator bank/ stairs	
Large open offices	4	14m2	56m2		
Small open offices	12	10m2	120m2		
Conference room	2	23m2	46m2		
Printer/copier/ fax	2	6m2	12m2		
Kitchen/break room	1	30m2	30m2		To be used by administration + field production employees
File area	1	13m2	13m2		
Documents room	1	22m2	22m2		
Service room	1	15m2	15m2		

Supply enter	1	4m2	4m2		
Open work stations	10	8m2	80m2		
Restrooms	2	12m2	24m2		
Sub total			**440m2**		
FIELD PRODUCTION MANAGEMENT					
General manager office	1	17m2	17m2		
Super visor	3	12m2	36m2		(1)Office per production/storage type
Restroom	3	3m2	9m2		(1)Per production/storage area
Control room	3	46m2	138m2		(1)Preproduction/ storage type; to include computer-based controls and analyzing equipment
Subtotal			**200m2**		
COMMUNITY CENTER/PUBLIC SPACES					
Lobby/Exhibit	1	130m2	130m2		Entrance for employee and visitors
Reception Area	1	12m2	12m2		Receptionist/ greeter desk
Art Room					
Dance Studio					
Small Theater					
Computer Room					
Multipurpose Rooms/ Large Classrooms	4				
Library	1	50m2	50m2		
Gym w/ Lockers					
Conference Room					
Large Office Workspace	2	30m2	60m2		
Staff Conference Room					
Director's Office	1	15m2	15m2		
Restrooms					
Reflection/ Retreat Room					
Café					
Workshop with show room	3	30m2	90m2		
Secondhand shops	4	12m2	48m2		
Mechanical item shops	5	12m2	60m2		
Game zone					
Day care					

6.4. Design Approach

6.4.1. Design Objective

The design objective of this thesis is to design a new community center for public engagement with trash through the design of a Waste-to-Energy Plant, a public educational component and landscape.

6.4.2. Approach to site

There are three types of design generators, and they are commonly known as the three C's of design: Concept, Content, and Context. The concept is an idea of notion which guides the design in a certain way. It can be analogical, metaphorical, or pragmatic. Sometimes content can be a starting point of the design. The program of a building can be a subject of design to achieve more exceptional space efficiency, connectivity, or reinventing of specific functional typologies. The context is another essential springboard for design. Since architecture is geographically specific, a design will be absorbed or reflect the uniqueness of its physical surroundings, culture, or climate.

In a design, all three generators of (Concept, Content, and Context) co-exist with a certain degree of dominance one on top of others. It is up to the designer to emphasize or generate the form or space of the design. In some instances, one of them becomes very important to the other due to the building typology, the uniqueness of the site, or the relevance of creative notion.

Content:

In the beginning to work with the program of the WTE plant and community center component on-site, the placement of the WTE plant drove design decisions. In order to assess placement, the flows of trash and the flows of public were examined, as seen in Figure 55. It makes the most sense for all systems of flows o place the WTE plan on the upper side of the site near o the secondary road is very compatible to the process.

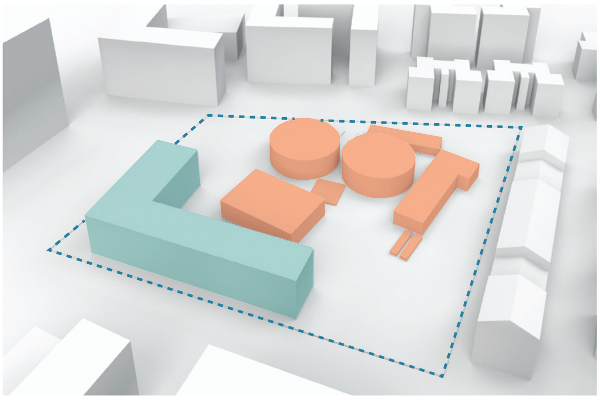
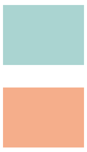


Figure 40: Massing
Illustrated by the author



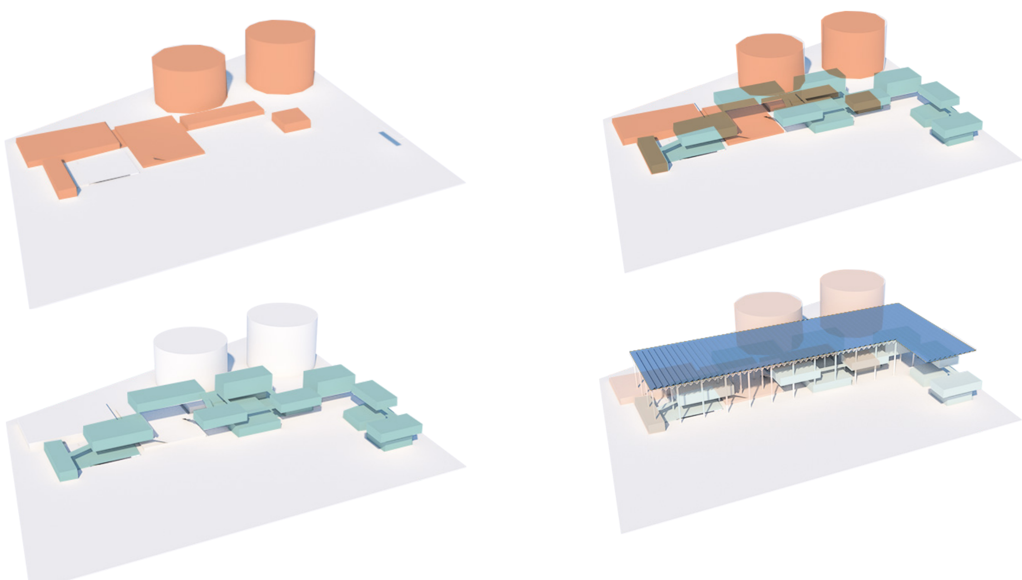


Figure 55: Evolution diagram

Contextual Approach:

In the context of Ethiopia, tree shade has a different use for the community in many regions. The community from different age group use the tree shade. It serves as a children's playground, study area, relaxing, elderly use the shade fro community gathering space. The space character changes the use of the space changes.

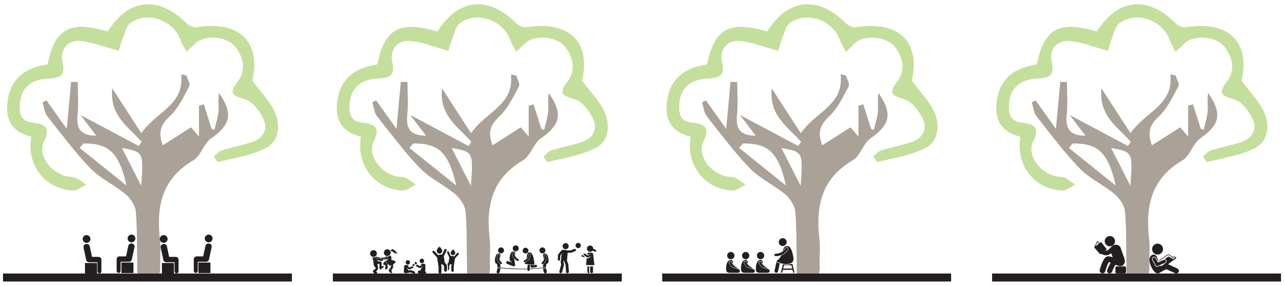


Figure 56: Different use of tree shade space

Conceptual Approach:

This concept of shade use for this project. The objective of this project is to create a waste-to-energy integrated with the community center to create awareness. One of the approaches to achieve that creates flexible space like the tree concept.

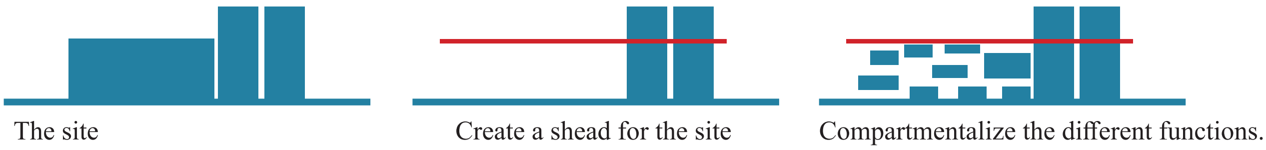


Figure 57: Conceptual approch

Design as a layered system of flows and Multifunctionality

This design proposal attempts to integrate multiple systematic infrastructures into a singular cohesive design. The flows that guide the project are 1) the flow of waste, 2) the flow of landscape, and 3) the flow of public. These flows operate in multiple directions and dimensions, however, the overarching linear nature of the design emphasizes the flows operating from the neighborhood.

The integration of Waste in the design

The flow of waste, as shown in the diagram below, figure 58. Waste enters the site in the form of garbage trucks. The trucks move into the building at the entrance on the secondary street, where they move through a sequence from weight station to the tipping floor where they unload their trash. From here, the trash moves through the process described earlier in the flow chart, from storage pit to sorting, smashing & to the silo and at the end the compost output. The process is linear, the people will be engages with the trash on the sorting and smashing. These spaces are semi-visible for the visitors.

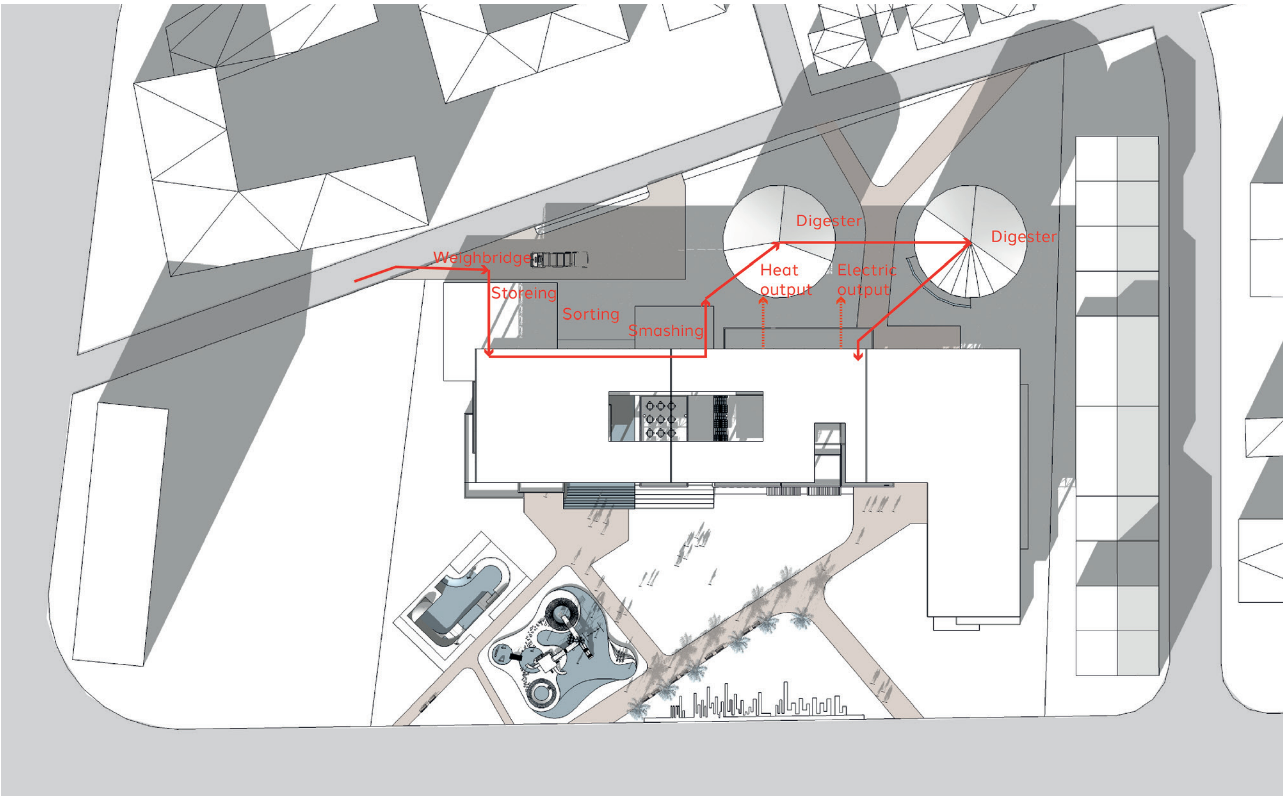


Figure 58: Flow of waste to out put

The Integration of Landscape in the design

The site was a park before, and now on this design proposal, the landscape will be the central component and also act as a mediator and facilitator between trash and people. The landscape is what enables this project to become an amenity for the public as well as a hybrid model for integrating architecture and landscape design. This can be seen in the diagram below, figure 59. The diagram shows the programmatic elements of landscape design. This programs here serve as initial design strategies and could become more robust in further design.

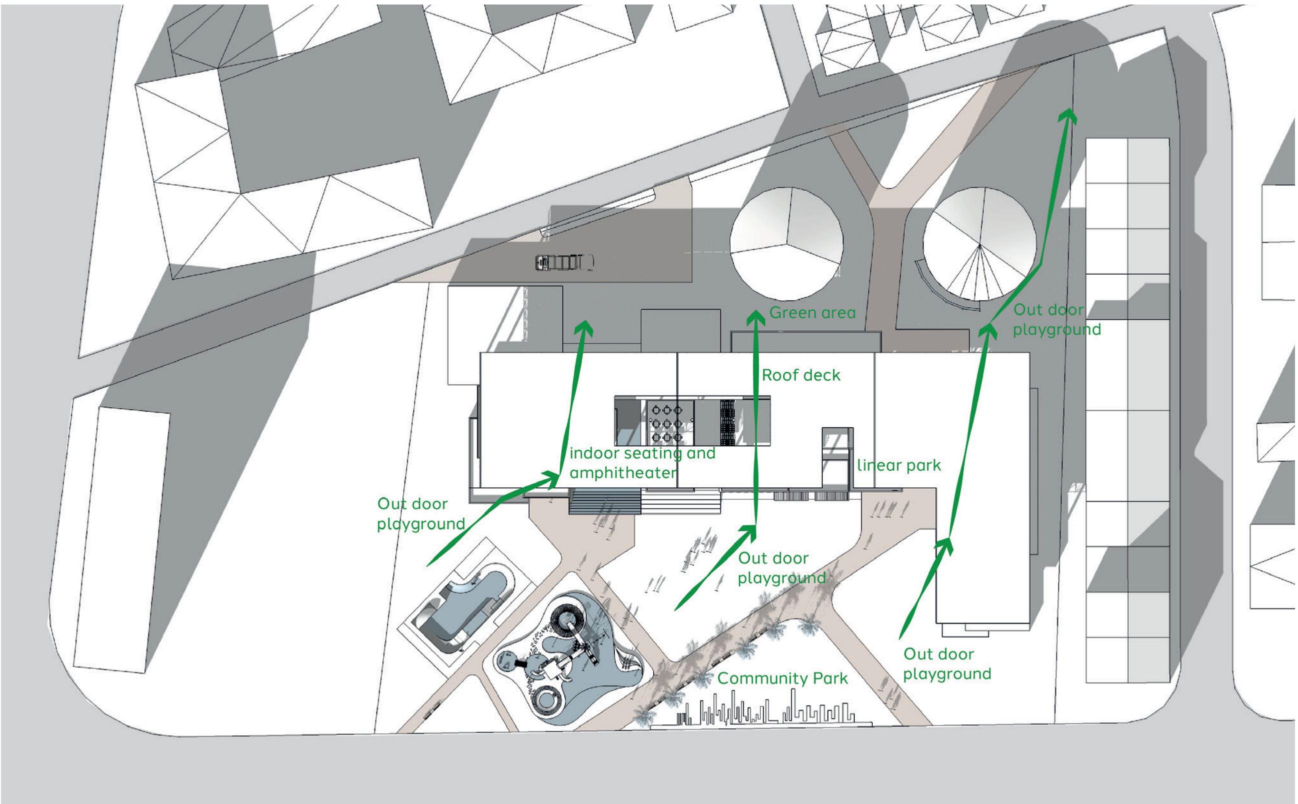


Figure 59: Flow of landscape

The integration of the public in the design

The integration of the public will follow the landscape flow. It is one of the critical layers of the design. The main program of the project is a community center, so on this flow of public tried to connect the people to the waste. The community center has different programs which the neighborhood community will spend their time. In addition to that, the visitor center which allows visitors to show the process of the WTE to create awareness.

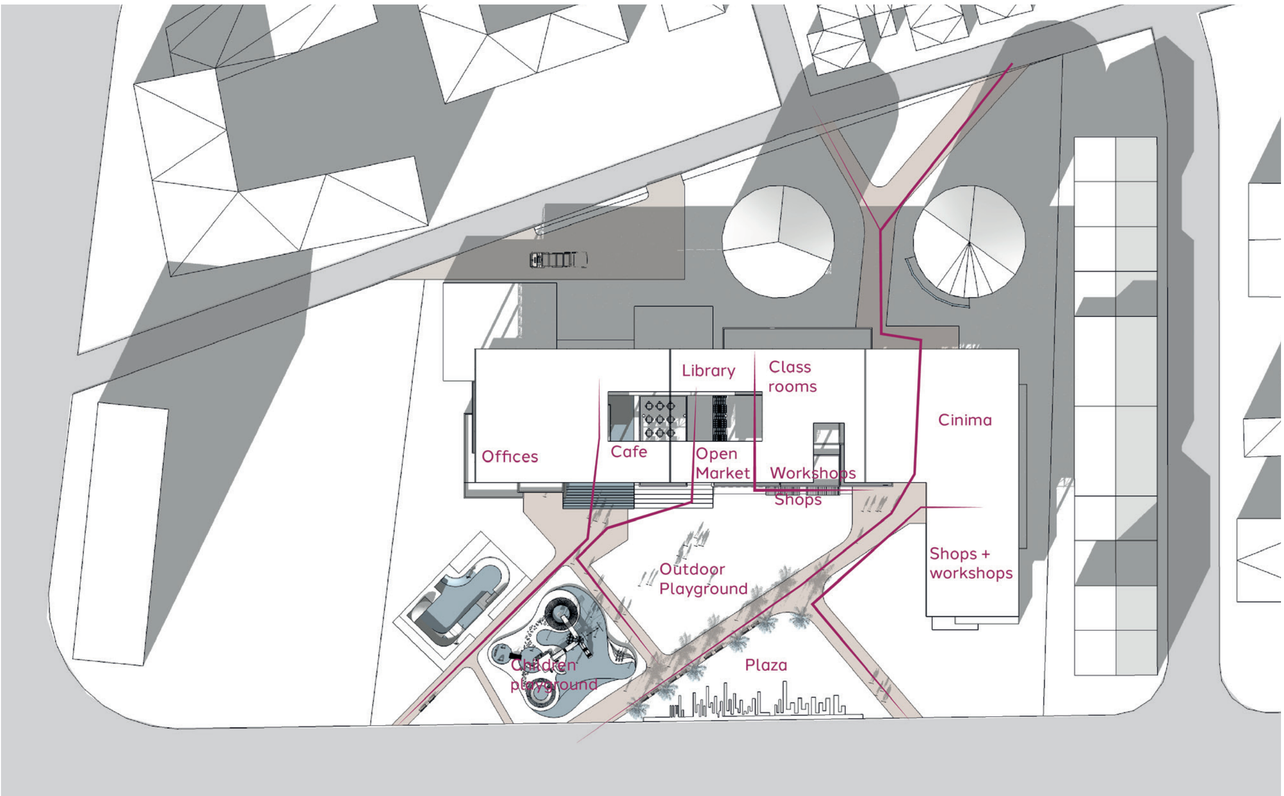
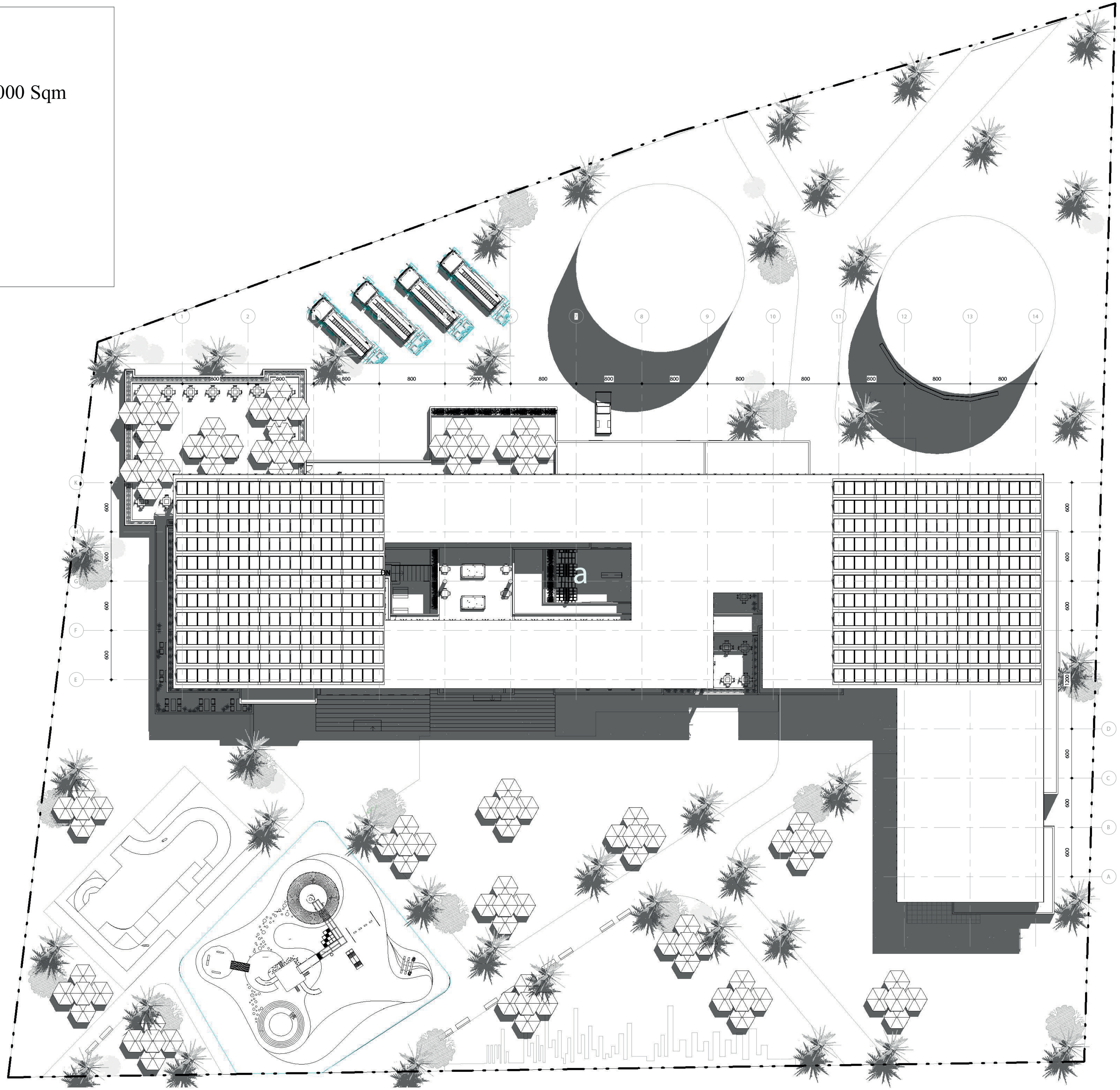
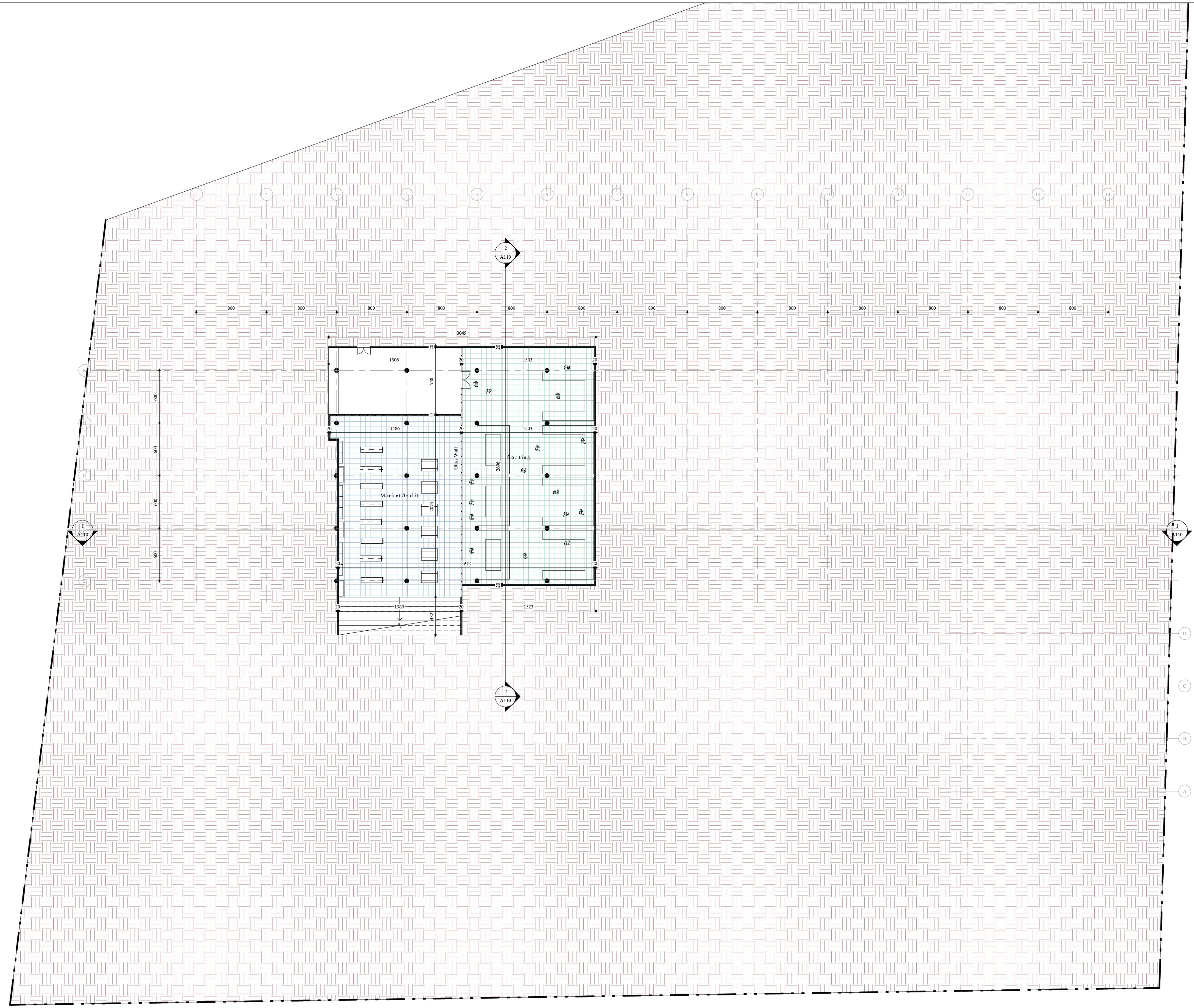


Figure 60: Flow of public

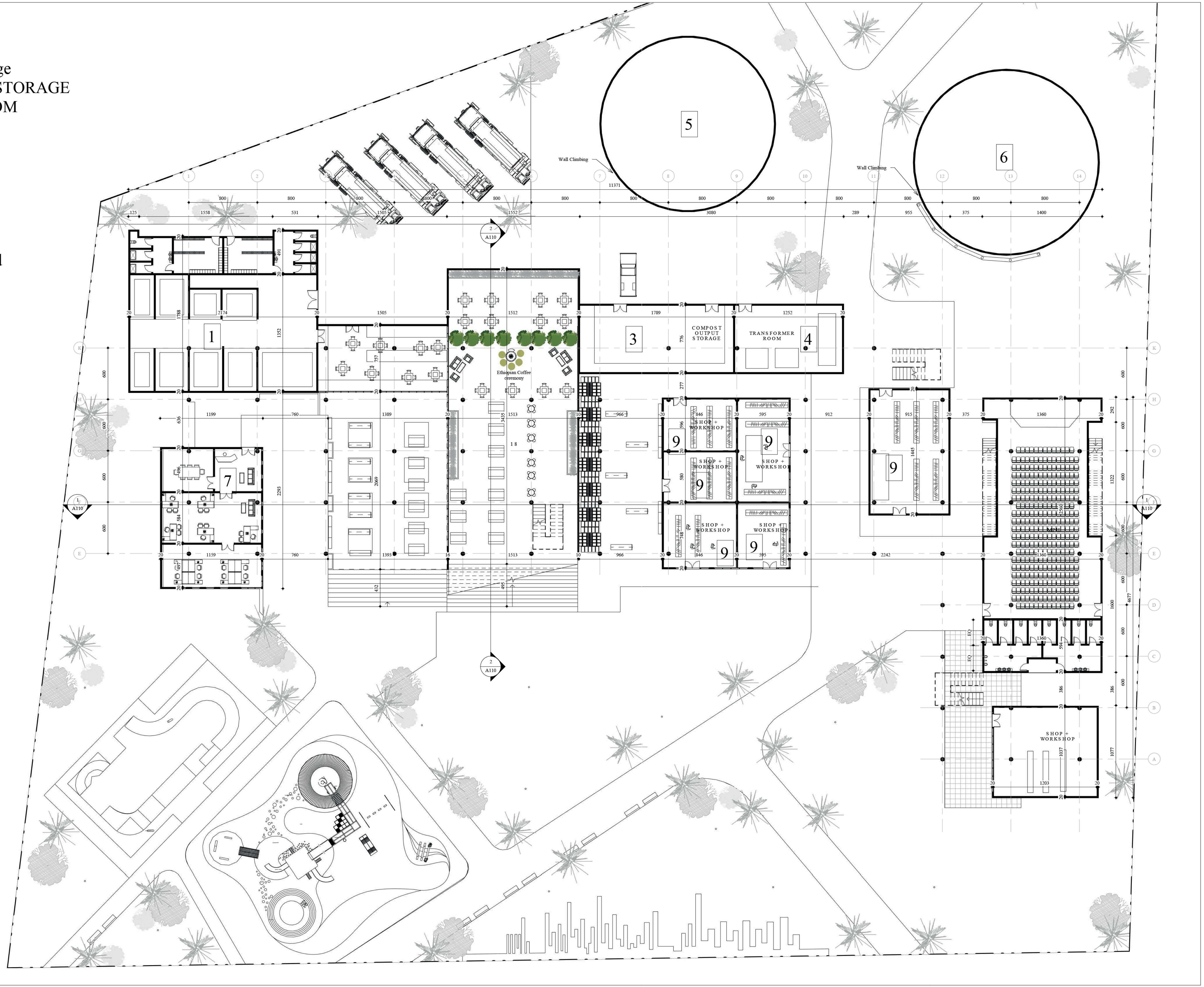
LEGEND
A. Main Road
B. Main Entrance
C. Shopping Center = 10,000 Sqm
- Superette
- Restaurant-Café
- Cold Room
- Rural Bank
- Laundry
- Hairdressing
- Gym space



1 Site Development Plan
1 : 250



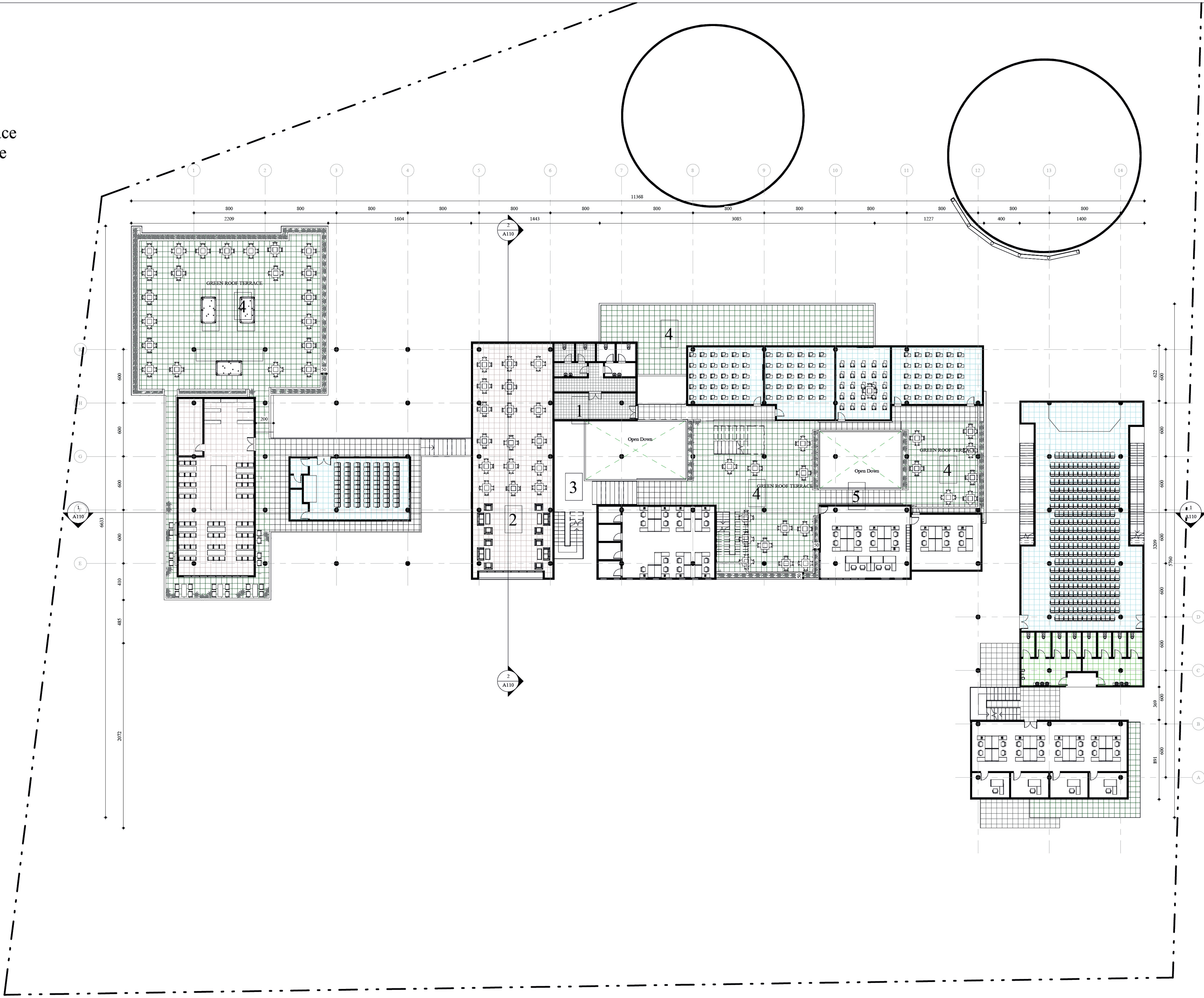
1 Semi-Basement Floor
1 : 200



LEGEND
1. Storage Pit
2. Compost Output Storage
3.COMPOST OUTPUT STORAGE
4.TRANSFORMER ROOM
5. Transformer Room
6. Digester Silo
7. Administration Room
8. Informal Market
9. Workshop + Shop
10. Multi - Purpose Hall
11. Skating
12. Children's Playground
13. Weight Bridge
14. Parking
15. Plaza

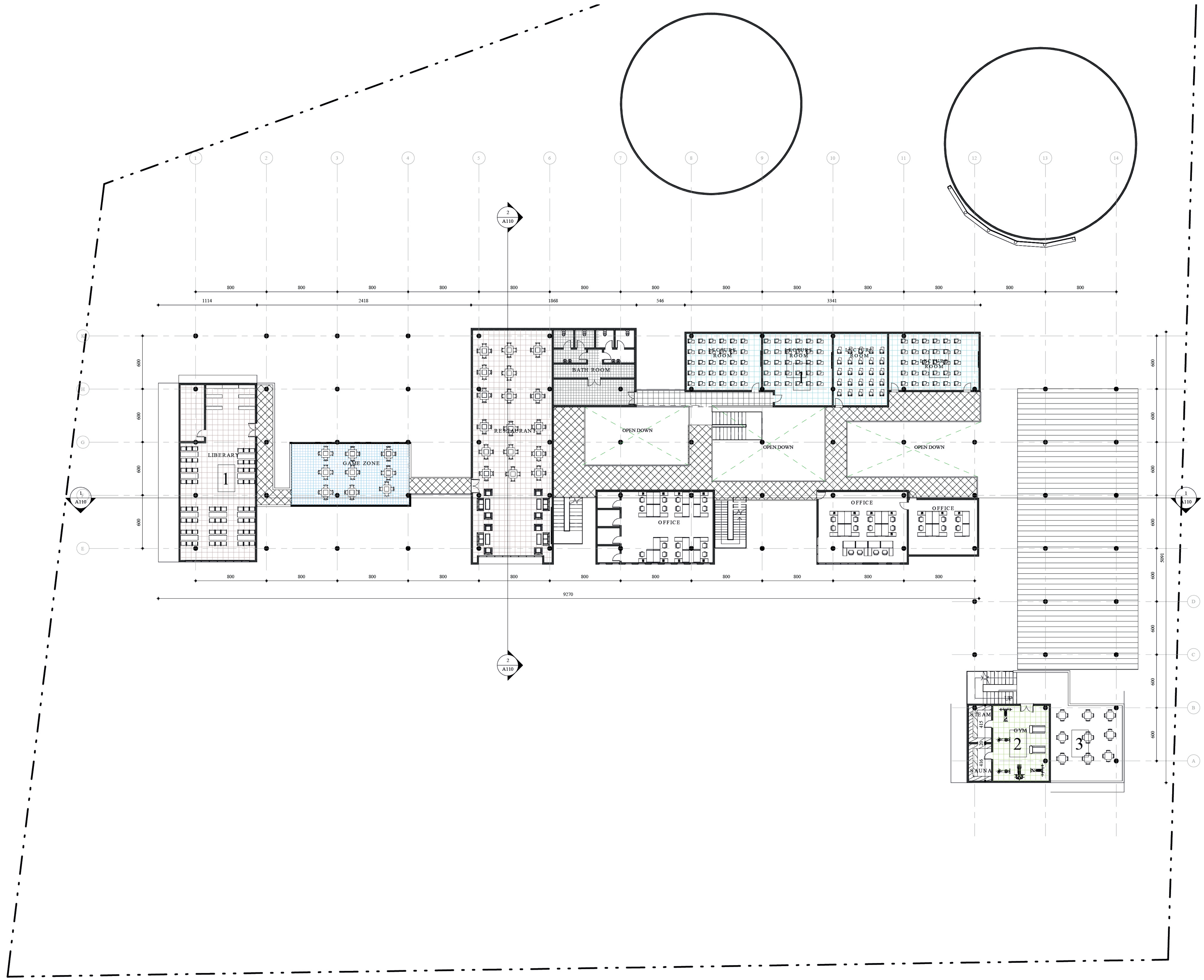
1 Ground Floor
1 : 200

LEGEND
1. Toilet
2. Library
3. Bridge
4. Green Roof Terrace
5. 1.8m Wide Bridge

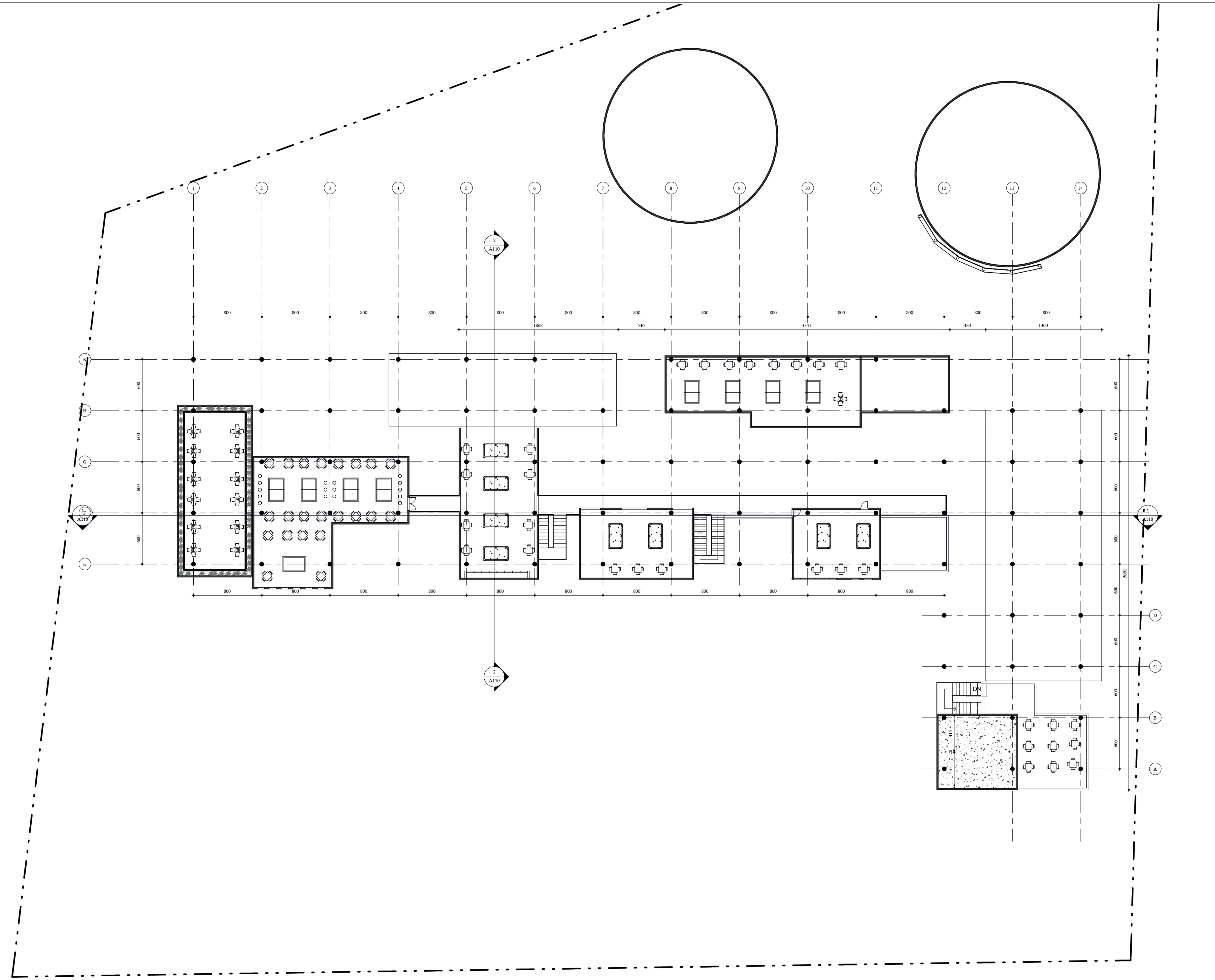


(1) First Floor
1 : 200

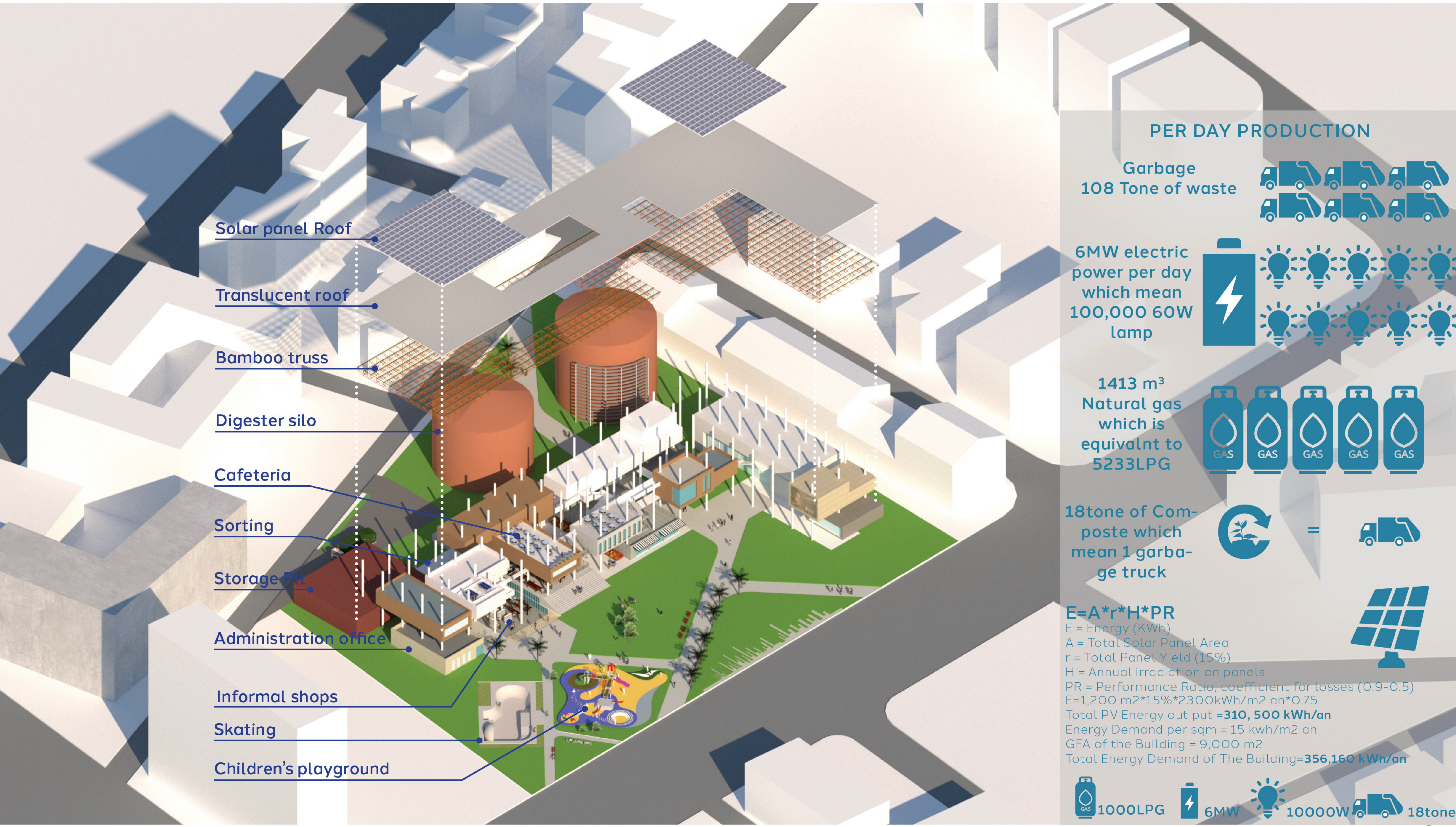
LEGEND
1. Game Zone
2. Gym
3.Terrace



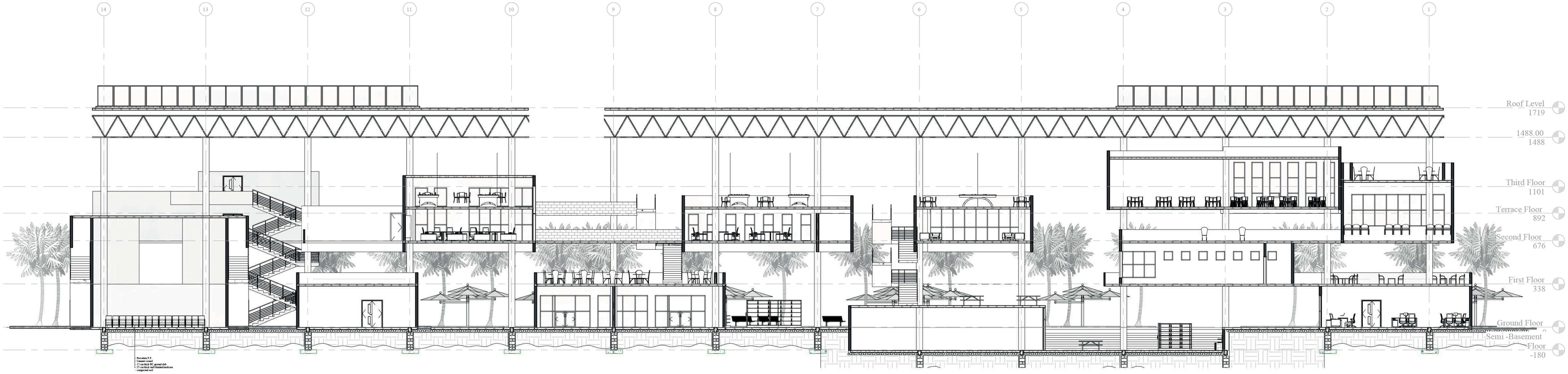
1 Second Floor
1 : 200



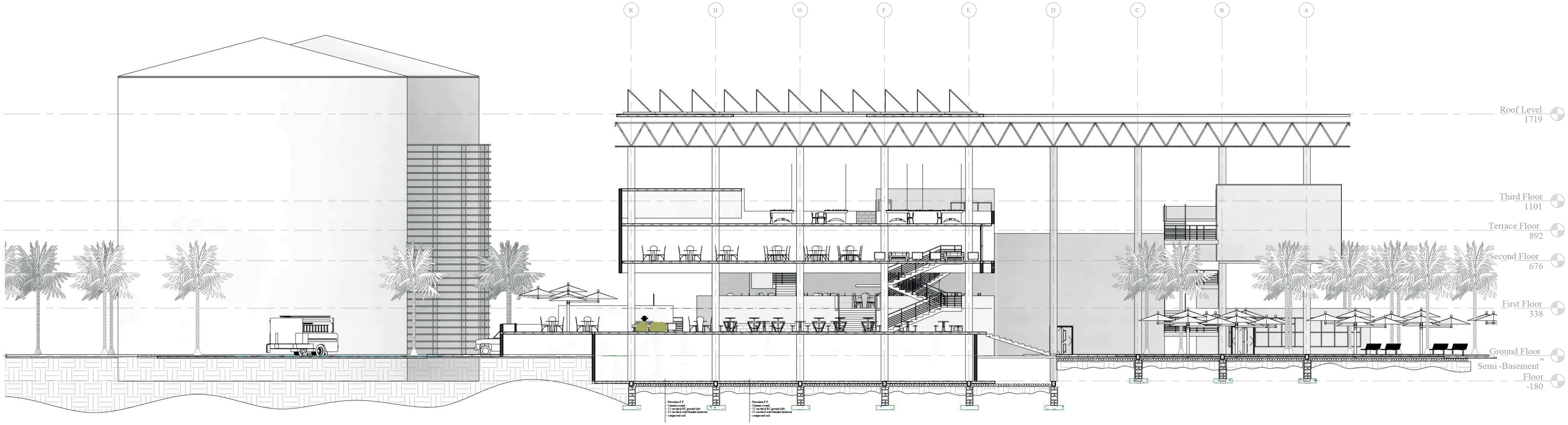
1 Terrace Floor
1 : 200



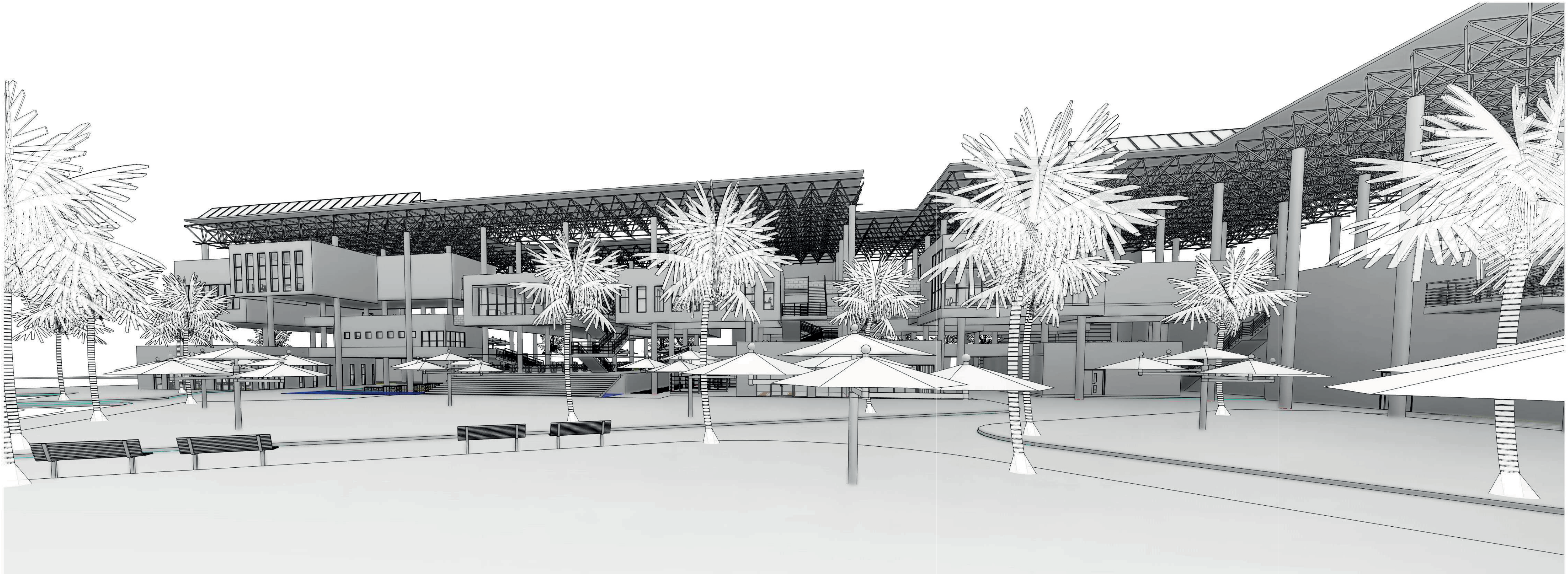
Solar panel Roof
Translucent roof
Bamboo truss
Digester silo
Cafeteria
Sorting
Storage Pit
Administration office
Informal shops
Skating
Children's playground
PER DAY PRODUCTION
Garbage
108 Tone of waste
6MW electric power per day which mean 100,000 60W lamp
1413 m³ Natural gas which is equivalnt to 5233LPG
GAS
18tone of Com-poste which mean 1 garba-ge truck
=
E=A*r*H*PR
E = Energy (KWh)
A = Total Solar Panel Area
r = Total Panel Yield (15%)
H = Annual irradiation on panels
PR = Performance Ratio, coefficient for losses (0.9-0.5)
E=1,200 m2*15%*2300kWh/m2 an*0.75
Total PV Energy out put =310, 500 kWh/an
Energy Demand per sqm = 15 kwh/m2 an
GFA of the Building = 9,000 m2
Total Energy Demand of The Building=356,160 kWh/an
1000LPG
6MW
10000W
18tone



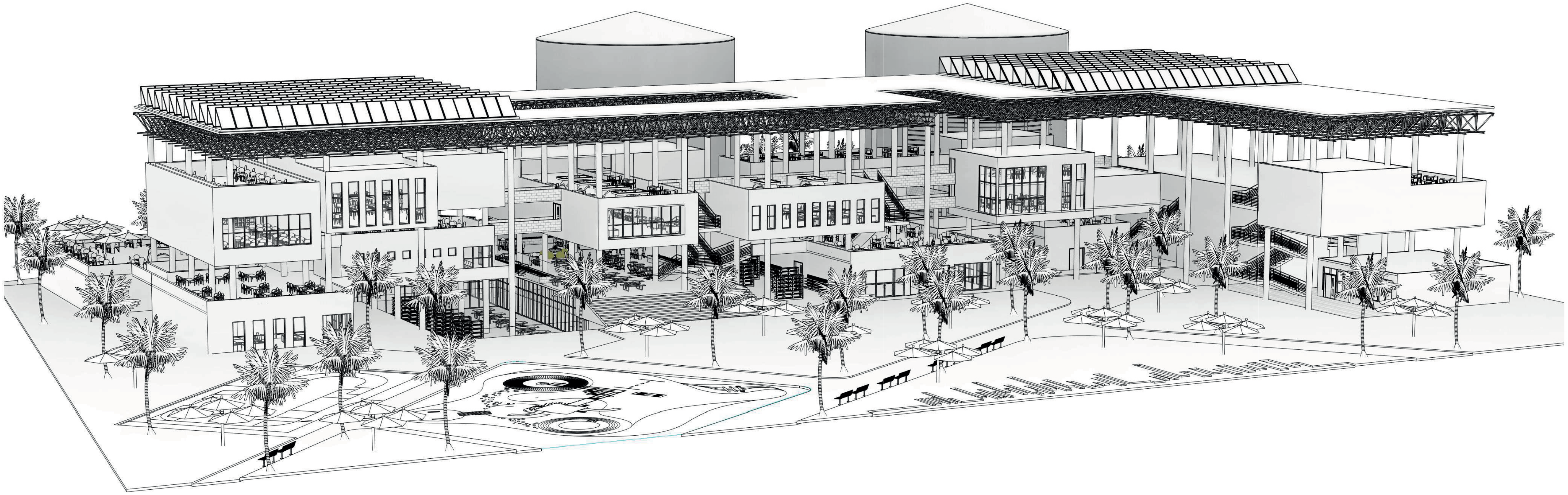
Section 1
1 : 150



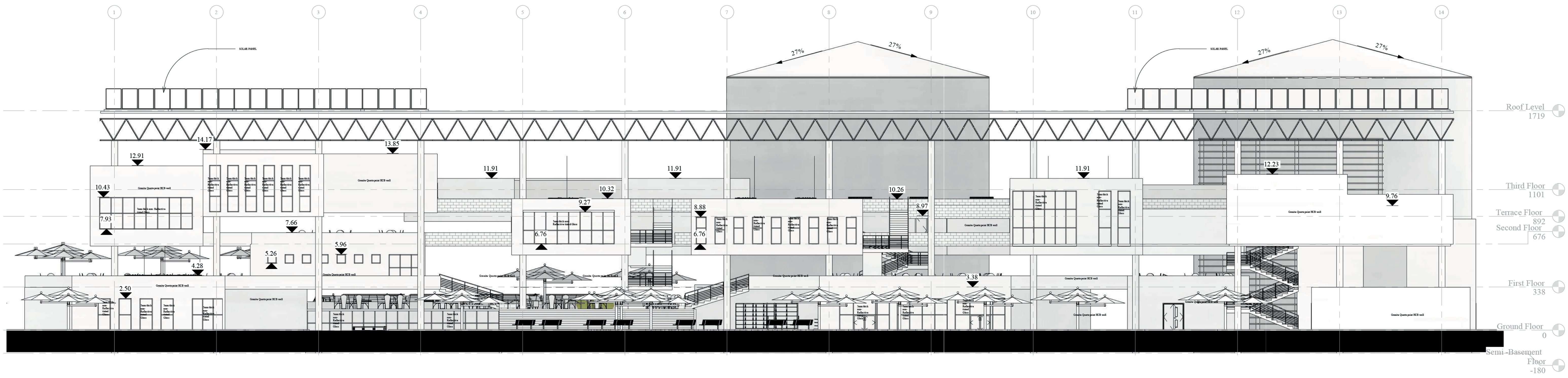
Section 2
1 : 150



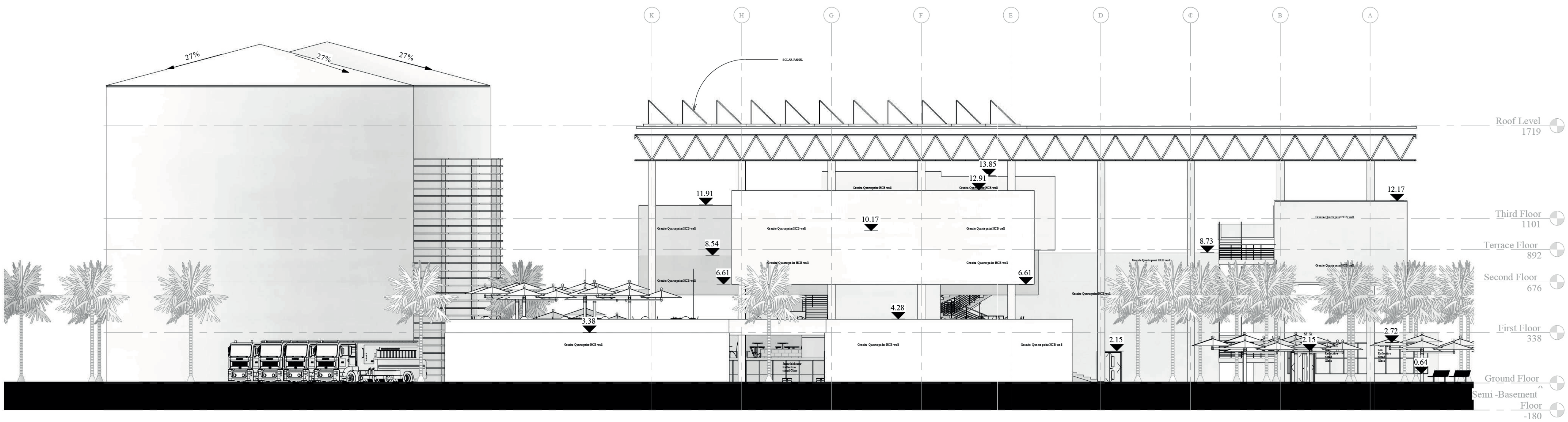
1 3D View 1



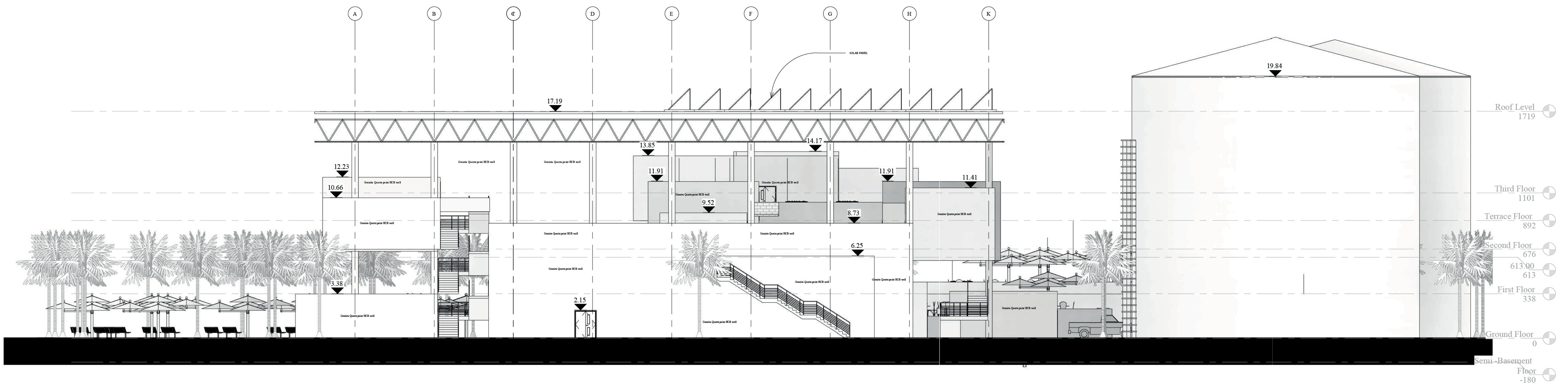
2 3D View 2



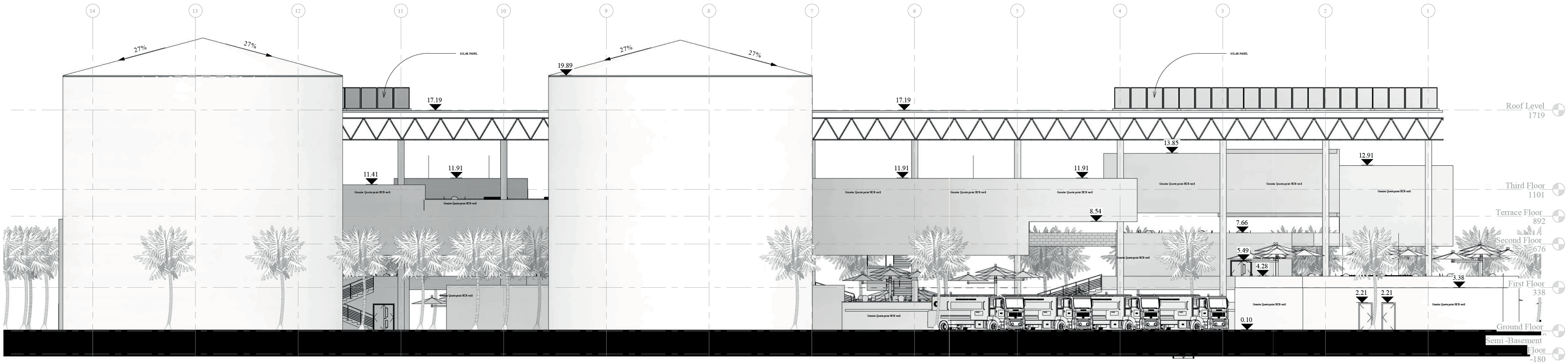
1 South Elevation
1 : 150



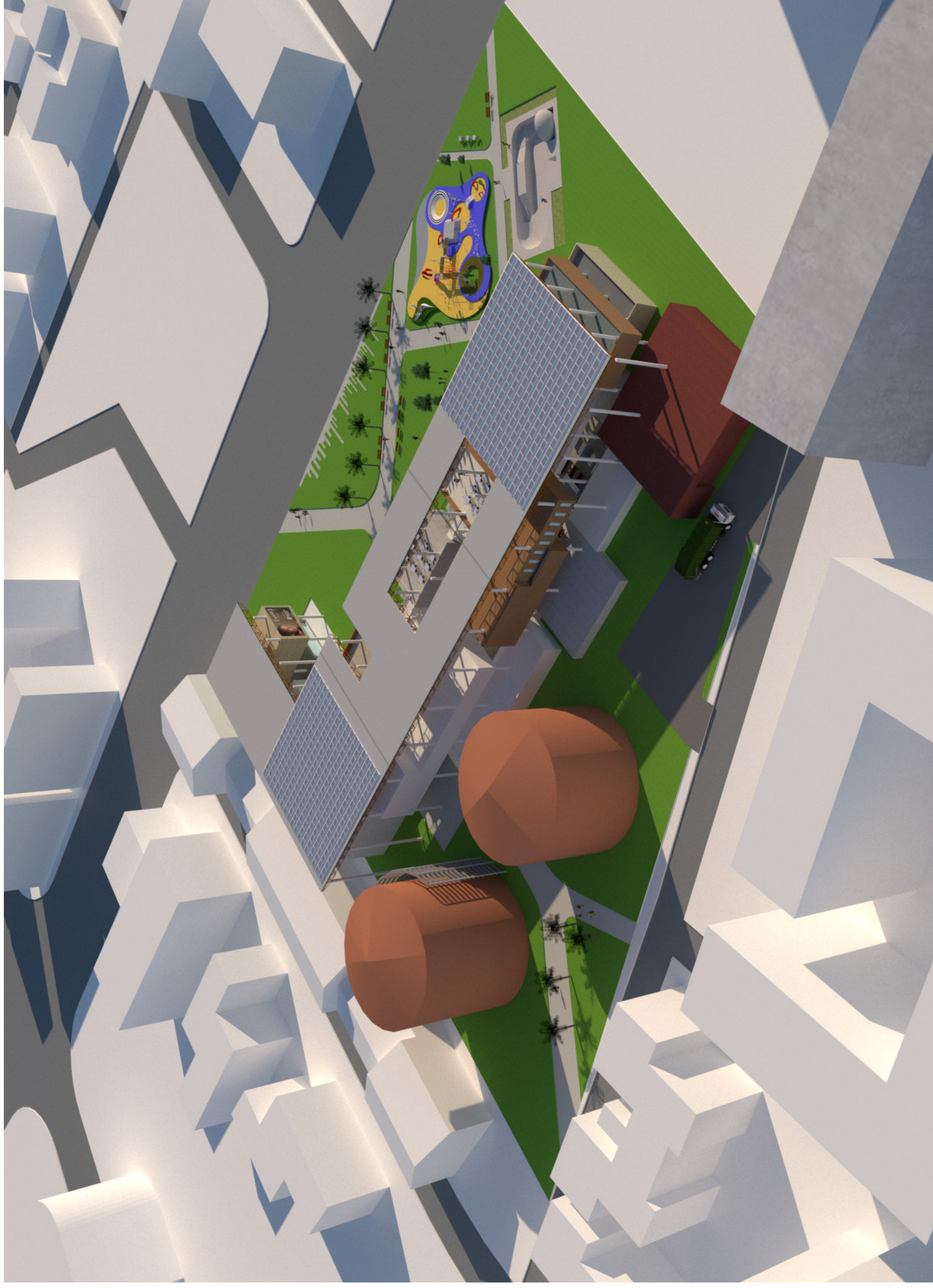
2 West Elevation
1 : 150



1 East Elevation
1 : 150



2 North
1 : 150

7. Conclusion

According to a 2015 World Bank report, the spatial growth of Addis Ababa is estimated to have 46% vacant land, while the city center has a high density of up to 30,000 people per km (i.e., around 30% of the population on 8% of the land). This is a wake-up call to integrate waste management with this rapid urban growth.

Cities are complex ecosystems with many interwoven systems. As we think about the opportunity to integrate waste networks with other urban networks, we can start to look for synergies: places that require us to abandon our binary view of the urban environment: building vs. landscape, private vs. public. Instead, we can turn to nature where complex systems overlap and any synergy between two improves efficiency. Therefore, in analyzing these waste-oriented projects, the hybrid condition elicits further analysis. Several projects, both conceptual and those completed in recent years, allow us to see ways in which designers have been able to engage the general population in the process of waste management. All of these projects take place in cities, varying from all over the world (e.g., the examples in Copenhagen and Barcelona, and German that are described in this paper). These are places where urban dwellers can connect in a new way to the waste that they are generating and understand the critical link between themselves and this more extensive system of which they are an integral part.

In conclusion, this thesis seeks to examine ways to rethink the relationship between people, cities, and the waste they generate. Especially in Addis Ababa, waste has been considered as an untouched and unconsidered topic for a long time, and this speculative design project along with the research that supports it seeks to act as a catalyst and tool for further discussion about ways to reevaluate the perception, management, and treatment of waste. This thesis serves to open the conversation of engaging designers in waste processing.

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