Ethiopian Institute of Architecture Building Construction and City Development (EiABC)

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Enhancing Green Infrastructure and the Thermal Quality of Bare walls through Vertical Greenery Technology:

The Case of Institutional Plots in Addis Ababa, EiABC campus

By

Abdelwehab Yehya Mohammed

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This thesis is submitted to the Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) and to the School of Graduate Studies of Addis Ababa University in the partial fulfillment of the requirements for the degree of Masters of Science in Urban Design and Development.

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Abdelwehab Yehya Mohammed

Approved by Examining Board:

Fisseha Wogayehu (Ph.D.)

(Master's program coordinator)

Chairman Signature......................Date.............................

Alazar Assefa (MSc)

Advisor Signature.......................Date..............................

Dagim Asfaw (MSc)

Internal Examiner Signature........................Date.............................

Girmachew Tariku (MSc)

External Examiner Signature.........................Date.............................

Declaration

I hereby declare that the thesis entitled with Enhancing Green Infrastructure and the Thermal Quality of Bare Walls through Vertical Greenery Technology has been carried out by me under the supervision and continuous advice of Alazar Assefa Wondim, within the Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University, during the year of 2017/18 as a part of the Master of Science program in Urban Design and Development. I further declare that this work is my original work and not presented and submitted to any other University or Institution for the award of any degree or diploma.

Addis Ababa

October 2018

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Abdelwehab Yehya Mohammed

Confirmation

I state that Abdelwehab Yehya Mohammed has carried out this research work on the topic entitled "Enhancing Green Infrastructure and the Thermal Quality of Bare Walls through Vertical Greenery Technology" under my supervision and it is sufficient for submission for the partial fulfillment for the award of MSc Degree in Urban Design and Development.

Institute Advisor's Name: **Alazar Assefa Wondim (MSc)**

Signature: .... Date of submission..

Abstract

Globally, flooding and Urban Heat Island effect (UHI) increase are among the alarming environmental problems of urban centers. Ethiopia, as part of the global temperature increase, is facing the challenge several times. In addition to the global increase in temperature, Addis Ababa, the capital city of Ethiopia experiences the UHI effect phenomena in recent times. The rapid construction of buildings and lack of sufficient Green Infrastructures in the city are contributing to UHI formation. Specifically, the existing bare walls on buildings and other gray infrastructure, without local climatic consideration during their design and development process, contribute to UHI effect formation. The research mainly investigated how to enhance the Green Infrastructure of the city and thermal quality of bare walls through innovative and cost-effective vertical green design and technologies. To realize this, the research first tried to identify bare walls of selected buildings which are the main source of UHI effect; secondly to design living block prototypes for living wall construction and finally to develop the scale-up strategy by taking a case area of the public buildings for their UHI effect reduction and stormwater management effectiveness. Both qualitative and quantitative methods were applied in the study by selecting sample buildings within the EiABC compound. In addition, a case area was selected for scale-up strategies.

The selected buildings as a case in EiABC campus consist of Urban Building, Library Building, Student Café and Dormitory Building and Workshop with the potential to recompense 49%, 12%, 58% and 45% of their footprint respectively by changing their bare wall into a living wall using the proposed prototype design. The scaling up test is carried out on sample condominium building blocks, which is typical in Addis Ababa, reveals that the design can utilize 16.4% of their annual roof rainwater runoff and can decrease their surface temperature by 11 Degree Celsius by changing their bare walls into the Living Wall. Finally, the study concluded that bare walls of buildings, fences, shear walls and retaining walls are among major structure with huge potential for Green Infrastructure development in order to reduce the impact of flooding and local climatic modification in Addis Ababa and other densely developed cities. Motivating vertical greening practices, setting regulations for bare walls to be green with further researches on the structural stability of living blocks is the major part of the recommendations of the study.

Key Words: Stormwater Management, Living Block, Building Footprint, Scale-up Strategy

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At last but not least, I would like to thank the Water Resilient Green Infrastructure in African cities (WGA) research team members, for their initiative on the landscape-based stormwater management project in EiABC campus which provided very important input for the study.

Table of Contents

Lists of Figures

List of Tables

Acronyms

EiABC Ethiopian Institute of Architecture, Building Construction, and City Development

FAO Food and Agriculture Organization (of the UN)

GI Green Infrastructure

GIS Geographical Information System

GS Green Space

HCB Hollow Concrete Block

IA Impervious Area

IDCIA Indirectly Connected Impervious Area

LWS Living Wall Systems

TIA Total Impervious Area

UHI Urban Heat Island Effect

UN United Nations

VG Vertical Green

WHO World Health Organization

CHAPTER ONE:

1. Introduction

1.1 Background of the Study

Nowadays architects and engineers try to design and develop environmentally friendly buildings and infrastructures in order to compensate environmental degradation due to rapid conversion of the natural landscape into built-up areas. In this regard, urban developers are currently searching vacant space within already developed urban areas either on rooftops, bare building walls, fences or on other suitable structures to plant vegetation. Hence, the greening of the façade of building walls, known as vertical greening systems, is gaining popularity (Wong et al., 2009). According to Yu-Peng yeh (2010), the color green can bring harmony to people's mind. People living or working in cities, especially need to slow down their fast-paced life by looking at green plants. The widespread use of vertical greening systems on the numerous building walls in cities do not only represent a great potential in reducing urban noises generated from traffic and machines, it is also a highly impactful way of mitigating the urban heat island effect (UHI) and transforming the urban landscape (Wong et al., 2009). Accordingly, greenery claims to have many benefits such as aesthetics, energy saving, air quality improvement, decreasing the temperature and a sound insulation character (Bioscience, 2007).

Many studies conducted to increase knowledge about the effects of the greening of urban areas on the available open green spaces. However, more research is needed about the new applications for green facilities on urban structures such as rooftops and walls. Land becomes expensive in urban areas and there is not enough space to create green infrastructure. With other words, lack of available spaces is the main problem for urban green applications. In this regards, more research will be helpful in order to quantify and to get more insight into the benefits of vertical greenery. This will help to justify the claims made in history about the applicability of the system. Furthermore, the application is more important within dense cities, the greening of buildings (green façades and roofs) can be a promising option to fulfill the shortage of urban green. Roof gardens and green façades, though not a new concept, increase the percentage of greenery in the urban built-up area and bring back the vanishing urban green space (Wong et al., 2003).

1.2 Problem Statement

The Constitution of the Federal Democratic Republic of Ethiopia sets the overall environmental values to preserve and protect under the Environmental Objective of 92(sub-articles two & four). However, the uncontrollable rate of urban population growth in the country started to damage the environment by degrading the natural landscape, which has the capacity to regulate both micro and macro level climatic situations. The ongoing rapid construction dynamics of buildings and other infrastructure without considering the natural hydrology and green system will create unprecedented challenges to our urban areas in the form of pollution, flooding and localized heating (Urban Heat Island effect).

Currently, rapid road constructions carried out in urban centers of Ethiopia, particularly in Addis Ababa, is very extensive in terms of land cover change. Following this road construction, multistory and multi-functioning buildings are developed along the roads. The concentration of buildings alongside the roads facilitated to increase and formation of UHI. Recently, the local temperature is higher around those buildings as areas dominated by impervious parking lots, roads and paved walkways. As a result, multi-storied buildings, which are situated next to wide vehicular roads, are suffering from noise pollution, vehicular smoke pollution, and dust particles, lack of privacy and discomfort due to increased temperature and CO_2 from the smoke. This might be due to lack of thinking to have proper green spaces and unpaved surfaces in the city. As a result, the city of Addis Ababa is exposed to damages from stormwater flooding, UHI effect, and other related environmental crisis. Green barriers that can be sequestrated CO_2 reduce the local increase in temperature and flooding produced from larger built up masses in the city.

Furthermore, there is another environmental problem recently happened in a densely developed part of the city which rises from the utilization of heat absorbing and alien cladding materials over the facades of buildings. This might be to decorate the building facades in a fashionable manner using metal or plastic sheets. Such materials do not complement the environmental or the aesthetic performance of the buildings from sustainable design's point of view. When the entire building is covered with these materials, the development does not merge into the environment, emerge from the environment or have no anchoring natural element that connects the buildings to the surrounding natural system.

1.3 Objectives

General Objective

To enhance green infrastructure and the thermal quality of bare walls of urban areas through the innovative and cost-effective design of vertical green wall for public buildings.

Specific Objectives

1. To identify and measure bare walls potentials for green wall construction of selected buildings in EiABC campus.

2. To design alternatives for a new prototype of the living block for green wall construction.

3. To develop a strategy for upscaling of the green wall design into the public buildings of Addis Ababa for stormwater management and urban heat island effect reduction effectiveness.

1.4 Research Questions

1. How much suitable space is available from the selected building for living wall construction in EiABC campus?

2. What are the possible alternatives to living block design that increase growth media for plantation?

3. How to scale up the green wall to the facades of public buildings of Addis Ababa?

1.5 Scope

EiABC campus is selected as a case study due to being an institutional plot and being an academic center for design and planning. The advantages of technological demonstrations also considered during the selection of the study area. The research area is about 7.8 hectares that include all the existing buildings of the EiABC campus, and only five selected buildings included in the assessment of available vertical spaces /bare walls for vertical greening and living wall construction. The vertical space analysis only focuses on the surfaces exposed to sunlight and suitable for vertical greening. The natural analysis, land use and land cover of the research area is included in the scope of the study. The research aimed to focus on space provision for vertical greenery through design alternatives of the living block and the thematic aspect is excluded due to time restriction.

1.6 Limitation

The research encounters limitation of Technology, finance and time. Limitation of technology on vertical greenery practices influence the strength of the research. Regarding money, the budget given by the University is not enough to taste each design prototype of the living block, as the study mainly relies on demonstration via modeling. Time-wise, the study topic is the current issue of the globe and it is difficult to cover all recent technologies on the study field and also to include social aspects of the study area within the given period.

1.7 Significance

The research will contribute to many parts of the community. For researchers, it can be a takeoff for further study; students can use it as a reference to build Green Infrastructure knowledge for similar studies in this area. Individual investors on HCB block manufacturing can use as a startup for new designs of the living block and can use it as a source of income. For policymakers and the municipality, they can use the research as guidance for urban environmental policy.

1.8 Method of Analysis

The research is categorized under the Applied Thesis Project. Data related to vertical gardening and living walls collected from the EiABC campus. Five selected buildings from the existing 26 building blocks having bare walls have been assessed for their potential and measurement of the area of the bare wall, which can be used for vertical gardens and as living wall. The data are collected, tabulated, analyzed and presented using maps, charts and graphs. Based on the finding from the first objective, new design alternatives of the living block are proposed. Data are also collected from primary and secondary documentary sources of the research area and other sources. Extensive literature used to have a wider understanding of vertical greenery and GI in the research area.

1.8.1 Methods of Data Collection

Vertical gardening and green infrastructure data depend on the physical information of the research area and to collect these physical data, fieldwork observation and surveying method have been used to extract qualitative data from individual building blocks (research area, EiABC campus in Five selected building structures) through the techniques of photographing, sketching, sorting, counting, measuring and classification of buildings and walls.

Table 1: Data Collection methods and techniques

No	Data Type	Sources Type	Methods	Techniques
1	1 Primary	Base map (CAD)	Modeling	Revit graphics
		Maps	GIS Analysis	Shapefile
		Google earth images	GIS Analysis	Shapefile
		Fieldworks	Surveying	Counting
				Classifying
				Sorting
			Observation	Photographing
				Sketching
2	Secondary	Books	Scanning and Skimming	Citing
		Reports		
		Journals		
		Articles		
		Magazines		

(Source: Author)

1.8.2 Data Sources

Primary and secondary data were used. Primary data for Green infrastructure and vertical gardens were maps (Google and a real) and five building blocks of the research area chosen. Secondary data were from master plan reports, books, CAD files and Internet search engines.

1.8.3 Sampling

The research area was represented by 5 blocks to control and manage data from the research area and to properly handle it. Purposive sampling was used for the selection of building blocks and availability of the bare walls for living wall construction. For the selection of the building blocks, availability of CAD file, and Modeling techniques are also taken into consideration as the analysis also included the building footprint comparison with the available bare wall.

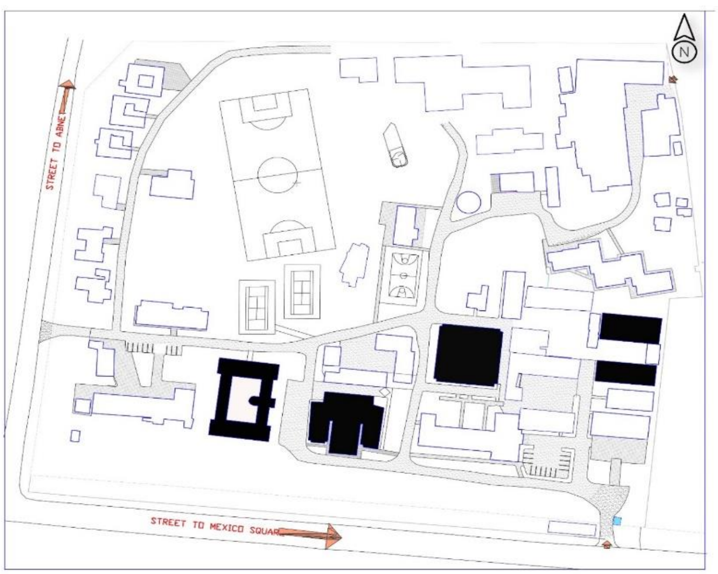

Figure: 1 Selected Building for analysis, (Source: GIS Analysis, Author)

1.8.4 Research Design/General Methodology

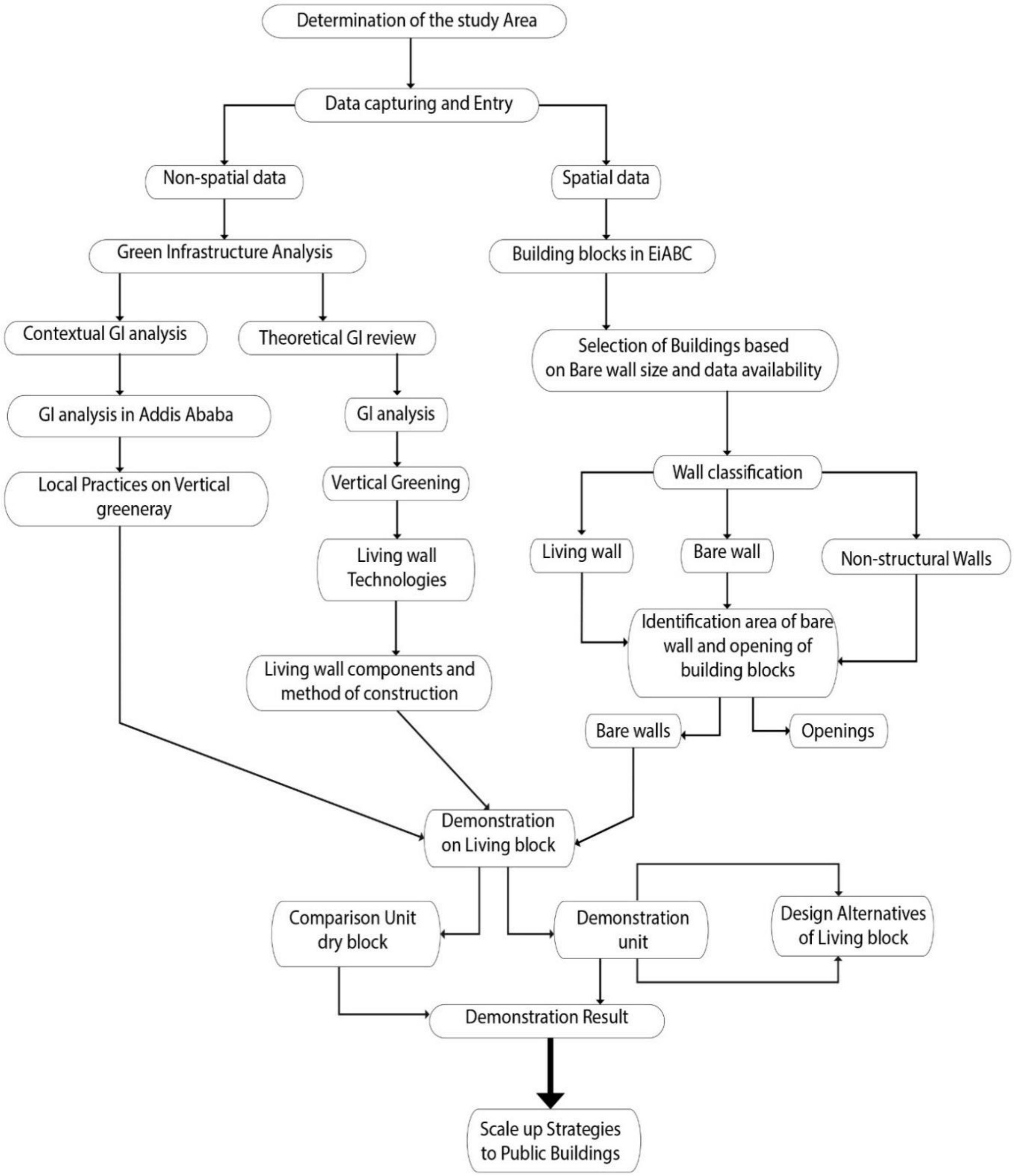

Figure 2: Research Methodology, (Source: Author)

1.8.5 Data Analysis and Presentation

The collected data from primary and secondary analyzed in qualitative and quantitative data forms. Maps (Google and a real) and CAD files will be analyzed by Revit architecture and MS Excel and shown on maps and tables. The building, green space and impervious area analyzed by GIS into maps and tables. In addition, Demonstration supported by 3D modeling software presented. Generally, the data analyzed using different software is presented in maps, graphs, and tables. The table shows the analysis of data by different software.

Table 2: Data analysis tools and outputs

No	Software type	Input	Output
1.	GIS	Maps of Google and Aerial photograph CAD files	Maps Graphs Tables
2.	MS Excel	Raw data	Graphs Tables
3.	Revit Architecture	CAD files	3D Models 2D Pictures

(Source: Author)

CHAPTER TWO:

2. Theoretical Review on Green Infrastructure

2.1 Introduction

Green Infrastructure (GI) Green refers to nature (Moughtin & Shirley, 2005) and Infrastructure is a network of structure and sub-structures (Brad et al. 2001); Thus it is engineered green infrastructure, which mimics nature (Rutherford, 2007), and advocates design with nature. Generally, GI is defining as the network of green space, engineered green structure and substructure in a city. GI is consisting of natural and developed systems of parks and reserves; backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries (Martin and Pitman, 2012).

Different scholars have adopted the definition of GI differently in relation to the contexts and concern of different countries. It is defined as "a network of natural systems in urban areas‟ (Fawn and Chau, 2009). Emphasizing networking green areas is a strategic plan, which integrates different green spaces and enhances biodiversity (Mell, 2011). This helps to maintain the health of the ecosystem. Beyond the working of GI to connect greeneries, it recreates systems of declined and destroyed natural habitats (Lucius, et al., 2011). In some area it is a network of decentralized stormwater management (Center for Neighborhood Technology, 2010), and to some other country, GI is a hierarchy of network of hydrological techniques and projects of a city (Sexton, 2009), the engineered projects mimic natural system to mitigate climate challenges (North Michigan Council of Government, 2008).

Generally, GI is a system of connected natural and manmade structures of urban areas that create a harmony of green networks and green systems, which accommodates biodiversity in the urban areas.

2.2 History of GI

Green Infrastructure is not new in the design field; it is dated back to prehistory. Ancient Ziggurat of Mesopotamia is the first described for man-made, gardens above grade (Osmandson, 1999). Many of the flat landings of these stepped pyramids of stone are planted with trees and shrubs. These vegetated terraces offered resting places and relief from the heat during the climb to the top of the structure. The Hanging Gardens of Babylon provide another legendary example of GI. The terraced structures supported by a series of vaults to hold the soil and plant material. Generally, GI elements and systems are observed in many ancient civilizations of Egypt, India, Greek. The idea of integrating GI is to solve climatic condition (comfort) and to use local material and construction techniques (Osmandson, 1999).

On the contrary, modern theory behave differently from the above-mentioned history. It is a fashion in a city opposed to a countryside, in which cities are viewed as a physical manifestation of humanities separation from and controlling nature (Brazy and Dumpelmanm, 2011), due to this reason a city is considered as "second nature" (Heynen et al., 2006). Modern practice is engineering oriented megastructures, which subdued over nature governed by the theory of “freedom from nature” (Pickett et al., 2013).

In response to modern theory and practice, contemporary theory has extended to solve urban problems. The depth of thinking to elaborate GI has been increased in the course of time, to mention some of the theories: Garden City, the theory of Howard in 1902; is to solve pollution and social problems by providing gardens and green belt (Corocic, 2009), communal garden space. While Broadacre theory by Wright was advocating individual conquering of nature (Duany et al., 2003) and disperse dens city to enable individuals‟ enjoyment of open space and gardens. In addition, there were city beatification movements, to heal cities’’ problem by parks and geometric orders (Levy, 2009). The most recent theory is linking theory, as its name implies that it links the city with nature and advocates nature in the city (Pickett et al., 2013). Bio-urbanism is also another theory emerged as recently as 2010. It is an interdisciplinary science, which focuses on urban organisms and their complex interaction with urban systems (Caperna and Tracada, 2013).

2.3 Function of GI

Everything in the earth survives according to ecological processes (Youngquist, 2009). However, the process is greatly destructed in cities. The level of destruction is measured by green infrastructure yardstick. In this respect, it enhances connectivity for species and maintains bio-diversity (Lawton, 2010). The function of GI is mainly stipulated as follows: landscape setting and contextual development to integrate development area with the existing urban areas and surrounding natural areas. Also, habitat provision and access to nature, by maintaining key habitats (hedgerows, tree belts, ponds, watercourses, and ditches) and flood controlling mechanisms which incorporates water bodies (FCM, 2001). GI paves the way to integrate with Liner Park, the multimodal public right of way, green corridor, recreation/ sports areas, play areas, tree-lined street, and watershed. Conservation of habitat of retained tree and hedgerows, wild areas and wildlife corridors, restored water bodies and wetland environment (Crown, 2010). Food production and productive landscape of community garden, community park, allotment and plans organic farms. Flood attenuation and water resource management, in this case, GI works to manage the issues by using SuDS (sustainable urban drainage system) system in woodland and hedgerows, public squares, long-distance footpath and green roof (Rutherford, 2007). Countering heat island mitigates the situation by providing green building and other greeneries of the urban areas (Watkins et al., 2010).

Generally, the function of GI is to maintain natural systems, by creating connection and integration with the existing nature and restoring nature by conservation works in the degraded environment. The work of GI is extended towards bio-diversity formation and habitat protection in urban areas.

2.4 GI Index

It is a list of GI components in urban areas (Rutherford, 2007). The presence and mismanagement of many urban forms (structures) and functional systems affect the greenness of urban area. The index includes impervious area, water sensitive urban design, green networks, and green buildings. The content of GI is more than the aforementioned, but the scope of the research is to cover the green network and the green building concepts.

2.4.1 Green Network

It defined as the matrix of natural and developed open green spaces (Ada Development Service, 2006) or natural, semi-natural and urban green spaces (Matthew, 2012). The network reference to the connection (corridors) among the green space matrix (Ely and Pitman, 2012). The provision of green spaces in an urban area is different for different countries. In the developed country $40m^2$ per capita and $140m^2$ per capita is provided in urban and suburb respectively (Singly, et al., 2010). The minimum standard of green spaces provision by WHO and FAO in an urban area is $9m^2$ per person (Singly, et al., 2010). Generally, green space network is an interwoven space (green or open spaces) of natural and developed space in the urban area. The connection of green space is vital for people to relax and engage with nature and develop suitable biodiversity in the urban system (Moseley et al., 2013).

Green infrastructure network consists of hubs, links, sites, and buffers (Lauzen, 2013). Hub may be a large or small core area for green infrastructure network and provides space for local plants and animals. It is a center of attraction for wildlife, people and the ecological process. Links include linkages, corridors, and greenways that connect hubs, bind the system together encouraging green infrastructure network processing and maintain biodiversity as well. Green sites are small areas of green spaces that produce important ecological and social values. However, it may not be physically linked to the network established by hubs and links. Moreover, buffers are strip area needed to protect critical resources such as important habitats. The provision of the buffer depends on the sensitiveness of habitat; it is 25-300ft (Lauzen, 2013).

Habitat is defined as the element of land surfaces, which can consistently define spatially in the field (Bunce et al., 2008); connection refers to the degree of landscape that facilitates /impedes movement of organisms among resources patches (Tailor et al., 1993), and fragmentation is the entire process of habitat loss and isolation. Pattern fragmentation is the reduction of habitat amount and increases in a number of patches, decrease in their size, and increase in isolation of patches (Fahrig, 2003).

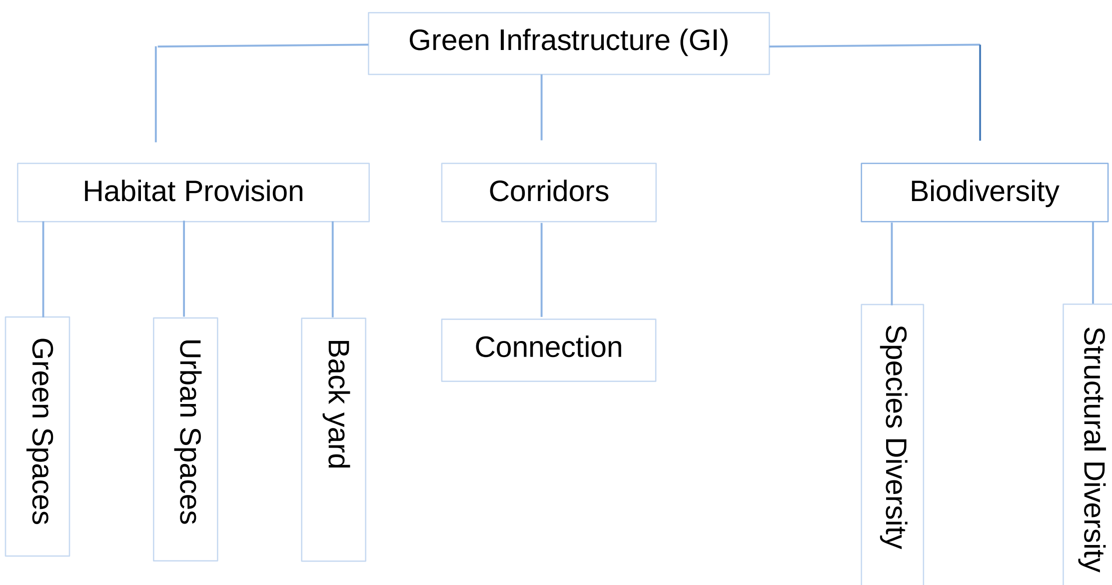

Fig 3. Green Infrastructure Network Diagram, (Source; Ely and Pitman, 2012)

2.4.2 Green Spaces Category

Table 3. Green Infrastructure Categories

Green Space (Open spaces)	
Natural Green open Spaces	Developed Green open Space
Woodland	Irrigated and Maintained Green Spaces
Native Vegetation	Pedestrian/Bicycle Circulation System
Geologic Land Forms	Open Play Areas and Play Fields
Historic/Cultural/Archeological Sites	Play Grounds
Water Bodies/Wetland/Riparian Areas	Picnic Sheltering and Seating
Hill Side Slopes	Architectural features/Buildings
Wild Life Habitat	Informal Recreation Spaces
Ridgeline	Housing Green Spaces
Scenic Buffer Areas	Domestic Gardens
Rangelands	Community Gardens
Agricultural Lands	Roof Gardens
Trails	High Way Trees and Verges
Grass Lands	Living Roof and Living Walls
Brown Field Site	Civic Spaces
Nature Reserves (statutory and no statutory)	Cemetery and Churches

Allotments, City Farms, Orchards, and Suburban and Rural Farmland	Green Corridors (River and Canals)
	Parks and Gardens
	Hedges
	Functional green space such as sustainable drainage schemes (SuDS) and flood storage areas

(Source; Ada Development Service, 2006)

2.4.3 Scale of Green Infrastructure

Most of the literature uses a hybrid definition, which spans from the regional to the site scale and encompasses the full range of green infrastructure practices that can be applied at those scales. Through this familiar definition, green infrastructure can serve as a system made up of component practices and organized into a pattern, which connects these components and their functions from the site scale to the regional scale. These are regional, local government, subarea/district/neighborhood and site (Rouse and Bunster, 2013).

Table 4: Examples of Scales of Green Infrastructure

Regional Scale	City Scale	Neighborhood Scale	Site / Building Scale
Working farms and forests	Urban forest/tree canopy	Local parks	Bio-swales

Regional parks and nature preserves	Urban parks	Constructed wetlands	Rain gardens
River corridors and greenways	Parkways and boulevards	Green streets	Permeable pavement, Green Building Facades

(Source: American Planning Association, APA)

2.5 Green Building

It is not a new phenomenon but used throughout the history of urbanization. The pronouncing of green building in recent time related to global warming and energy crisis (Chamber, 2011). Green building is a system of practice to green the conventional building with vegetation as part of the green infrastructure model in an urban area. It serves as an opportunity to gain green space in scarce green space and congested areas (Thompson and Sorving, 2008). The component of Green buildings (structures) is a green wall (living wall) and a green roof. The study focuses on the green wall (Living wall Technology).

2.5.1 Bare/Blank Wall

According to the definition provided by the free dictionary, bare/bank wall is a wall whose whole surface is unbroken by an opening. In addition, other literatures define bare wall in different denominations. The bare /blank wall is a wall (including building façades and retaining walls) is considered a blank wall if it is over 3.048metert in height has a horizontal length greater than 6.096 meters and does not include a transparent window or door (Citywide Boise Design Review Guidelines, pg.86, 2014).

In architecture, the expression blank wall used to describe the side of the building in which there are no openings - doors nor windows. Usually, the blank walls reveal an unplanned urban development, resulting in an unqualified image of the place (WMESS 2016). Blank walls in cities sometimes found cladded by different artificial materials like aluminum, glasses, and different plastic finishing panels. In urban areas, Blank walls are causes for urban heat island effect due to their character of reflecting and absorbing heat.

Walls, fences, and railings provide transitions between the private and public realm and contribute to the spatial definition of streets and privacy of yards and courtyards (Urban Design Standards & Guidelines, 2017). In urban design, the notion of alignments of buildings along streets regards to the position of the buildings facades on the street. When the alignments between adjoining buildings are different, green walls used as an element of urban composition to rectify this aspect. The application of green walls can be used to express urban design contents such as the regulation of buildings height, the definition of buildings alignments along the streets, the camouflage of blank walls with absolutely no aesthetic relevance or the reinforce of the sense of intimacy in small spaces (A. Virtudes, M. Manso, Green façade, 2011).

2.5.2 Bare/Blank Wall for Greenery

One of the most import aspects the urban design is the building height due to its context in the surrounding area. Thus, green walls can be used as refined elements in order to promote the harmony in between different building heights. They can be a way to promote the sense of regularization of low-rise buildings, which are surrounded by higher buildings (WMESS 2016).

2.6 Vertical Greenery Technologies Review

2.6.1 Introduction of Vertical Green

Plants grown on vertical surfaces can be simply called a vertical greenery system (Safikhani et al., 2014). Many decades ago building facades were decorated with the use of self-climbing plants and vines growing upward or cascading down rooted on the floor, containers, or rooted on coarse of building surface (Greenscreen, 2012a). In addition, there were instances of using twinning plants supported by trellis and pergolas or use of individual plants on vertical surfaces such as stacked rocks (Jaafar et al, 2011). Recently, vertical greenery systems use traditional architectural features along with advanced materials and advanced technology to enhance design flexibility and to promote sustainable building functions (Kohler, 2008). Apart from using of building façade as growing or supporting media for vegetation, separate structural systems are also attached to the building façade with plants grown on it which is called a living wall (Loh, 2008). As green wall technology is still at its infancy stage it requires proper maintenance, a special consideration in terms of irrigation, drainage, and supply of nutrients. It is challenging to maintain regular plant substance for a long time span over large vertical surfaces (Greenscreen, 2012a).

2.6.2 What is Vertical Green?

Vertical green, also commonly referred to as a 'Vertical Garden' is a descriptive term that used to refer to all forms of vegetated wall surfaces. It is also called a system to attach plants to civil engineering structures and walls of buildings or vertical greened façades are walls that are either partially or completely covered with vegetation, and they have exuberant green looks (Yu-Peng yeh, 2010). Green or greened façades typically feature woody or herbaceous climbers planted either into the ground or in planter boxes in order to cover buildings with vegetation. Supporting systems are sometimes necessary and planter boxes can require specific growing media, much like green roofs, or supplemental irrigation. Annual maintenance is necessary to promote plant survival and growth at the façade (Köhler, 2008). Living wall systems (LWS) involve planter boxes or other structures to anchor plants that can be developed into modular systems attached to walls to facilitate plant growth without relying on rooting space at ground level. The technology can closely ally with green roofs and allows a greater variety of plant growth forms than green façades (Köhler, 2008).

2.6.3 Benefits of Vertical Greenery Systems

Integration of greenery into buildings grants an extensive range of environmental, economic and social benefits. Vertical greenery systems are gaining popularity as a new building technology mainly due to its wide range of positive benefits (Loh, 2008).

2.6.3.1 Environmental Benefits of VG

Green facades improve environmental benefits by basically enhancing the potential area for greenery in urban settings (Kohler, 2008). Green walls contribute to reducing heat island effect by lowering the temperature of building envelope by "Shading, reducing reflected heat, and evapotranspiration" (Green Roofs for Healthy Cities, 2008: p. 14). Green facades found to be the most viable solution for reflection of heat from hard surfaces, which known as the main causes for heat island effect in cities and for the deficiency of greenery in crowded urban environments (Loh, 2008). The increased thermal performance of buildings further contributes to minimizing greenhouse gas emissions by reducing the energy consumption of the air conditioning system of a building (Loh, 2008). A study showed that in Hong Kong, 'canyon air temperature decrease reaches 8.4^{o}C maximum and 6.9Oc daytime average in the green-all case while for the green-wall case these numbers become 3.9^{o}C and 2.5^{O}C, respectively" (Alexandri and Jones, 2008, p.486). "when both walls and roofs are covered with vegetation, reaching up to 8.4Oc maximum temperature decrease for humid Hong Kong" (Alexandri and Jones, 2008: p.493).

According to Sheweka and Magdy (2011) vertical greenery systems also provide environmental benefits by enabling control of water runoff from the building roof and minimizing the sound pollution in the urban areas by acting as a sound barrier. Environmental benefits of the vertical greenery systems further extend to air quality improvement by reducing the concentration of airborne particles and absorbing gaseous pollutants (Sheweka and Magdy, 2011). Green facades facilitate tolerable substitute environment for urban vegetation and inhabitant wildlife (Sheweka and Magdy, 2011). Some of the other possible benefits that can be gained from green walls include enhancement of urban biodiversity and urban food production (Loh, 2008).

2.6.3.2 Economic Benefits of VG

Vertical greenery systems vastly contribute to reducing the energy cost of heating and cooling of a building by acting as effective shading to the building façade (Sheweka and Magdy, 2011: Loh, 2008). The degree of the economic benefit depends on the number of factors including climatic conditions, distance from sides of buildings, characteristics of the building envelope and configuration of the greenery cover (Green Roofs for Healthy Cities, 2008). Effective use of vertical greenery systems can contribute to a significant reduction in building cooling load. According to Wong et al. (2012a) in tropical climates, maximum reduction of 11.58^{O}C of wall surface temperature can be obtained, which will greatly impact on the reduction of building energy consumption.

Vertical greenery systems also help to reduce the extent of the use of stormwater drainage infrastructure of the building (Sheweka and Magdy, 2011). In addition, vertical greenery systems "protects exterior façade finishes from UV radiation, the elements, and temperature fluctuations that wear down materials" (Green Roofs for Healthy Cities, 2008, p.16) which will result in reducing cost on the painting materials and other finishes (Sheweka and Magdy, 2011). Vertical greenery systems can be further used as a green marketing tool which will provide indirect economic benefits (Green Roofs for Healthy Cities, 2008).

2.6.3.3 Social Benefits of VG

Enhancing the visual richness of the environment with plants can be considered as social benefits as greenery effect on human psychology and enable stress releasing which results in health benefits (Sheweka and Magdy, 2011; Loh, 2008). “plants can generate restorative effects leading to decreased stress; improve patient recovery rate and higher resistance to illness” (Sheweka and Magdy, 2011; p. 596). Thus, visual and physical contacts that can be created by vertical greenery systems can result in direct social benefits of the occupants in the building as well as the general public.

In summary, vertical greenery systems can be considered as an upcoming conception of incorporating greenery into built environment mainly in urban settings in which its applications, benefits, and technical information are yet to be fully explored and exploited to gain optimum benefits (Wong, Tan, Tan et al., 2010b; Loh, 2008).

2.6.4 Classification of Green Walls

Green walls can be categorized into three types in relation to walls shape and to apply vegetation into it, like a climbing wall, hanging down the wall and modular wall (Thompson and Sorving, 2008). Climbing green wall is a plain wall and covered with climbers (self-climber-no support need, twining climber-support need and rambling shrub strained) with on container soil or fixed on the ground. Hanging down type wall is from a balcony or podium and vegetation installed on the balcony or podium and hanging down from the container soil of balcony or podium. Table Five shows the construction technique of green wall.

Table 5. Construction Technique of Green Wall

construction technique type	Description	Sketch
Block	Engineered with gaps where plants root through the wall	
Crib Wall	concrete or wood elements stacked “log cabin” style	
Frame	stacked interlocking O-or diamond shape masonry	

Though	stacked soil-filled tubs (retaining of free-standing).	
Gabion	stone-filled wire baskets, strong but permeable	
Mesh	like mini gabions, holding a thin layer of soil to a surface	
Cell	flexible strong honeycomb filled with soil also use horizontally	
Sandbag	geotextile wrapped around soil formally called "vegetated geo-grid".	

(Source; Thompson and Sorving, 2008)

The construction methods and material for green wall vary among professionals, particularly the modular wall. They develop a different type of construction techniques and methods. Today bare walls of buildings are being used frequently for living wall construction. New technologies and systems for living wall are construction applied in different parts of the globe. The most recent systems of living wall construction are listed in Table Six.

Table 6: Current Living Wall Systems

Living wall system	Description	Picture
Vertical Displays	Typically, vertical displays use grids to support potted plants. Plants are placed in a pot-holding system providing better planting options than a trellis system. costing the consumer US $75-$125 sq. /ft., installed.	
Trellised Walls	Trellised walls use grids or cables to support climbing plants. The plants are at the bottom of the grids or cables, on the floor indoors or on the soil grade when planted outdoors. Trellised walls are used	

	most often outdoors. It is generally the least expensive option, costing the US $50-$75 sq. /ft., installed.	
Modified Trellised Walls	Modified trellised walls use grids to support climbing plants, which are planted in modules within the system instead of on the ground or floor. This is generally a less expensive option, costing US $75-$100 sq./ ft., installed.	
Planting Pockets	With a planting pockets system, fiber plant pockets mounted on a wall, and soil media and plants planted directly into the pockets. This type of system used in outdoor and indoor spaces. This is generally another less expensive option, costing the US $65-$95 sq. /ft., installed.	

Engineered Modular Systems	With an engineered modular system, modules of plants are used. These have supports to keep in the growth media and weigh around 20-25 lbs. per sq. ft. The growth media support can be complex and expensive. This is an excellent system for highly designed walls and typically has a Three-month grow-in period. Irrigation is usually built-in and placed on automatic timers. This is a more expensive option, with costs ranging from US $100-$200 sq./ ft., installed.	
Fixed Hydroponic	Fixed hydroponic vertical walls are lightweight and allow for a large variety of planting options. In this bare-root, system plants with little or no soil placed in pockets attached to a support structure. Hydroponic systems use other growing media instead of	

	traditional soil, such as rock wool. These walls generally range from the US $90-$150 sq. /ft., installed.	
Modular Hydroponic	Modular hydroponic systems are also lightweight and allow for a large variety of planting options. Similar to fixed hydroponic systems, plants placed in a module with hydroponic growth media and attached to a support structure or incorporated into a modular system. The roots are interwoven with the hydroponic media. Irrigation is also provided at the top of the wall, and very dependent upon regular irrigation and fertilization. Costs can be higher, generally ranging from the US $100-$175 sq. /ft., installed.	

Biofiltration Walls	Biofiltration walls are essentially a highly specialized fixed hydroponic wall, which also allows for a large variety of planting options. In these systems, the plants placed in hydroponic growth media attached to a support structure and integrated with the building's HVAC system. These walls are the most expensive and generally, range from the US $250-$300 sq. / ft., installed.	

(Source: Green Plants for Green Buildings 2014).

2.6.5 Summary of Literature (Researcher Point of View)

2.6.5.1 Description of Vertical Green Systems

Vertical green can be applied in different forms. It is possible to divide vertical greening systems according to their structure, growing substrate, plant species, and watering system if necessary. After a comprehensive literature study, the vertical greenery of buildings can be divided into three different main categories: 1) Green façades 2) Wall vegetation 3) Living Wall Systems (LWS)

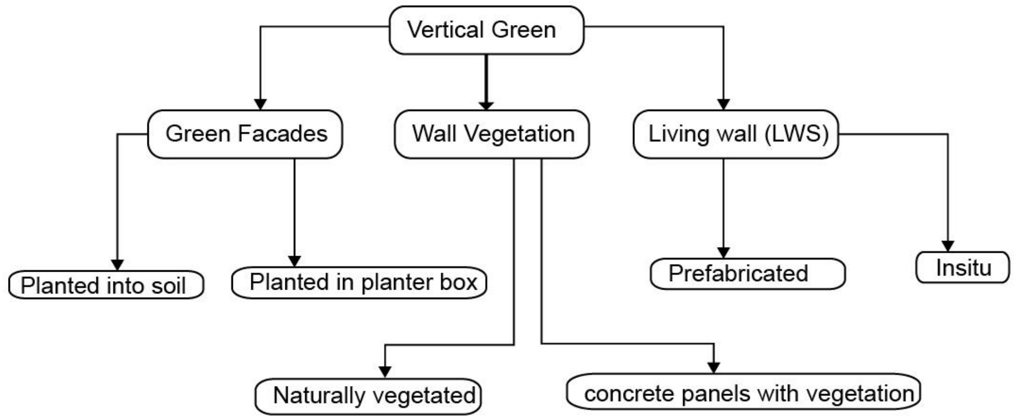

Fig.:4 Summary of Living wall literature, (Source: Author summary)

2.6.6 Concrete panels with vegetation

This type of vertical green, with concrete panels, is a new development of green structures. Presently there are studies in the process to make and test some concrete panels with vegetation on it. The panels are designed with the purpose to take water from natural sources such as rain and snow. The aim of this paper also is similar to such kind of technology, which is to provide space for plantation on hollow concrete blocks that is named “Living Block design”.

2.6.7 Scale-up

According Macmillan dictionary, scale up means to make something larger in size, amount etc. than it used to be. “Scaling-up” is the process of reaching large numbers of a target audience in a broader geographic area by institutionalizing effective programs. While there is no precise definition identifying the amount of increased programming or coverage required for scaling-up, scaled-up programs usually reach (or providing access for) much of the targeted population within a specified area (AYA, 2017).

The term ‘scales up’ is strongly linked to the context. Here the concept of scale-up mainly related to scaling up strategies for the design outputs to public buildings found in the city of Addis Ababa.

2.6.8 Summary

In the review discussion chapter two, it can conclude that the GI is the network of green space and green structures of urban areas. The definition of GI is related to the context and vision of countries to many scholars. The historical development of GI traces back, but its scale of development is a recent phenomenon in response to global warming which ignited by contemporary theory and practices. GI components are an impervious area, green space, green street, green buildings, and WSUD. Green streets and green buildings deal with managing rainwater, UHI reduction and increment of green area in an urban area using vegetation and pervious surfaces. The current initiations and technologies on the vertical green wall for greening buildings playing a great role in environmental protection and biodiversity protection as well.

Generally, using vertical, bare walls of buildings for greening buildings is very important as it highly contributes to UHI effect reduction and increasing GI proportion in urban areas.

CHAPTER THREE

3. Study Area Description

3.1. Description of the Study Area –EiABC Campus, Addis Ababa

3.1.1 Green Infrastructure in Addis Ababa, Ethiopia

Addis Ababa, the capital city of Ethiopia, is one of the largest urban centers in Sub-Saharan Africa. It is located between latitudes 8˚49'N - 9˚5'N and longitudes 38˚38'E - 38˚54'E, covering a total area of 51,957.92 ha (Figure 6). Altitudinal zones of Addis Ababa range from 2054 m to 3023 m above sea level, situated in the foothills of the Entoto Mountains, spread across many wooded hillsides and gullies, cut through with fast flowing streams. At present, the city divided into 10 sub-cities and 116 Woredas (administrative districts). Long-term mean annual maximum and minimum temperatures of the city are 24.4˚C and 7.2˚C, respectively. The total population of Addis Ababa is 3,275,348, which is about 60% of the total urban population in Ethiopia (CSA, 2015).

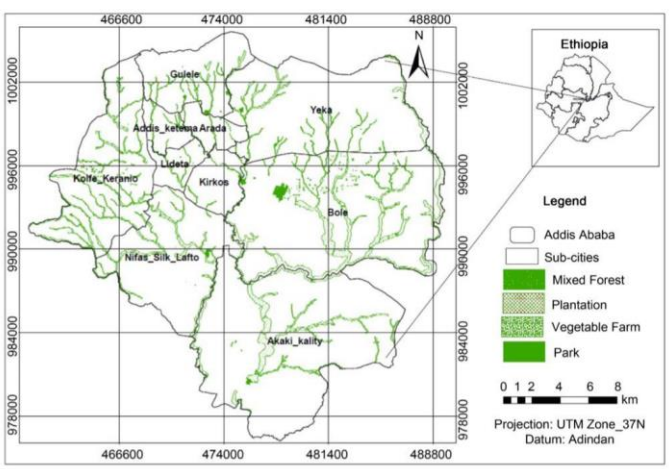

Fig. 5: Location map of Addis Ababa (Source: Assaye, et al. (2017)).

According to Assaye, et al. (2017), the thick vegetation, bare land, and cropland land use and land cover of Addis Ababa have declined, whereas the area of settlement has shown an increase in extent on the comparisons of 1986, 2000 and 2015. The study summarized its result of land use and land cover of Addis Ababa as follows:

Land-use/land cover category	1986		2000		2015	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Thick vegetation/ forest land	11,040.50	21.2	5238.90	10.08	2730.42	5.26
Urban crop land/ grassland	20,705.40	40	18,835.10	36.25	10,756.70	20.70
Settlement	7005.60	13.4	14,037.60	27.02	25,715	49.49
Water body	4416.84	8.5	5870.10	11.30	6838.6	13.16
Bare land	8789.58	16.9	7976.22	15..35	5919.20	11.39
Total	51,957.92	100	51,957.92	100	51,957.92	100

Fig. 6. Land-cover distribution of the year 1986, 2000 and 2015, Addis Ababa,

(Source: Assaye, et al. (2017)

Green area and is distribution patterns in the Addis Ababa city are decreasing year to year. Yeka and Gulele sub-cities have only about 0.005% of the green area, Akaki-Kality sub-city; Nifassilk-Lafto and Bole have only less than 0.002% green area. Arada Kirkose and Lideta sub-cites hold too low green areas and Addis Ketema sub-city has almost no vegetation cover while Kolfe Keranio has 0.03% green area (Assaye, et al. (2017)).

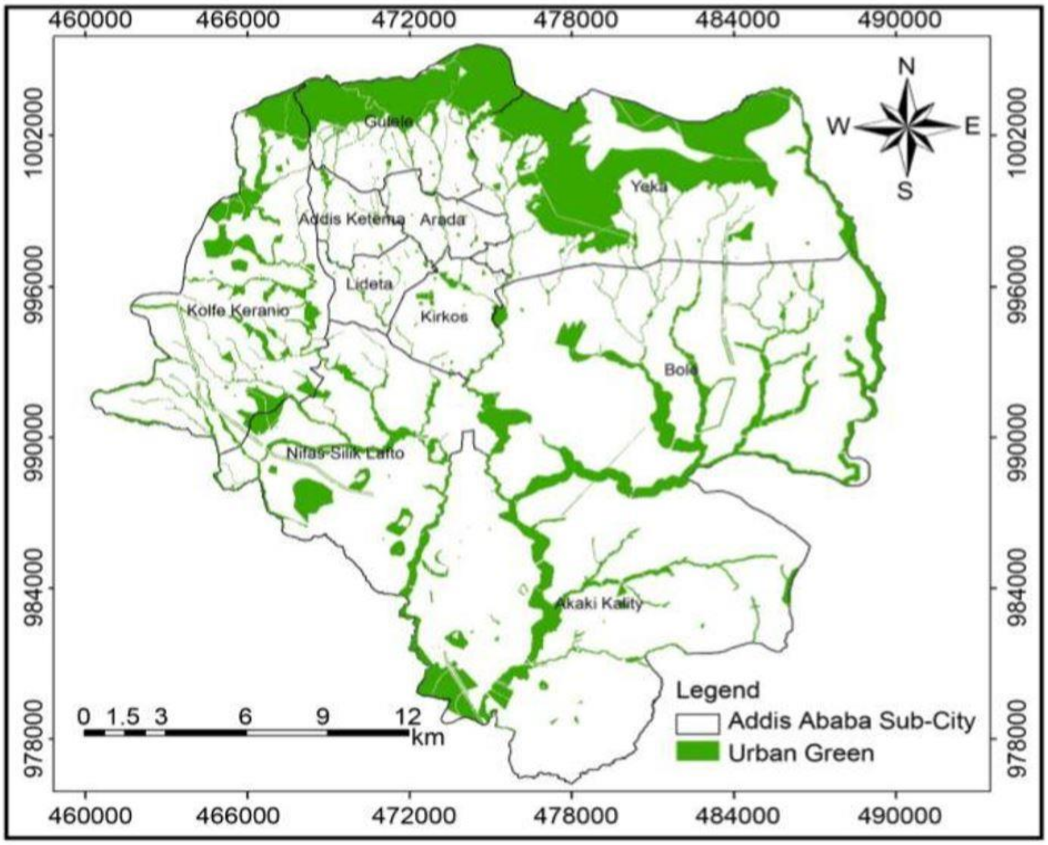

Fig 7: Urban green space in Addis Ababa (2015), (Source: Assaye, et al. (2017))

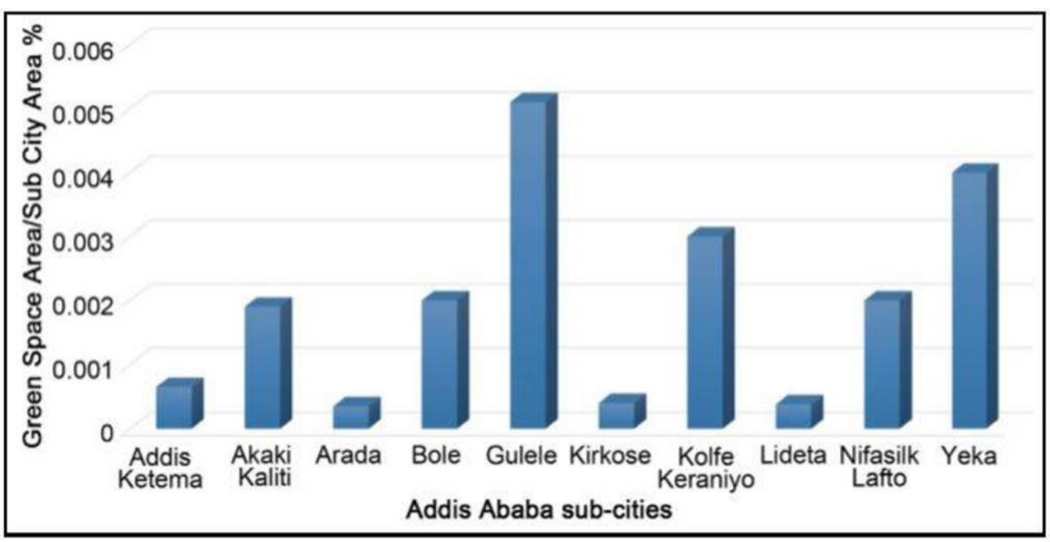

Fig 8: Comparison of urban green space in 10 sub-cities of Addis Ababa,

(Source: Assaye, et al. (2017))

At this moment, the increase in the level of imperviousness against the reduction in natural landscape in Addis Ababa signifies the deterioration in environmental quality in the city. Vegetation, cropland/grassland, bare land, settlement and water bodies were either increased or decreased in extent in different rates during 1986-2015 in Addis Ababa city area. The greenness of the area serves as a means of urban environmental quality (Assaye, et al. (2017)). Information on the green area in cities is important for maintaining urban environmental quality. Vegetation is very useful in filtering air, water and sunlight, cooling urban heat, recycling pollutants, moderating local urban climate and providing recreational areas for the people. The ecological functions of vegetation cover in urban parks may filter up to 85% of the air pollutants (Liang, B. and Weng, Q. (2011) and (Bolund, P. and Hunhammar, S. (1999).

According to the study done by Assaye, et al. (2017), In Addis Ababa city, Yeka and Gulele sub-cities has about 0.005% of the green area, while Kolfe-Keranio covers 0.03% green area and Akaki-Kality, NifassilkLafto and Bole contain <0.002% green area. Other inner areas in the city such as Arada Kirkose and Lideta hold too low green areas and Addis-Ketema sub-city contains almost zero or no vegetation cover. Green space in Kirkose, Addis-Ketema, Lideta, Arad and kolfe having least green space (4.8-× 10−6 square meters) are the poorest. Gulele and Yeka have <1.5 × 10−5 square meter vegetation area. The suggested standard of green area for cities is 7 to 12 square meters per capita. This indicates that none of Addis Ababa's sub cities contain the required extent of the green area to maintain environmental quality. Overall, the results point to a decline in vegetated areas in the Addis Ababa city area, and an increase in settlements, cropland, bare land, population explosion, as well as greenhouse gas emission, which act as a threat to the environment of the city (Assaye, et al. (2017)).

3.1.2 Examples of Vertical Greenery Practices in Addis Ababa

Based on Climatic Resilience Green Economy (CRGE) document of Ethiopia, the sequestration rate for both afforestation and reforestation was set at 10.75 t CO2e/ha/year, a number directly taken from the afforestation/reforestation CDM project in Humbo. Thus taking the park coverage of the Addis Ababa City Administration into account; i.e. 196 ha (UEESM Reader, 2013) the amount of carbon sequestration is estimated to be 2,107t CO_2e/ha/year.

Given the importance of green areas for economic, social, environmental, structural and aesthetic benefits; the attention deserved to the management, maintenance, protection, and utilization of green areas are not revealed and barely adequate to the requirement of Addis Ababa City.

According to Asmelash, (2015), the 125 years old, Addis Ababa has the poor green infrastructure and hence the city faced with enormous environmental, social, and economic problems associated with the poor development and management of the green infrastructure. Meanwhile, developing and managing the city green infrastructure will only mean the Renaissance of Addis Ababa. Therefore, if the city's green infrastructure is developed well, Addis Ababa will truly be "New flower" when celebrating its 150-year anniversary (Asmelash, 2015).

Even though the initiative for green infrastructures and green areas is weak in Addis Ababa, but some private developers and governmental institutions, practice some technologies of a green roof in the city. Here are a few examples of green roof practices:

3.1.3 Hope College of Business, Science and Technology, Addis Ababa

In 2003 Hope College of Business, Science and Technology founded by Dr. Minas Hiruy and established under the aegis of Hope Enterprises. The college designed by Geluk en Treurniet Architecten, a Dutch architectural firm, with all the important features befitting an integrated campus. The campus is inaugurated by the President of Ethiopia in 2006. Its first class of students admitted in September 2011. Hope College of Business, Science and Technology are located on Five hectares of land in Nefas Silk Lafto Subcity, Lebu, and Addis Ababa. The architectural design and the urban landscape integration of the buildings taken as an example of practices on green infrastructure in Addis Ababa, (http://www.hopeuniversitycollege.org/).

Fig 9&10: Hope College of Business, Science and Technology, overall site plan and Green Roof of HUC (Source:(http://www.hopeuniversitycollege.org/)

3.1.4 The Gullele Botanical Garden (GBG)

The Gullele Botanical Garden (GBG) is a newly established conservation initiative located at the northwestern tip of the Addis Ababa City Administration. The site covers an area of 1000 ha which is representative of the central plateau of Ethiopia.

Underpinning the establishment of GBG is the fact that a number of Ethiopia's endemic plant species are facing extinction and require protection. One way to guard their survival is by establishing an in-situ botanical garden where endangered plants are grown and nurtured, creating a living gene bank. The GBG co-managed by the Addis Ababa City Administration and Addis Ababa University (through the Horn of Africa Regional Environment Centre & Network (HoAREC&N) in collaboration with the Oromia Regional State. It is the first botanic garden in the country. The main objectives of the botanical garden are to safeguard the future survival of a diverse set of species, conduct plant research, create an urban park for recreation, and improve the practical knowledge of students and the general public in the fields of sustainable gardening, horticulture, floriculture, urban agriculture and forestry (https://www.bgci.org).

Fig11: Gullele Botanic Garden location and territory, (Source: (www.bgci.org))

3.1.5 Summary

As it can be understood from the aforementioned documentation of green infrastructure existence and practice in Addis Ababa, the city is poor on practices of living wall, green roof, and green spaces. The city of Addis Ababa needs more technologies on vertical gardening and green infrastructure practices to recover and to be comfortable for its dwellers. Accordingly, this paper will focus on the technologies of Living wall to enhance the urban environment by replacing the existing drywall by Living walls mainly focusing on institutional plots of Addis Ababa. The land consumed by the impervious area can negotiate by having a large amount of living wall in the urban area.

3.2 Study Area Analysis – EiABC Campus

3.2.1 Location

EiABC is located at latitudes 9˚0'45''N - 9˚0'43''N and longitudes 38˚43'44''E - 38˚43'54''E, covering a total area of 7.8 ha and attitudinal zones of the EiABC range from 2346 m to 2370 m above sea level. EiABC, when founded in 1954 the initial educational scheme aimed to offer a three-year diploma program in building engineering. This shortly upgraded to a four-year program leading to a BSc. Degree in Building Engineering. In 1969, the Building College merged with the college of engineering and formed the Faculty of Technology at Addis Ababa University, and remained as such until 2009 (http://www.aau.edu.et/eiabc/).

Currently, EiABC is an academic institution with a vision to serve Ethiopia’s need in the fields of architecture, urbanism, construction technology, and management.

Currently different academic programs conducted in the Institute such as architecture, construction management, urban planning, urban design, environmental planning, and landscape design. The Institute's major duties and responsibilities are teaching, research and community outreach in the mentioned fields. In general, the Institute produces a higher level of skilled graduates and knowledge as well as provides consultancy service in the specified fields, and plays a crucial role towards sustainable urbanization and urban development of Ethiopia (http://www.aau.edu.et/eiabc/).

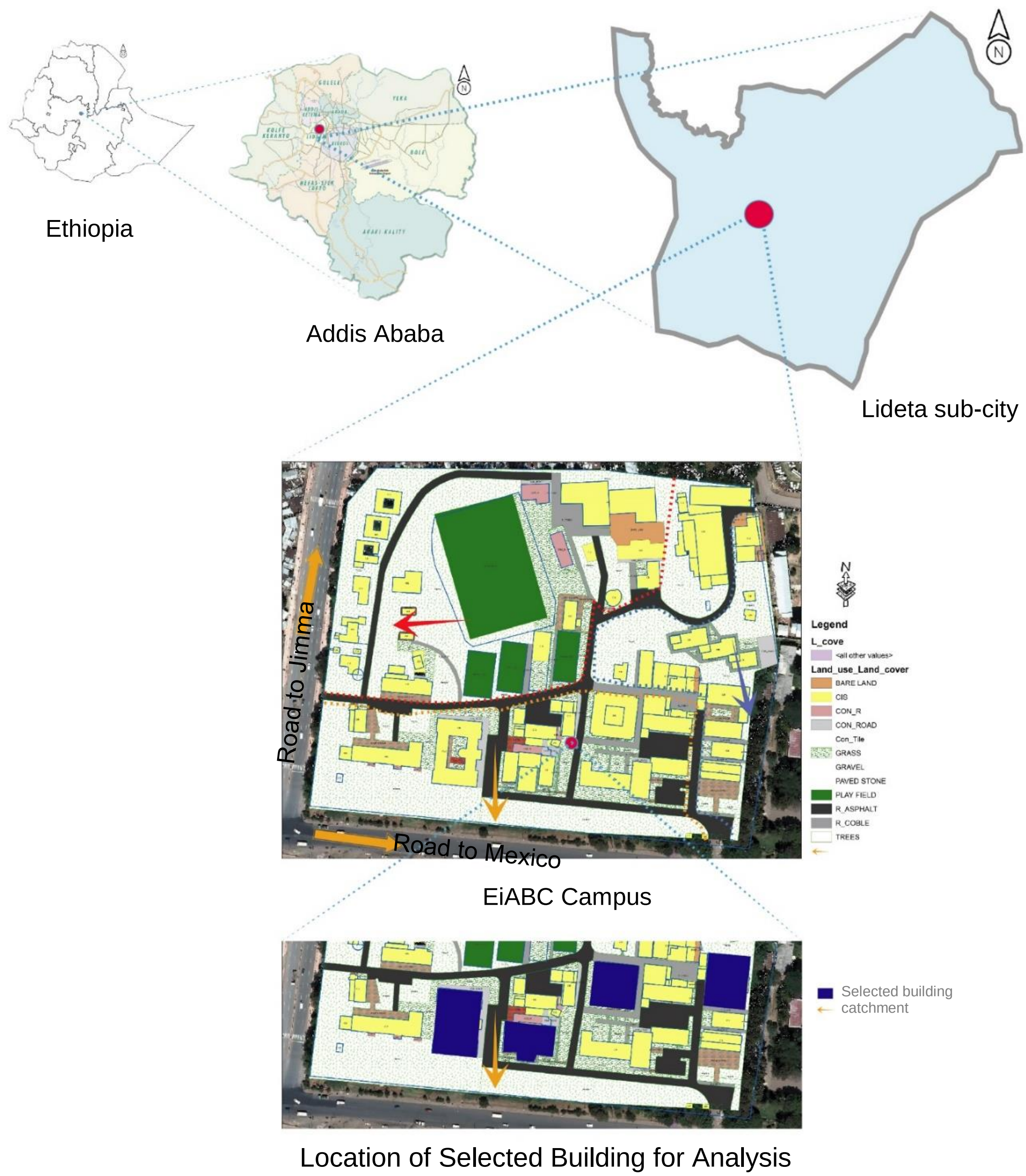

Fig. 12: Location map of EiABC campus, (Source: Author)

Topographically, EiABC is situated within the Little Akaki River catchment. Being in the upper catchment of Little Akaki River, stormwater from EiABC contribute for the flooding of downstream areas like Mekanissa. The natural and artificial analysis of the study is presented below.

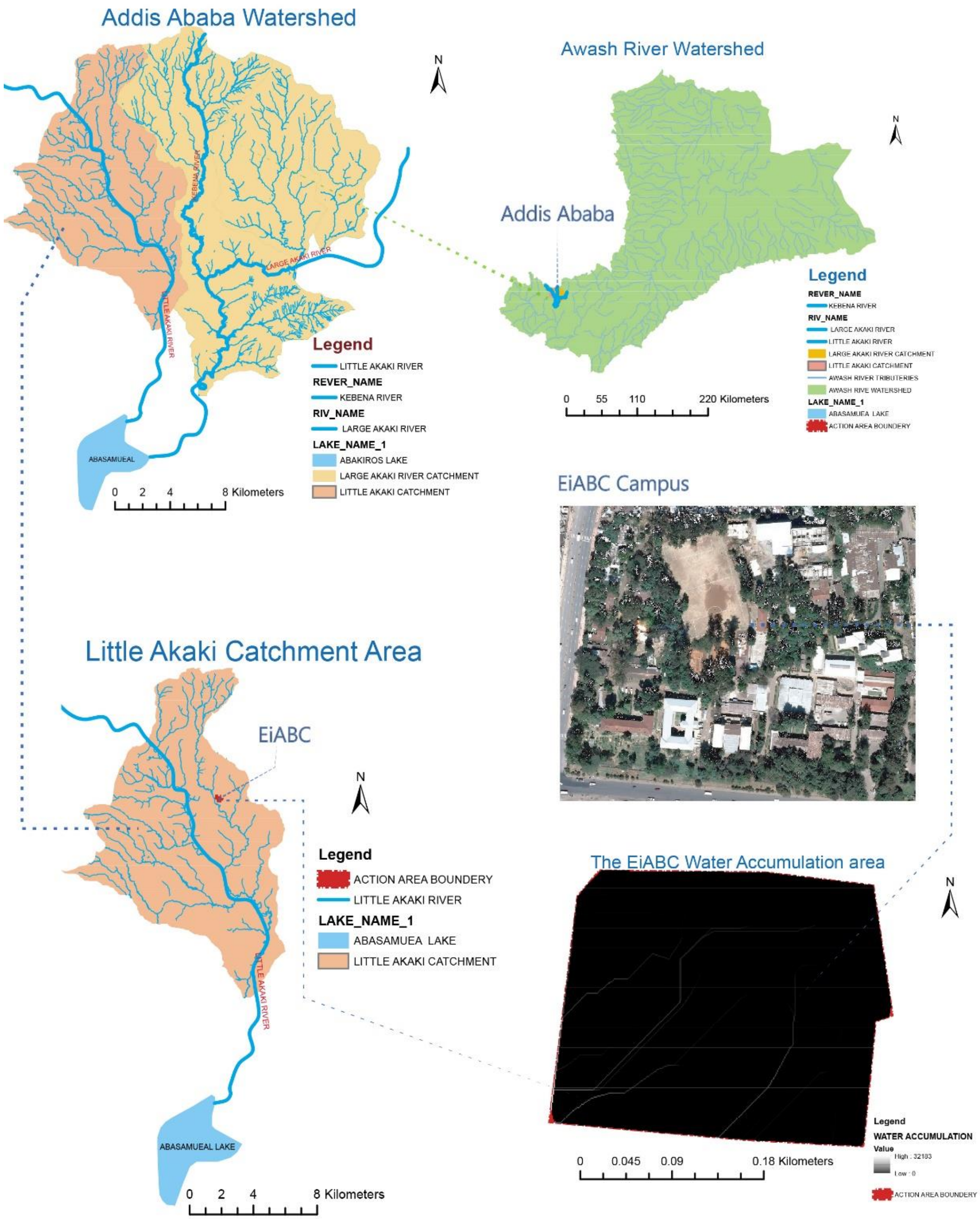

Fig. 13: watershed map of EiABC campus, (Source: Author)

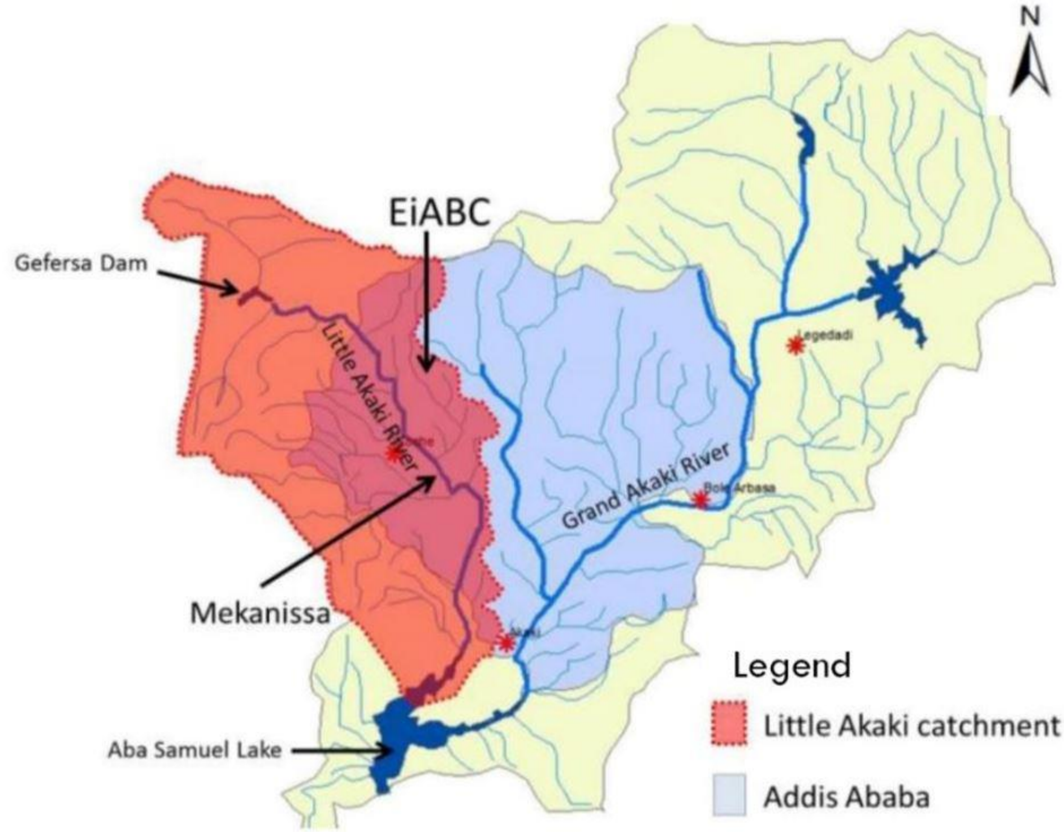

Fig. 14: Catchment category of EiABC campus, (Source: Author)

3.2.2 Topography of the EiABC Campus

Altitude of the EiABC Campus varies from 2341m to 2375m A.S.L. The elevation increase from Southwest to Northeast. This implies that the EiABC situated on an average of 2358m altitude above sea level, having the elevation difference of 34m.

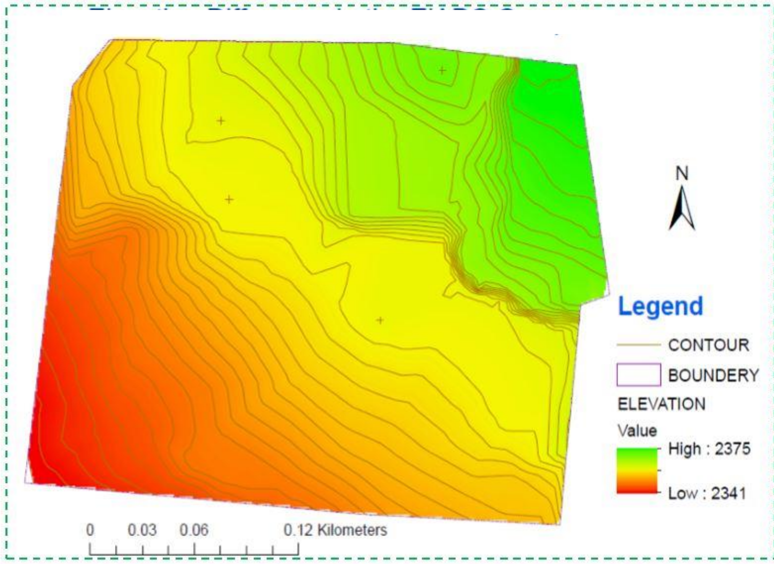

Fig. 15: Elevation difference map, (Source: GIS analysis, Author)

3.2.3 Slope Category of the EiABC Campus

The EiABC Campus slope categorized into seven slope categories. Majority of the topography of the EiABC compound falls in the gradient of 2-5%, which cover an area of 3.05 hectare (39%).

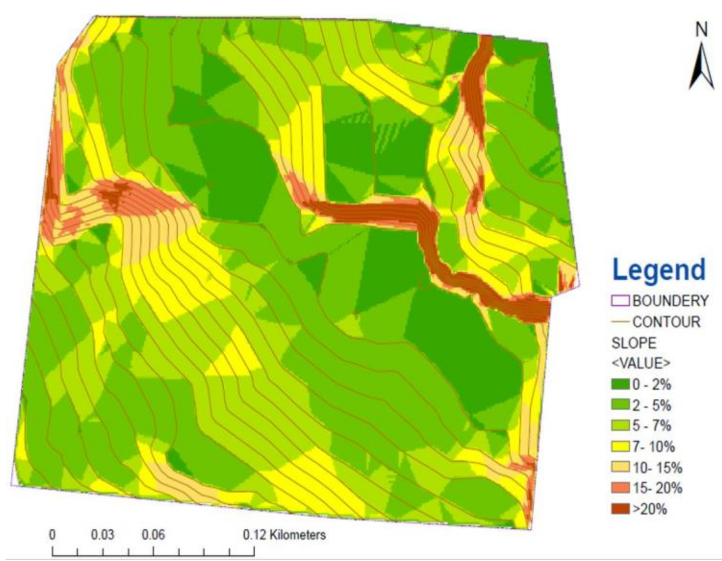

Fig. 16: Slope analysis map of EiABC campus, (Source: GIS analysis, Author)

3.2.4 Aspect of the EiABC Campus

Aspect analysis of an area is important for plantation and building orientation. The solar radiation and its angle are naturally important for plants and vegetation, then following the aspect analysis of an area will contribute positively towards vertical greenery and living wall practice.

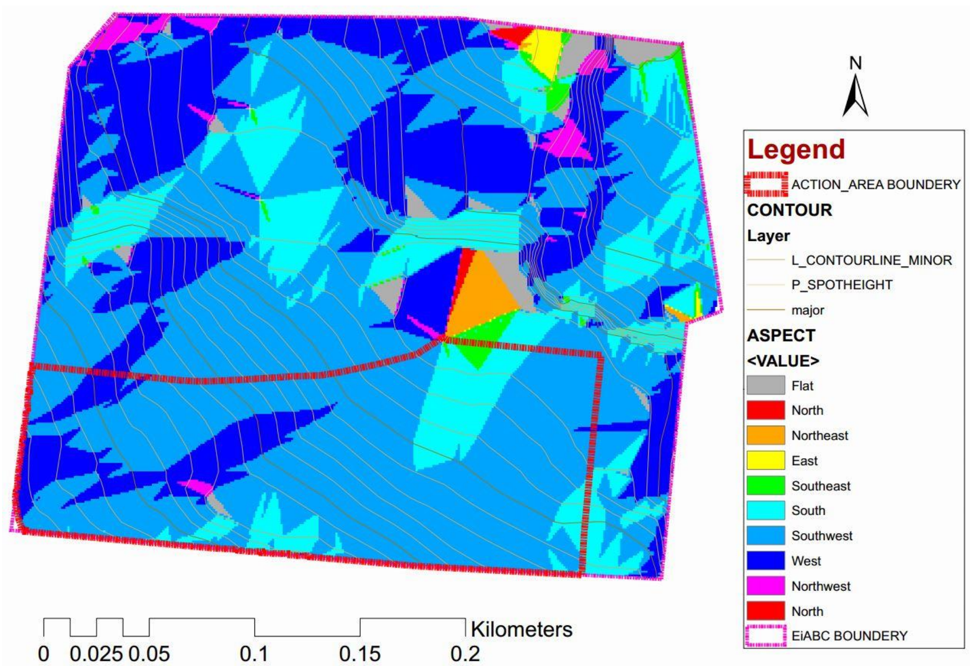

Fig. 17: Aspect analysis map of EiABC campus, (Source: GIS analysis, Author)

The aspect of the EiABC campus is mostly southwest and west aspect that covers an area of 79%. On the other hand, northwest aspect covers the small area, which accounts for 0.13% of the total area. Geographically, South and Southwest topographic aspect is the best aspect, which has solar radiation access. On the other hand, North Aspect used to cool the hot microclimate since it shades the northern topographic feature of the site.

The practice of vertical greenery needs considerations of aspect analysis of the practice area. As vertical greenery uses most of the time part of a building or fence, the possibility of gaining solar radiation is very important which is directly linked to the aspect of the area.

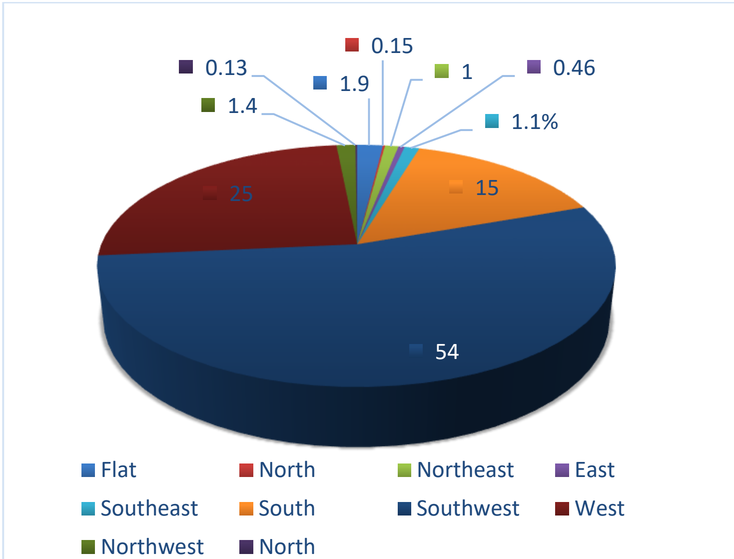

Fig. 18: Aspect proportion of EiABC campus, (Source: Author)

3.2.5 Soil Type of the EiABC Campus

Conventionally soil is basic for plants to grow. Even though modern technologies on vertical farm allow plantation without soil using different technologies like hydro-culture technology, Soil is still important for plants because it holds roots that provide support for plants and stores nutrients. According to the GIS analysis, the types of soil found in the EiABC campus are Eutric nitisols, which is one of the best and most fertile soils of tropical. This type of soil can suffer from acidity when organic carbon decreases they become very erodible soils. Nit soils have moderate resilience and moderate to low sensitivity.

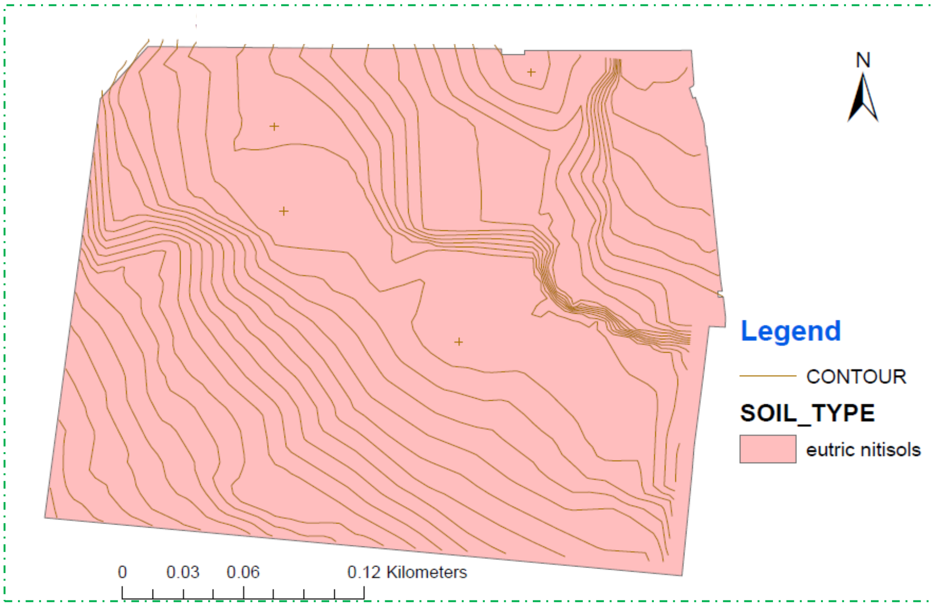

Fig. 19: Soil type map of EiABC campus, (Source: GIS analysis, Author)

3.2.6 Water Table of the EiABC Campus

The water table is the upper surface of the zone of saturation, the zone of saturation is where the pores and fractures of the ground saturated with water (Freeze, R. Allan; Cherry, John A. (1979)). The depth of the water table and its accessibility is directly related to the surface treatment and green cover of an area. The water table in the EiABC Campus is 27-39m depth, which is relatively shallow as compared to the other part of Addis Ababa city, which is mostly above 39m. Relatively it is the shallow water table in Addis Ababa, so it is easily accessible for ground recharging.

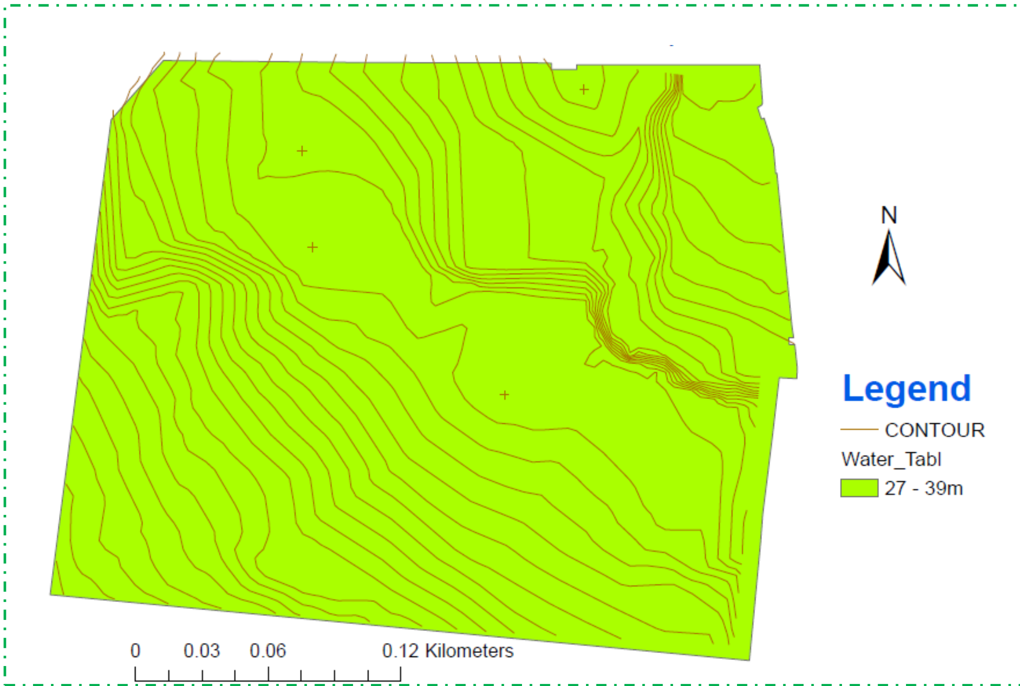

Fig. 20: Water table map of EiABC campus, (Source: GIS analysis, Author)

3.3 Total Annual Rainfall Data of the EiABC Campus

Generally, according to Clima Temps.com, Addis Ababa is provided with on balance 1089 mm (42.9 in) of rainfall per year, or 90.8 mm (3.6 in) per month. On average, there are 148 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 12.3 days with a quantity of rain, sleet, snow etc. per month. The driest weather is in November when an average of 9 mm (0.4 in) of rainfall (precipitation) occurs. The wettest weather is in August when an average of 269 mm (10.6 in) of rainfall (precipitation) occurs (http://www.addis-ababa.climatemps.com/).

The study area shares the character of Addis Ababa in general. The following description of the rainfall data for the study area included the return period calculation of maximum rainfall based on the data provided by the Ethiopian national meteorological agency Tikur Anbessa station. The annual rainfall return-period data on the site calculated by taking the 30 years' annual rainfall data obtained from the nearest station called Tikur Anbessa meteorology station.

3.3.1 Probability of Occurrence and Return Period of Rainfall for the EiABC Campus

Taking the appropriate and representative sample of the data for the intended purpose is the major task to achieve the objective of the study, so the 30 years' data (1987-2016) is analyzed by the return period and its probability of occurring as follows in the table below.

The calculation of the return period was very crucial for the research on vertical greening. The vertical greening research of bare walls in the EiABC campus is proposed to use the rainwater for the irrigation system of the living walls.

Table 7: Annual rainfall and return period of EiABC campus

	YEARS	ANNUAL RAINFALL(mm)	RANK	FREQUENCY OF OCCURRENCE	RETURN PERIOD (years)
1	1993	1567.9	1	1.67	60
2	1996	1548.5	2	5.00	20
3	2005	1460.1	3	8.33	12
4	2001	1452	4	11.67	9
5	2010	1381.2	5	15.00	7

6	2008	1352	6	18.33	5
7	2006	1341.2	7	21.67	5
8	1998	1337.7	8	25.00	4
9	1989	1321.3	9	28.33	4
10	1987	1317.9	10	31.67	3
11	2007	1308.6	11	35.00	3
12	2009	1240.6	12	38.33	3
13	2013	1239.6	13	41.67	2
14	1988	1222.1	14	45.00	2
15	2000	1202.6	15	48.33	2
16	2003	1191.1	16	51.67	2
17	2004	1173.3	17	55.00	2
18	1991	1158.5	18	58.33	2
19	1995	1153.5	19	61.67	2
20	1990	1145.6	20	65.00	2
21	1992	1125	21	68.33	1
22	2014	1101	22	71.67	1
23	2012	1081	23	75.00	1
24	2011	1057	24	78.33	1
25	1994	1052	25	81.67	1

26	2015	1043	26	85.00	1
27	2002	1034	27	88.33	1
28	1997	1016	28	91.67	1
29	1999	952	29	95.00	1
30	2016	929	30	98.33	1

(Source: Ethiopian national metrological agency Tikur Anbessa station and Own computation, 2018).

The maximum annual rainfall is estimated to be 1567.9mm of water, which has a return period of 60 years with a probability of occurrence 1.67%, 1548.5 mm 1460.1 mm is also annulled rain water 20 and 12 years return period with a probability of occurrence of 5% and 8.33% respectively. 1352mm having Five years return period data with a probability of occurrence 18.33%.

The study area has rainfall amount ranging from68 to 98 mm every year. The five-year return period taken into consideration in the analysis and design of vertical greenery and living wall construction.

3.4 Land Use and Land Cover Assessment of the EiABC Campus

According to the GIS analysis of the research, the Ethiopian Institute of Architecture, Building Construction, and City Development (EiABC) campus cover a total area of 7.8 hectares of land. From the physical analysis and site observation, the land use and land cover of the site are categorized into eleven types of land use and land cover.

Fig. 21: Land use and land cover map, (Source: GIS analysis, Author)

From the total area of the land, 37% (2.90ha) of the campus is covered with scattered trees 24 %(1.84ha) of the total is covered by corrugated iron sheet roofs. The land covered by Asphalt road which accounts for 11 %(0.85ha) grassland and plays field having an equal proportion of 8.6 %(0.67ha) of the total area.

Table 8: Land use and land cover proportion of EiABC campus

OID	LAND USE LAND COVER	AREA IN HA	PERCENTAGE
1	Bare Land	0.10	1.2
2	Corrugated Iron Sheet Roof	1.84	23.6
3	Concrete Roof	0.07	0.9

4	Concrete Road	0.18	2.3
5	Grass	0.67	8.6
6	Gravel	0.01	0.1
7	paved stone	0.17	2.2
8	play Field	0.67	8.6
9	Asphalt Road	0.85	10.8
10	Coble Road	0.34	4.4
11	Trees	2.90	37.2
	Total	7.80	100

(Source: GIS analysis, Author)

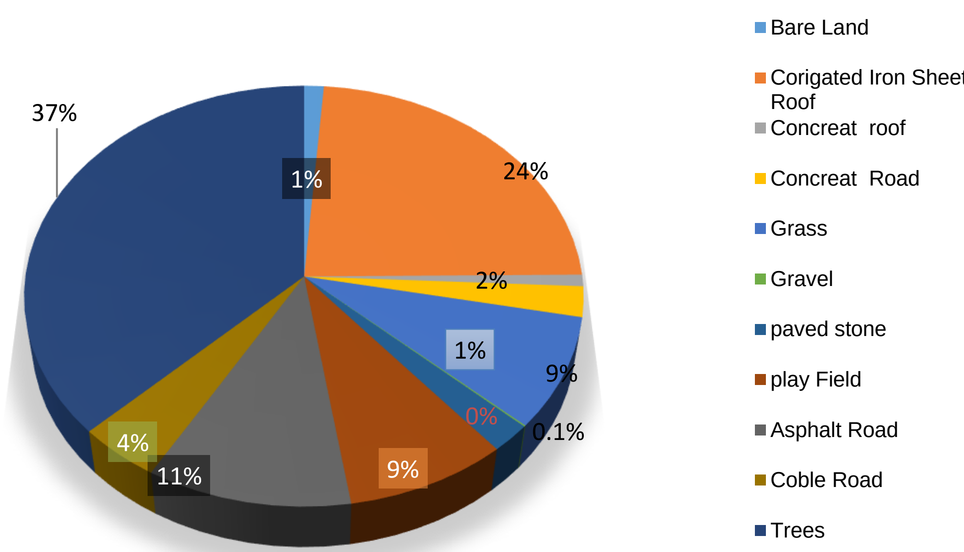

Fig. 22: Land use and land cover proportion chart of EiABC campus,

(Source: GIS analysis, Author)

In addition, the proportion of the impervious surface of the EiABC campus is increasing due to new developments and construction in the compound. According to GIS Based analysis of the site about 37.60% of the campus is impervious and 6.7% surface of the campus is semi-pervious.

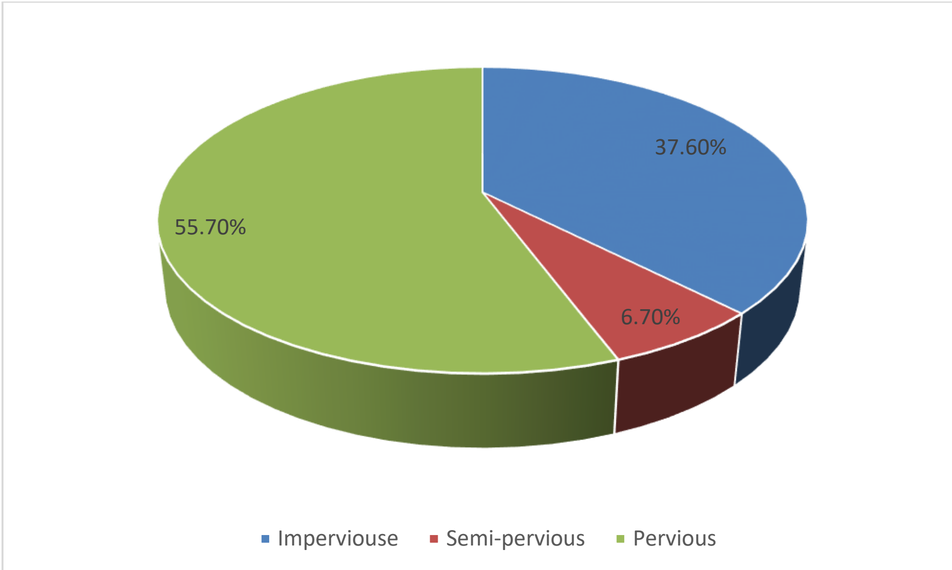

Fig 23: Imperviousness diagram of EiABC campus, (source: Author)

Impervious surfaces are land surfaces that repel rainwater and do not permit it to infiltrate (soak into) the ground. Adding these surfaces to the landscape can alter the flow of rainwater and streams. From the above data interpretation, it is clear that the study area started to be dominated by impervious surfaces. As a result, an increase in imperviousness will damage the natural system of the study area.

3.5 Stormwater Generation of the EiABC Campus

Runoff generated from the site depends upon the nature of the land use, land cover and slope of the surface. Based on the land use and land cover analysis result of the site the total runoff generated by the site and the contribution of each land use and land cover presented in the table below.

Table 9: calculated runoff from each land use and land cover of the EiABC campus

	Land use and Land cover	The area in (ha)	The slope of the surface												Total water volume (m³)	Percentage (%)
			0-2%				2-7%				>7%					
			Area (m²)	Coeff.	Rain intensity	water volume (m³)	Area (m²)	Coeff.	Rain intensity	water volume (m³)	Area (m²)	Coeff.	Rain intensity (mm/h)	water volume (m³)		
1	Bare Land		300.00	0.60	0.064	11.52	100	0.70	0.064	4.480	500	0.80	0.06	25.60	41.60	1.43%
2	Corrugated Iron Sheet Roof	1.84	0.00	0.95	0.064	0	0	0.95	0.064	0	18400	0.95	0.06	1118.72	1118.72	38.33%
3	Concrete Roof	0.07	700.00	0.95	0.064	42.56	0	95.00	0.064	0	0	0.95	0.06	0	42.56	1.46%
4	Concrete Road	0.18	1800.00	0.95	0.064	109.44	0	0.95	0.064	0	0	0.95	0.06	0	109.44	3.75%
5	Grass	0.67	430.93	0.25	0.064	6.89	4586.33	0.30	0.064	88.058	1673.24	0.40	0.06	42.83	137.79	4.72%
6	Gravel	0.01	100.00	0.40	0.064	2.56	0		0.064	0	0	0.00	0.06	0	2.56	0.09%
7	paved stone	0.17	1700.00	0.88	0.064	103.36	0		0.064	0	0	0.00	0.06	0	103.36	3.54%
8	play Field	0.67	6700.00	0.35	0.064	150.08	0		0.064	0	0	0.00	0.06	0	150.08	5.14%
9	Asphalt Road	0.85	644.31	0.95	0.064	39.17	6478.94	0.95	0.064	393.919	1341.55	0.95	0.06	81.57	514.66	17.64%
10	Coble Road	0.34	800.00	0.84	0.064	48.64	2097.704	0.84	0.064	127.540	582.36	0.84	0.06	35.41	211.59	7.25%
11	Trees	2.90	2789.91	0.20	0.064	35.71	16500	0.25	0.064	264.000	9700	0.30	0.06	186.24	485.95	16.65%
	Total	**7.80**													**2918.31**	**100.00%**

(Source: Own calculation, Rational Method of runoff calculation (Q=1/360*CIA)

The total volume of stormwater generated by the site is 2,918m^3 per hour. From the total runoff, 60.21% (1757.03m^3) is generated from the ground surface and 39.79% (1161m^3) of the stormwater is generated from the roof of the buildings. As it is shown on the chart the largest proportion, 38%(1118.72m^3) of stormwater is generated from corrugated iron sheet roof of buildings in the campus 18%, 17% and 7% of stormwater is generated by Asphalt road, land covered by tree and cobble road respectively.

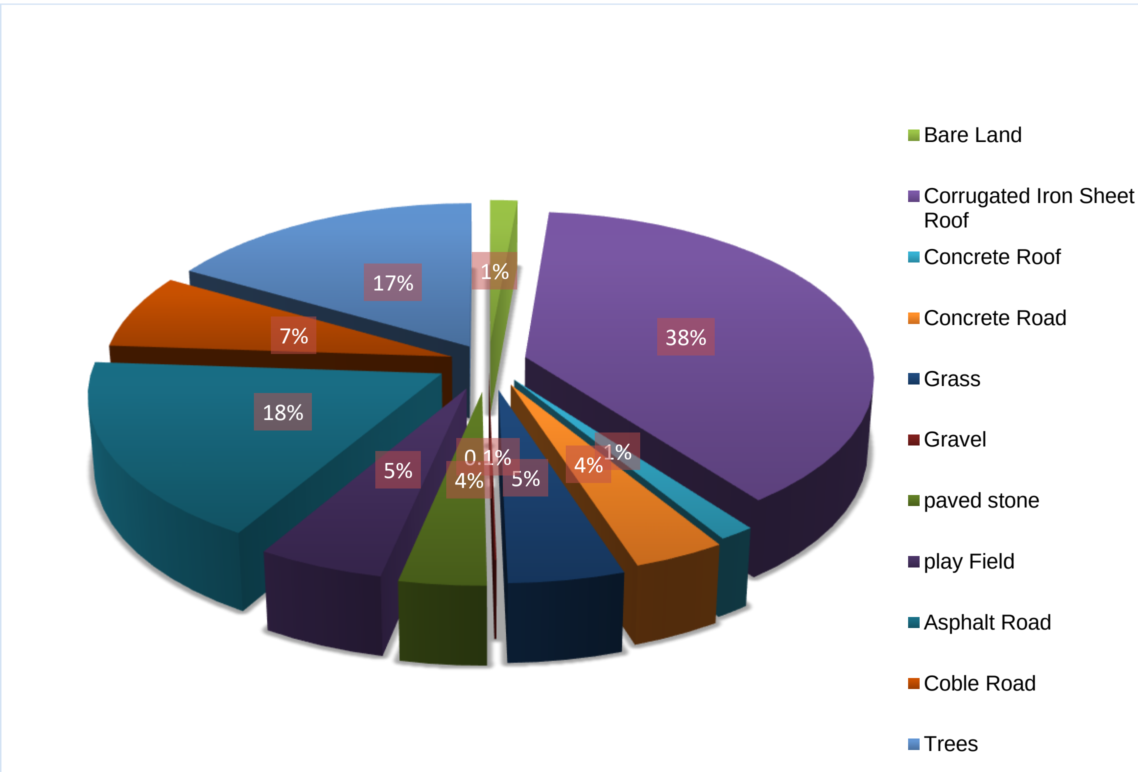

Fig. 24 Stormwater generated by EiABC campus, (Source: GIS analysis, Author)

3.6 Summary

The campus has only 55.70% pervious surface. The fact that pervious surfaces are surfaces which allow for stormwater or rainwater to percolate into the ground(soak), the stormwater generated from impervious surfaces (44.30%) has to be stored or utilized.

Fig. 25: Runoff generated from EiABC campus,

(Source: Site Photograph, by Abdelwehab Mohammed)

Impervious surfaces are covering the horizontal space for green and plantation, the possibility to provide spaces for plantation and green is now shifting to vertical approach. The research's main aim is providing vertical space, which integrated with bare walls of buildings for vegetation and plantation. Based on the fact from the previous section, 24% of the study area land use and land cover covered with a corrugated iron sheet, which is not applicable for a green roof or other technology of vegetating surfaces. The research took building samples to present the data and identify their potential for vertical green and came up with new innovative design prototypes of the living block. The next chapter provides the data about the selected buildings and their potential for vertical green and living wall construction compared to their footprint.

CHAPTER FOUR

4. Data Presentation and Interpretation

4.1. Introduction

EiABC, the Ethiopian Institute of Architecture, Building Construction and City Development campus has above 34 building blocks with variations of building materials and construction techniques. None of the building blocks incorporated green wall or green roof. Taking the change (increase) in imperviousness of the campus into consideration, the research took samples of building blocks for data interpretation and green wall comparison.

Building physical assessment for the selected building is carried out by only taking the outer perimeter of the buildings as the main purpose is façade assessment for living wall construction. The exposure to solar radiation and irrigation, accessibility with aesthetical values of the walls are the basic criteria to choose the external perimeter of the buildings.

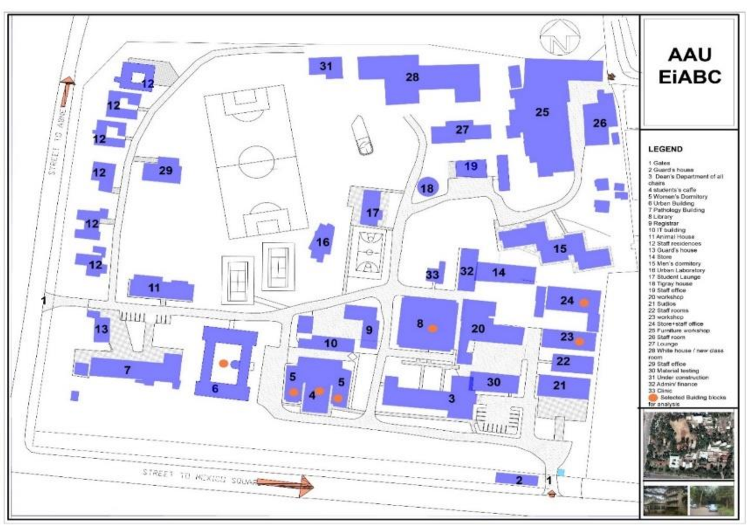

Fig. 26: Selected buildings for assessment, EiABC campus, (Source: Authors)

4.1.1 Data Presentation and Interpretation of Selected Buildings

4.1.2 Urban Building

Urban Building is among the new buildings found in the EiABC campus serving as chairs and department buildings of various departments like urban design, urban planning, and environmental planning and so on. The building contains staff offices, studios, toilets and meeting classrooms. The building covers a total area of 1134.4 m^2 excluding the inner courtyard and has an outer and inner perimeter of 174.65m, and 80.34m. The building has 86 a total number of windows on the outer perimeter with 2.8m^2 area of each window (1.50m x 1.80m). The urban building has a roof covered with a Corrugated iron sheet and bare walls made up of stone and hollow concrete block. General physical features of the building are presented in fig 27.

Fig. 27 Urban building location, (Source: Author)

The Urban Building has room height of 3.10m with semi-basement and basement floors. The building façade size varies as the building is constructed based on the existing topography. In the rear side of the building, the façade is Three stories and in its front, it has only Two stories. The assessment of the building presented below.

4.1.3 Data Interpretation of Urban Building

For the data interpretation purpose, the footprint of the building was calculated. The comparison also is done on both the bare wall and the opening size of the external perimeter of the building. The proportion between the building footprint and the potential of the building for the living wall taken as a comparison factor. All the sizes of bare wall available and the opening size of the external perimeter (façade) of the Urban Building is presented below.

Table 10: Physical evaluation of urban building

Building elevation	Total wall area of selected wall (m^2)	Window area of selected wall (m^2)	Bare wall area (m^2)	% of vertical bare wall compared to the total building footprint	Total Building Footprint (m^2)
Front Elevation	302.13	25.13	277.00	24.43	1134.4
Rear Elevation	440.35	102.60	337.75	29.77	

Left side Elevation	143.00	50.40	92.60	8.16	(100%)
Right side Elevation	190.60	67.20	123.40	10.88	
Stair case	104.47	21.50	82.97	7.31	
Total	1180.55	266.83	913.72	80.55	

(Source: Author)

From the above data interpretation, the Urban Building has a high potential for vertical green and living wall. The size of the existing bare walls on all sides of the building can recompense the building footprint. Even though, Only the external facades/perimeter of the building taken for assessment, the result showed more than 80% of the building footprint could be recompensed by greening the bare walls found on the external façades of the building.

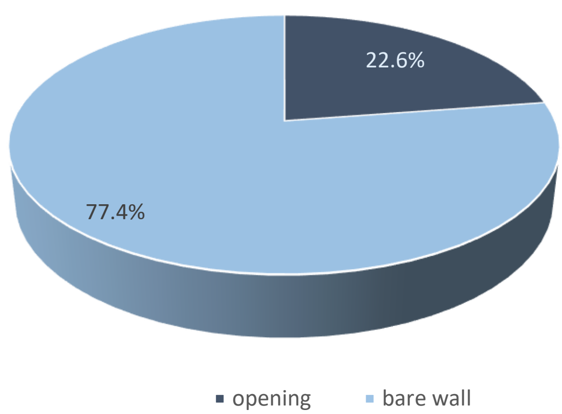

Fig.28: Facade, bare wall - opening proportion of urban building, (Source: Author)

As shown on the above chart, the Urban Building has more bare-wall proportion than the existing opening size of the external perimeter. The building has 266.83 m^2 of the area covered with openings including windows and doors. 913.72m^2 of the external façade of the building is a bare wall made up either of Hollow concrete block or stone.

4.1.4 Urban Building's Potential for VG

The environmental impacts of buildings are enormous. Conventional buildings use large amounts of energy, land, water, and raw materials for their construction and operation. To recompense the consumption of land, buildings can incorporate many green features. Some of the green technologies are a green roof, green wall, vertical farming and living wall technologies. These mentioned technologies are helpful to recompensate for the large consumption of land by the construction of buildings. In addition, building integrated green technologies helps to improve both macro and microclimate of urban areas.

The Urban Building data interpretation showed that the potential of the building external facades to recompense the footprint (land consumed by the building) is above 80%.

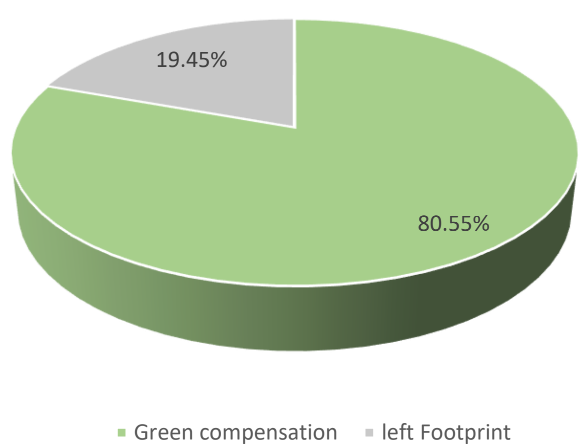

Fig. 29: Building Footprint comparison, (Source: Author)

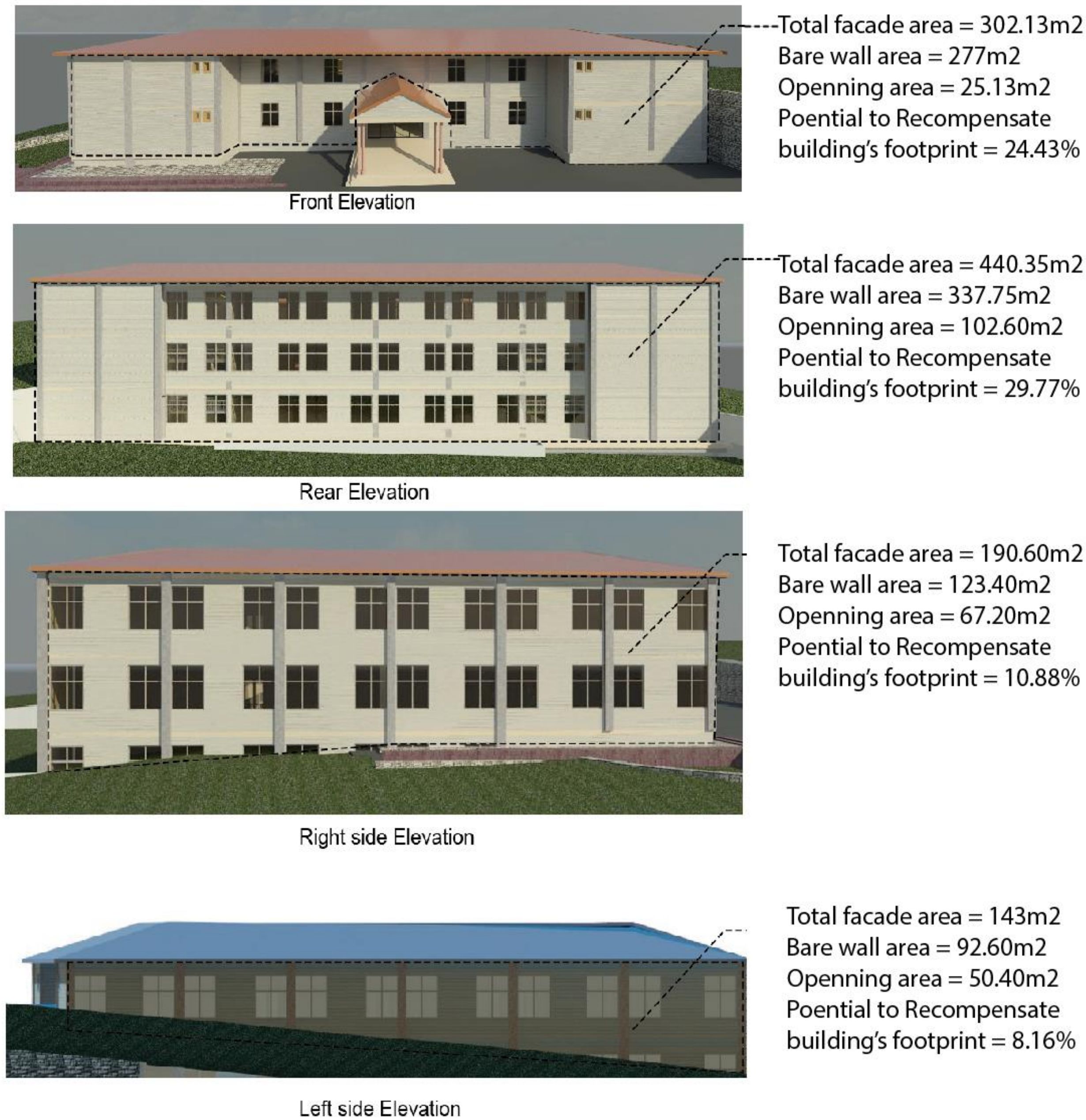

Fig. 30: External surfaces bare wall potentials of the Urban building, (Source: Author)

4.2. Library Building

Library Building in the EiABC campus is one of the selected buildings for the living wall potentials assessment of the campus. The building is a single story building with staff rooms and different reading rooms. The Library Building covers the total footprint area of 1015.60m^2. Total elevation area (external) of the building is 252.93 m^2 with 200.40m^2 of bare wall and opening area (informal opening shapes and doors included) 52.53 m^2. All the walls of the building are made up of brick and its roof is currently covered with a corrugated iron sheet. General physical features of the building are presented below.

Fig. 31 Location of Library building, EiABC campus, (Source: Author)

The Library Building has a room height of 3.00m. The building façade contains informal windows connected by doors. For the purpose of façade area calculation, the opening area considered cumulatively. Based on the cad files of the building and the physical survey of the building, the building assessed all its external facades to differentiate the bare wall and the size of the openings.

4.2.1Data Interpretation of Library Building

Similar to the above building, the footprint of the Library Building calculated for the data interpretation purpose. The comparison also is done on both the bare wall and the opening size of the external facades of the building. The proportion between the building footprint and the potential of the building for the living wall taken as a comparison factor. All the sizes of bare wall available and the opening size of the external façade of the urban building presented below.

Table 11: Physical evaluation of Library building, EiABC campus

Building elevation	Total selected wall area (m^2)	Bare wall area (m^2)	% of vertical bare wall compared to total building footprint	Total building footprint (m^2)
Front Elevation	58.88	45.00	4.43	1015.60 (100%)
Rear Elevation	61.20	48.96	4.82	
Left side Elevation	63.85	51.24	5.04	
Right side Elevation	69.00	55.20	5.43	
Total	252.93	200.40	19.72	

(Source: Author)

The Library Building is a single story building with a room height of 3m. The size of the existing bare walls on all sides of the building has the potential to compensate for the building footprint. Even though the building is single story and only the external facades/perimeter of the building taken for assessment, the result shows more than 19% of the building footprint could be recompensed by greening the bare walls found on the external façades of the building.

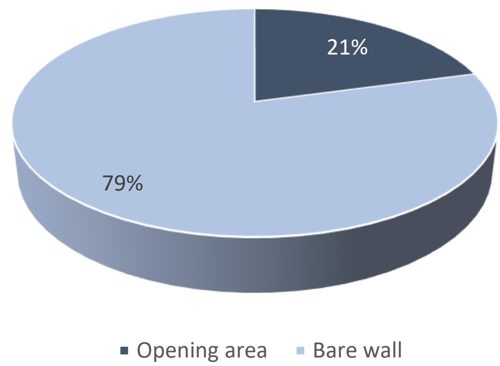

Fig. 32: Facade, Bare wall - opening proportion, (Source: Author)

As shown on the above chart, the urban building has more bare-wall proportion than the existing opening size of the external perimeter. The building has only 52.53 m^2 of the area covered with openings including windows and doors. 200.40m^2 of the external façade of the building is a bare wall, which made up of brick.

4.2.2 Library Building's Potential for VG

The Library Building data interpretation showed that the potential of the building's external facades to recompense the footprint (land consumed by the building) is above 19%. Comparing to the urban building, library building potential for living wall is less and only 19% of its footprint can recompense by the living wall construction.

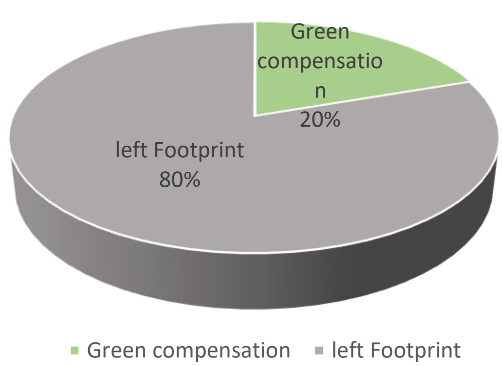

Fig. 33: Building Footprint comparison, (Source: Author)

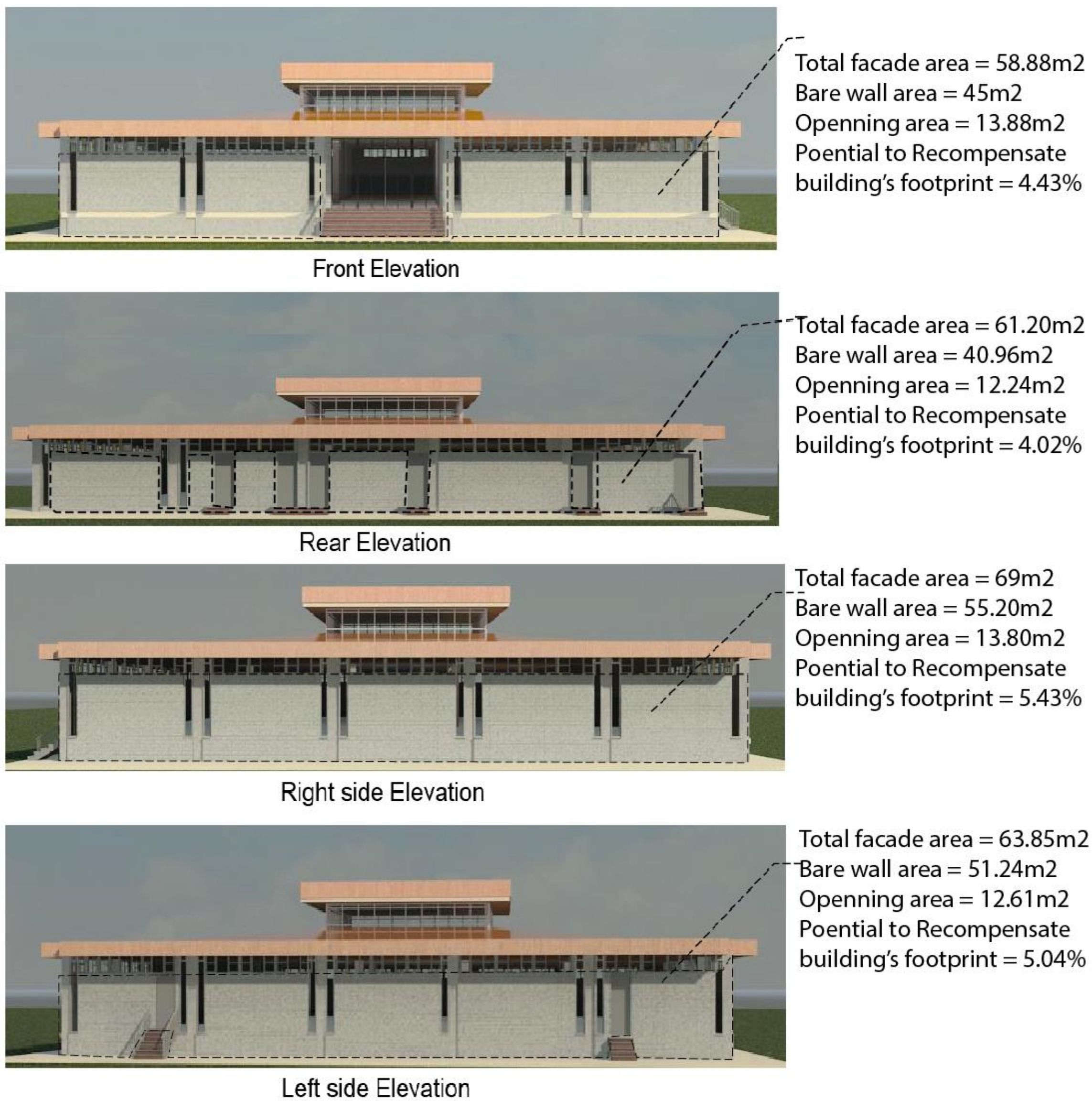

Fig.34: External surfaces bare wall potentials of Library building, (Source: Author)

4.3. Cafe and Dormitory Building

Third building selected for potential assessment of EiABC campus's buildings for vertical greenery is the café and dormitory composed building. The building contains four main building parts named as building wing One and building wing Two, café and a kitchen building. Both building wings are women's dormitories and the middle part has student café and kitchen and store buildings. The building as a whole has a footprint of 912m^2. In general, the building has a total bare wall area of 869.61 m^2 and 277.84m^2 of the opening area including formal windows, doors and informal openings.

Fig. 35: Location of Café and dormitory building, EiABC campus, (Source: Author)

The café and dormitory building have variations of room height. The building wings, which are dormitories for the female students of the collage, have a room height of 2.65m. The café has a room height of 3.40m and the Two-story kitchen and storage building has 2.80m room height. The building façade of the kitchen building contains informal windows connected by doors. For the purpose of façade area calculation, the opening area is considered cumulatively. However, the two wings of buildings have a formal shape of windows with a size of 0.95 m x 1.35m, and doors with a size of 1m x 2.10m and 1.20m x 2.10m. Based on the cad files of the building and the physical survey of the building, the building is assessed all its external facades to differentiate the bare wall and the size of the openings.

4.3.1Data Interpretation of Café and Dormitory Building

Here the potentials of the building are calculated. Different part of the external building façade calculated to know the number of bare walls found on the external facades of the building. The assessment also made a comparison between the footprint of the building and the potentials of the bare wall to living walls.

Table 12: Physical evaluation of Café and dormitory building, EiABC campus

Building Parts	Total selected wall area (m^2)	Bare wall area (m^2)	Opening area (Windows and Doors m^2)	% of vertical bare wall compared to the total building footprint	Total building footprint (m^2)
Building wing One	503.50	395.50	108.00	43.34	912.5 (100%)
Building wing Two	503.50	395.50	108.00	43.34	
Kitchen building	95.40	43.40	52.00	4.75	
Cafe hall	45.05	35.21	9.84	3.85	
Total	1147.45	869.61	277.84	95.30	

(Source: Author)

The café and dormitory buildings have varied room heights. Even though the building is single story and only the external facades/perimeter of the building are taken for assessment, but the result showed more than 95% of the building's footprint could be recompensed by greening the bare walls found on the external façades of the building.

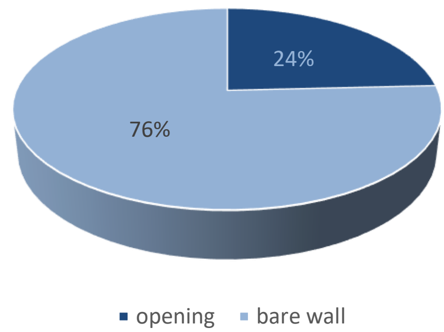

Fig. 36: Facade, Bare wall - opening proportion, (Source: Author)

As shown on the above chart, the café and dormitory building has more bare-wall proportion than the existing opening size of the external perimeter. The building has only 277.84 m^2 of the area covered with openings including windows and doors. 869.61m^2 of the external façade of the building is a bare wall which is made up of Stone and hollow HCB.

4.3.2 Café and Dormitory Building's Potential for VG

The Café and Dormitory building data interpretation showed that the potential of the building external facades to recompense the footprint (land consumed by the building) is above 95%.

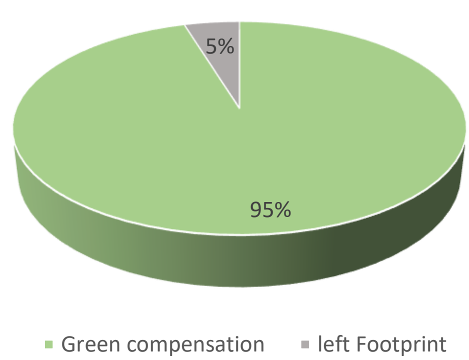

Fig. 37: Building footprint comparison, (Source: Author)

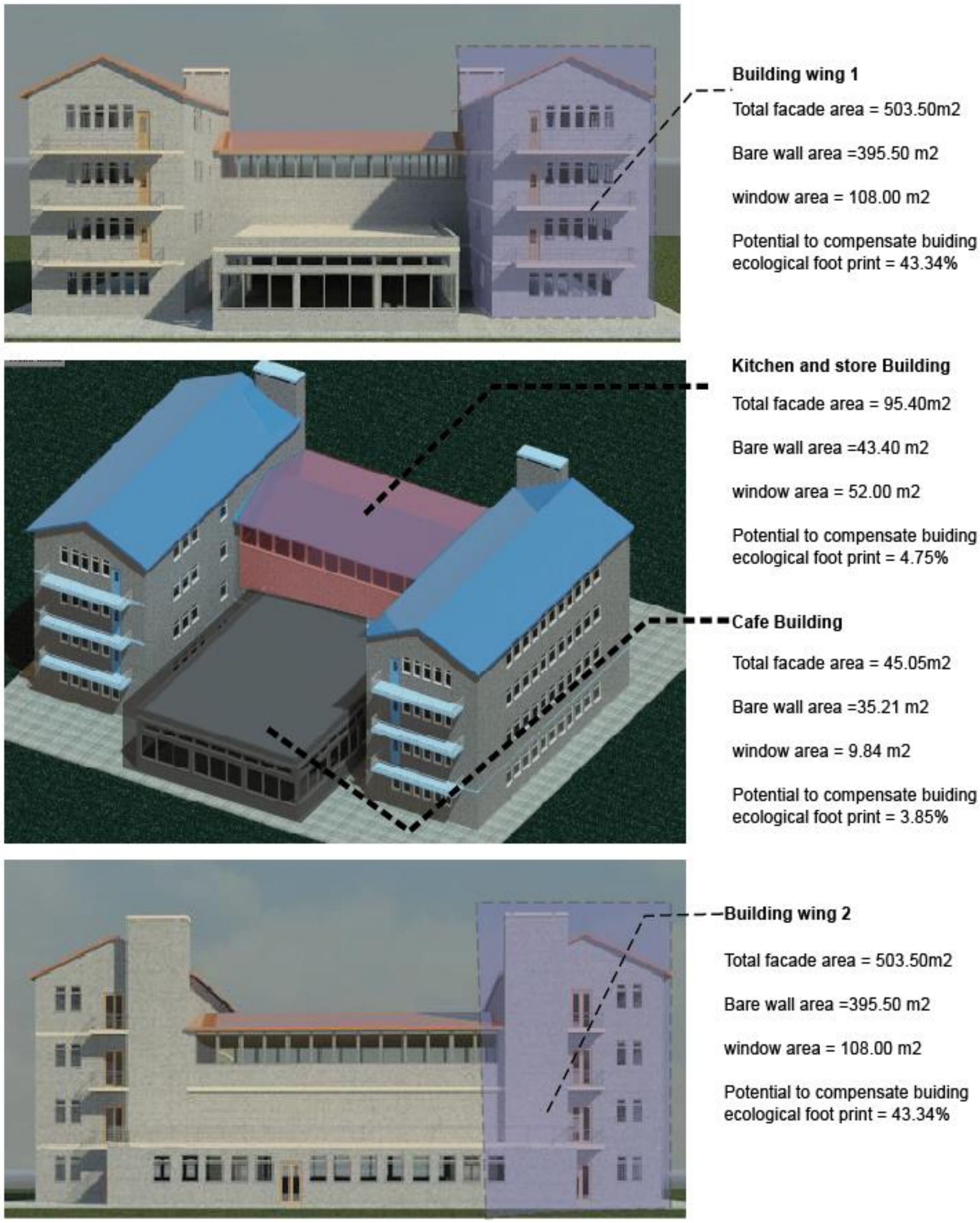

Fig. 38 External surfaces bare wall potentials of Cafe and dormitory building,

(Source: Author)

4.4 Workshop Buildings

Workshop buildings are selected for the data interpretation as part of variations of buildings for the potential assessment of vertical greenery and living wall construction. All types of buildings have the potential for vertical greenery and living wall on their bare wall surface. As mentioned already in the introduction chapter, the scope the research limited by time to assess all kinds of buildings. The selected buildings are possibly composed of different in use and in shape as well.

The EiABC campus has different types of workshops and stores. Here the material store and the metal workshop assessed their surface potential for vertical greenery and living wall construction. The buildings also have small staff rooms on their floor plan. The physical character of their external wall interpreted to know the amount of bare wall for vertical greening.

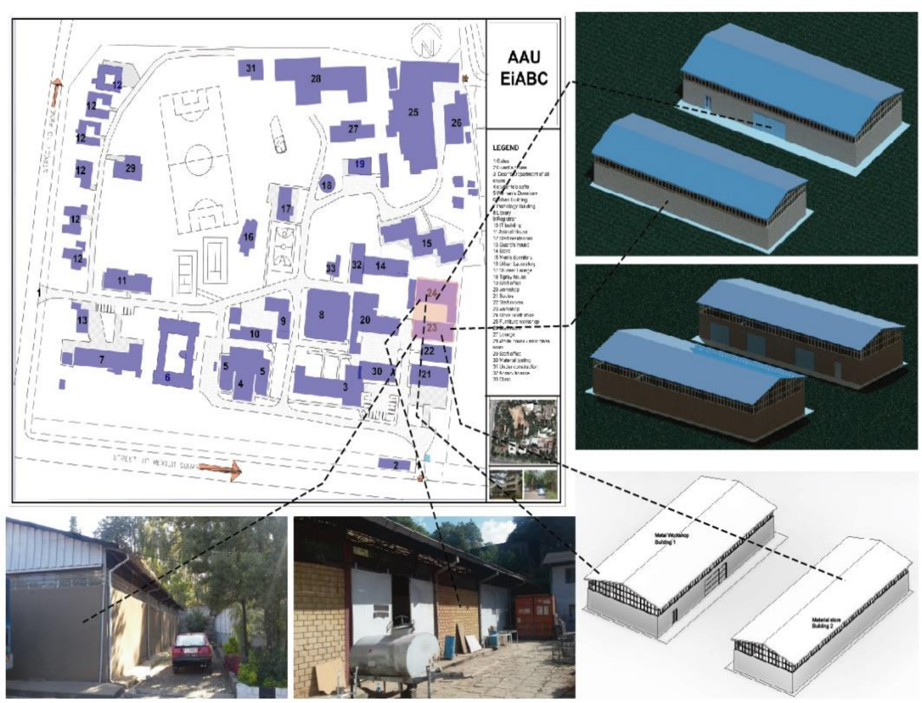

Fig. 39: Location of Workshop buildings, EiABC campus, (Source: Author)

Both Workshop buildings lay on about 634m^2 land inside the campus of EiABC. The buildings have a room height of 3.30m and have a total area of external surface 531.40m^2. The peculiar nature of such type of workshop buildings is they are single story and most of the time with above the average room height. These particular workshop buildings selected as a case have a room height more than 3.0m and covered with a pitched roof, which also provides extra ceiling space on the top of the clear room height.

4.4.1 Data Interpretation of Workshop Buildings

Different part of the external building façade calculated to know the number of bare walls found on the external facades of the workshop buildings. In addition, a comparison made between the footprint of the buildings and the potentials of the bare wall to living walls and vertical greenery. Both, the comparison between the opening area and the bare wall area and the comparison between the bare wall potential for vertical greening and the building footprint done and presented below.

Table 13: Physical evaluation of Workshop building, EiABC campus

Building elevation	Total selected wall area (m^2)	Bare wall area (m^2)	Opening area (Windows and Doors m^2)	% of vertical bare wall compared to the total building footprint	Total building footprint (m^2)
Building One	260.10	226.77	33.33	79.01	287

Building Two	271.30	240.00	31.40	69.16	347
Total	531.40	466.77	64.73	73.60	634

(Source: Author)

As shown in the above table, the workshop buildings have about 466.77m2 bare wall on their external surface together. The buildings also have the potential of recompensing their footprint to replace by the vertical greenery, which they can recompense about 73.60% of their footprint.

Building One

Workshop building 1 has only 33.33m^2 of the opening area on its exterior walls and the rest is a bare wall, which accounts 226.77m^2 of the exterior walls. Above 87% of the building's external surface can use as a vertical vegetated wall.

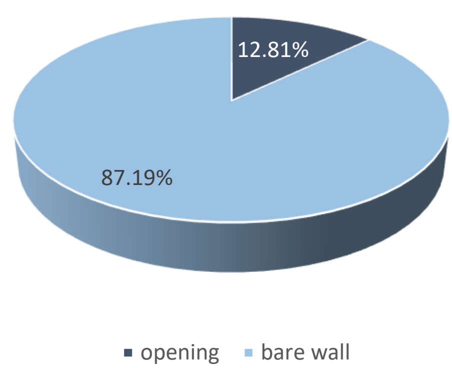

Fig. 40: Facade, Bare wall - opening proportion, (Source: Author)

Building One

Due to its dominant proportion of bare wall, Workshop building one has the potential to recompense its footprint by 79% if the entire bare wall surface used for vertical wall vegetation. As it is shown on the pie graph below, the building's potential for recompense its footprint, (land consumed by the building) is much stronger.

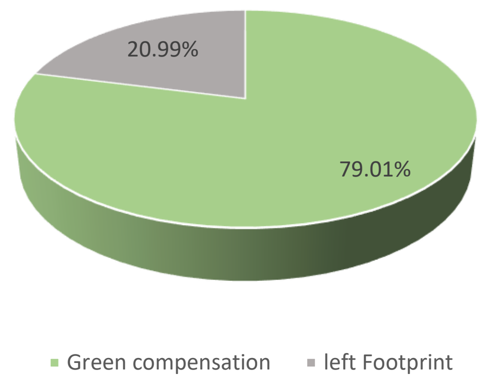

Fig. 41: Building footprint comparison, (Source: Author)

Building Two

Workshop building two has bare wall dominated external surfaces. The bare wall area of its exterior surface accounts for 88% of its total external surface (240m^2). The opening area of the building is limited to 31.40m2 which only accounts 12% of its total exterior surfaces area.

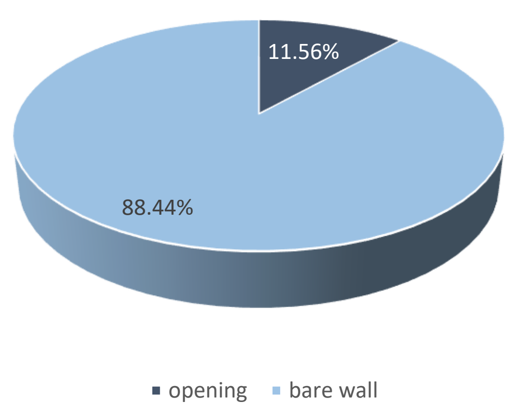

Fig. 42: Facade, Bare wall - opening proportion, (Source: Author)

Building Two

Buildings have the potential to recompense their footprint using their bare walls on their external surfaces. Workshop building two has 347m^2 area of the footprint and 69% of this area can be recompensed if the building's bare walls on its external surfaces used for vertical greenery.

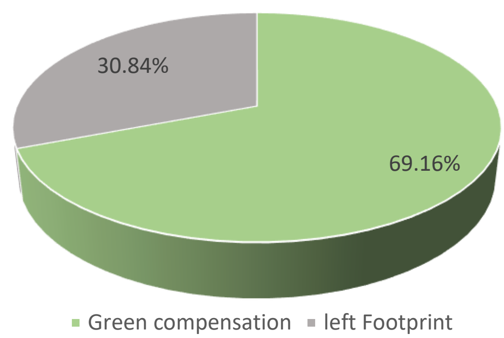

Fig. 43: Building footprint comparison, (Sources: Author)

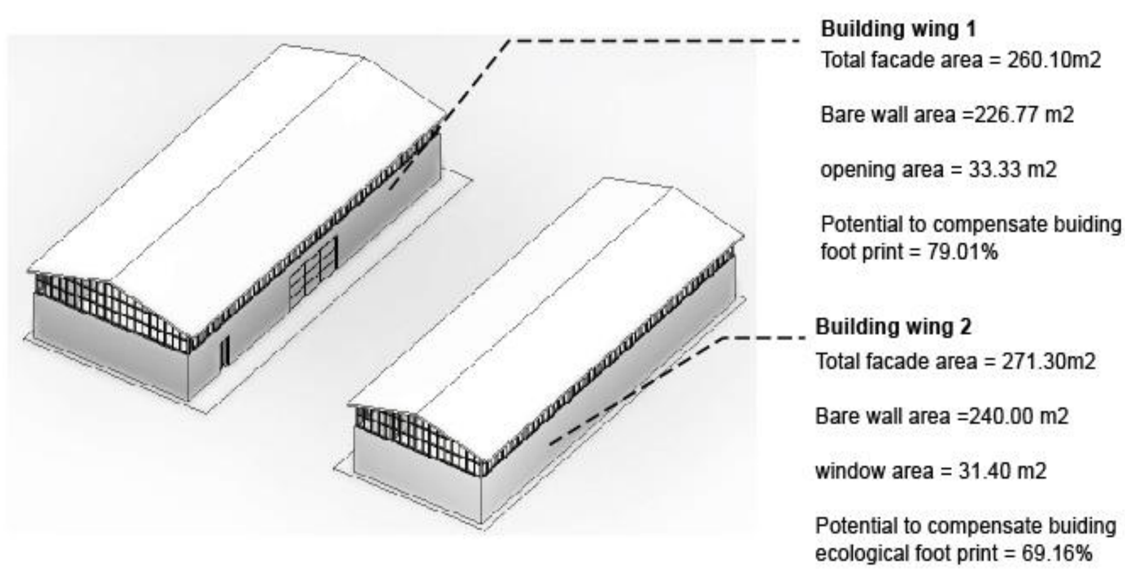

Fig. 44 External surfaces bare wall potentials of Workshop buildings,

(Source: Author)

4.5 Summary

All the data interpretation done in the study area and on the selected buildings showed the potentials for vertical greenery practices. Both the natural and the artificial analysis clearly proved the capacity of the campus for VG technologies and practices. Based on these potentials and possibilities the researcher designed a new Living Block design as an option for vertical vegetated wall construction. The following chapter discussed the design and development of Living Block.

CHAPTER FIVE

5. Design and Development

5.1. Introduction

From the previous chapters, the need for green infrastructure and the potential of the selected buildings found in the study area for vertical greenery showed that researches have to focus and made on how to incorporate space for vegetation on the bare walls of buildings in urban areas.

Based on the existing data and data interpretation done in the previous chapters, different design prototypes of hollow concrete block discussed in this chapter of the study. The design proposal named as “LIVING BLOCK” which mainly aimed to provide a dual function as wall construction material and as space for vertical vegetation.

The conventional hollow concrete block most commonly used for wall construction with additional wall construction material like stone, brick, and glasses. Here some introduction included from literature in the traditional hollow concrete block to show the difference and advantages of the new design proposal of “living block” for living wall construction or wall vegetation construction.

5.2 Conventional Hollow Concrete Block

Nowadays, Hollow Concrete Blocks (HCB) are becoming very popular. These blocks are being widely used in the construction of residential buildings, factories, and multi-storied buildings. These hollow blocks commonly used in the compound walls due to their low cost. These hollow blocks are more useful due to their light weight and ease of ventilation. The blocks and bricks made out of a mixture of cement, sand and stone chips. Hollow blocks construction provides facilities for concealing electrical conduit, water, and soil pipes. It saves cement in masonry work, bringing down the cost of construction considerably. The economy of the structure is one of the basic aspects upon which any design based. The stability plays an important role, but the best designer is one who comes out with design, which gives the stable and economic structure. The development of construction technology closely related to the development of adequate mechanization and handling technology. Hollow concrete is an important addition to the types of masonry units available to the builders and its use of masonry is constantly increasing.

5.3 Types of HCB

Hollow Concrete Blocks Confirm to IS 2185 (Part 1): 2005. This hollow Concrete Block has an open or closed cavity and can be used in the construction of load-bearing and non-load bearing partition walls. Hollow concrete blocks are either hollow or solid. A hollow unit is that unit which has a core void area greater than 25% of the gross area. Both types may use for both load bearing as well as non-load bearing walls. The focus of the research is on the possible shape design of hollow concrete block for vertical green wall construction. As a result, the contents are limited to physical properties of existing dry hollow concrete block (An Information series from the national authority on concrete masonry technology, 2017).

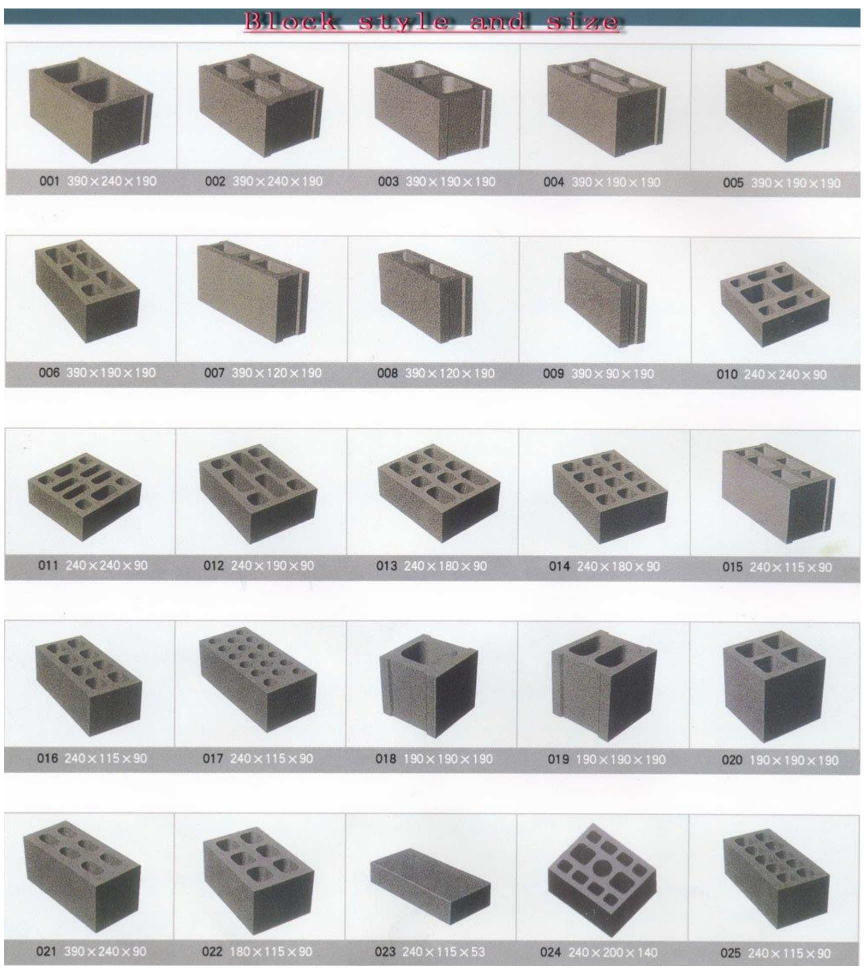

Fig. 45 Currently available shapes and sizes of Hollow concrete block,

(Source: Integrating Global Trade Leads)

5.3.1 Manufacturing Process

Hollow concrete blocks conventionally manufactured with cement to the aggregate ratio of 1:6 and the aggregate consists of 60% fine aggregate (sand or stone dust) 40% coarse aggregate (6 to 12 mm size). Mixing these proportions by filling in the mold to have the appropriate shape of the block. Also vibrating is an integral part of the manufacturing process, which always ends up with a curing period (An Information series from the national authority on concrete masonry technology, 2017).

5.3.2 General Properties

Even though there are different options available for the hollow concrete block, here are the most common size of the hollow concrete block. 39cm X 19 cm X 30 cm, 39cm X 19 cm X 20 cm and 39cm X 19 cm X 10 cm. The conventionally minimum requirement of density for hollow concrete blocks is1000 to 1500kg/m3 with >2 to 4 N/mm^2 of compressive strength. Water absorption is always set to be <10 to 15% by weight (An Information series from the national authority on concrete masonry technology, 2017).

5.3.3 Advantages of Hollow Concrete Blocks

1. The good concrete is compacted by high pressure and vibration gives substantial strength to the block. Proper curing increases the compressive strength of the blocks.

2. Low maintenance, Color, and brilliance of masonry withstand outdoor elements.

3. Provide Thermal and sound insulation: The air in the hollow of the block does not allow outside heat or cold in the house. Therefore, it keeps the house cool in summer and warm in winter.

4. Environment-Friendly, fly ash used as one of the raw materials.

5. No additional formwork or any special construction machinery is required for reinforcing the hollow block masonry if required.

6. It is a faster and easier construction system when compared to the conventional construction systems.

7. This construction system provides better acoustic and thermal insulation for the building.

8. Reduced Air Conducting Load: Approx. 50% saving.

9. No saltpeter or leaching: Reduction in maintenance (An Information series from the national authority on concrete masonry technology, 2017).

5.4 Disadvantages of HCB

Beside the above most important advantages of the hollow concrete block, it lacks to incorporate plantation media for wall vegetation. The study tried to keep these advantages and incorporate a space for vegetation by proposing new living block designs for vertical wall vegetation. The design proposals categorized in three different classifications for different uses of vertical bare walls. All the design proposals presented in detail in their physical properties under this chapter as follows.

5.5 Design Prototype "A"

Living block designed for bare walls, which are integral parts of the building. This design proposal mainly aimed to provide external space as an integral part of the hollow concrete block. The living block design considered the load balance of the wall, moisture transfer, and volume of soil for plantation.

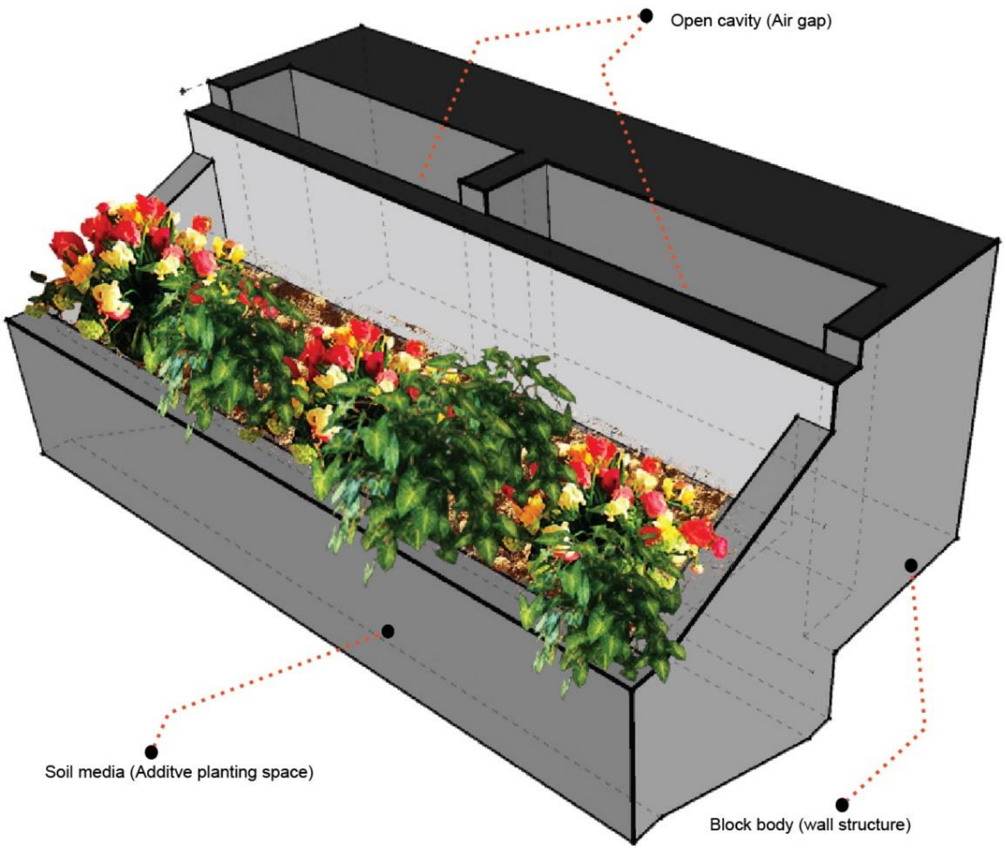

Fig. 46: Living block prototype "A", (Source: Author)

5.5.1 Physical Properties

The living block has overall dimensions of 42cm x 30cm x 20 cm. The soil media has overall dimensions of 42cm x 15cm x 10cm. the block has hallowed space inside it for dual purpose. To decrease the load of the block and to delay the moisture transfer to the inner side of the wall was the intended objectives of the hollow.

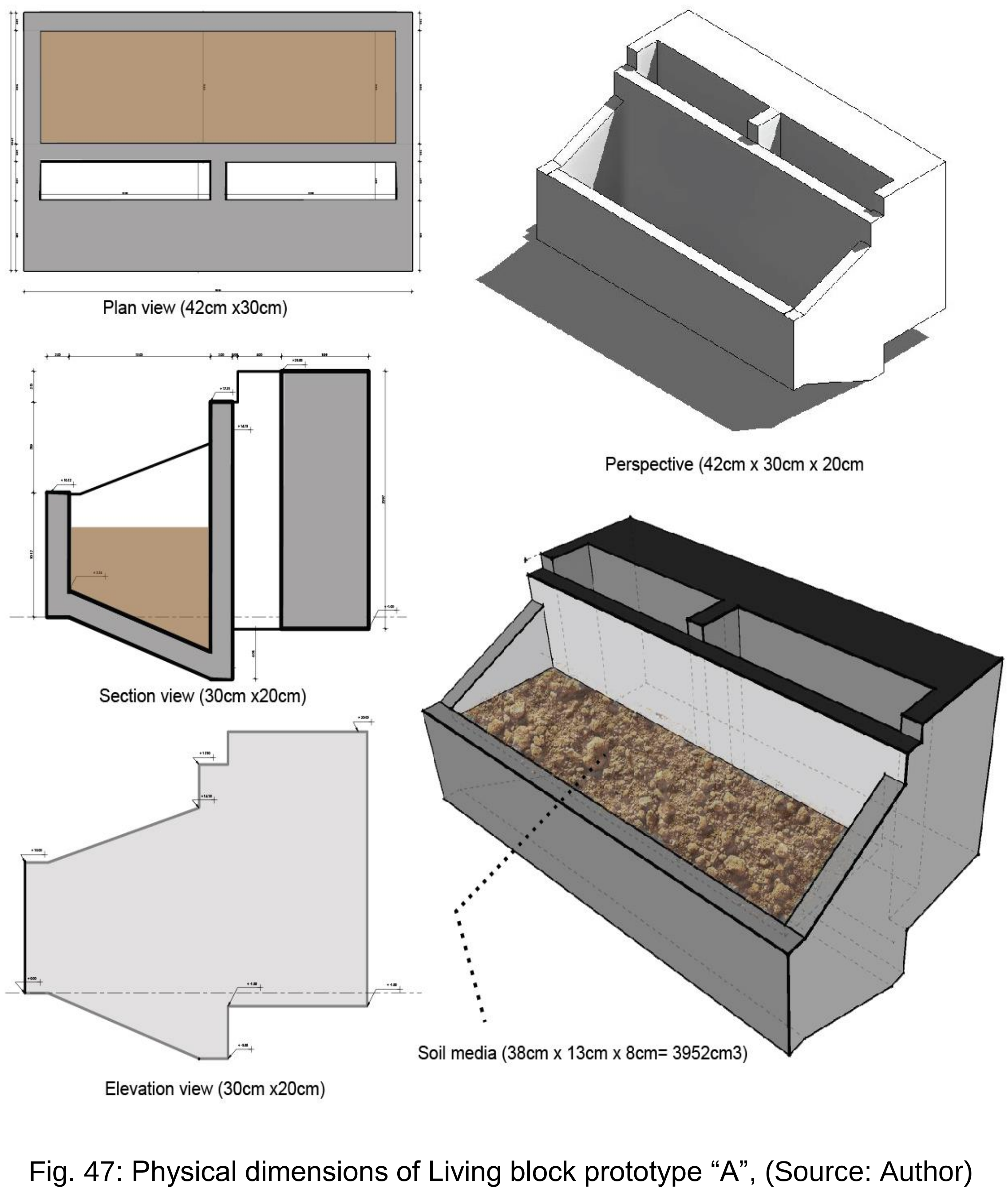

Fig. 47: Physical dimensions of Living block prototype “A”, (Source: Author)

5.5.2 Contribution

Living block prototype one provide a space for soil media for vegetation on bare-wall surfaces. The block length is based on the Ethiopian building code design document, which stated as 40cm as standard and with variations of three centimeters. The main part of the block has a width of 15cm and height of 20cm, which is totally within the range of the standards for hollow concrete blocks. Having the above-mentioned nominal dimensions, the living block prototype has the potential of providing space for about 0.004m^3 soil for vertical vegetation from a single living block. The soil media have clear volume of 3952cm^3 (38cm x 13cm x 8cm) which is equivalent to 0.004m^3.

Fig. 48: Wall made up of living block prototype “A”, (Source: Author)

5.6 Design Prototype "B"

The second design prototype of a living block mainly designed for fence's construction. The case study area selected for the green infrastructure assessment was institutional plots. The main reason behind the selection was due to the size of the plots and ownership of the plots which most of them owned by the government. In addition, of these factors within institutional plots like EiABC are significant as they are the centers of technology, urban design, and urban planning.

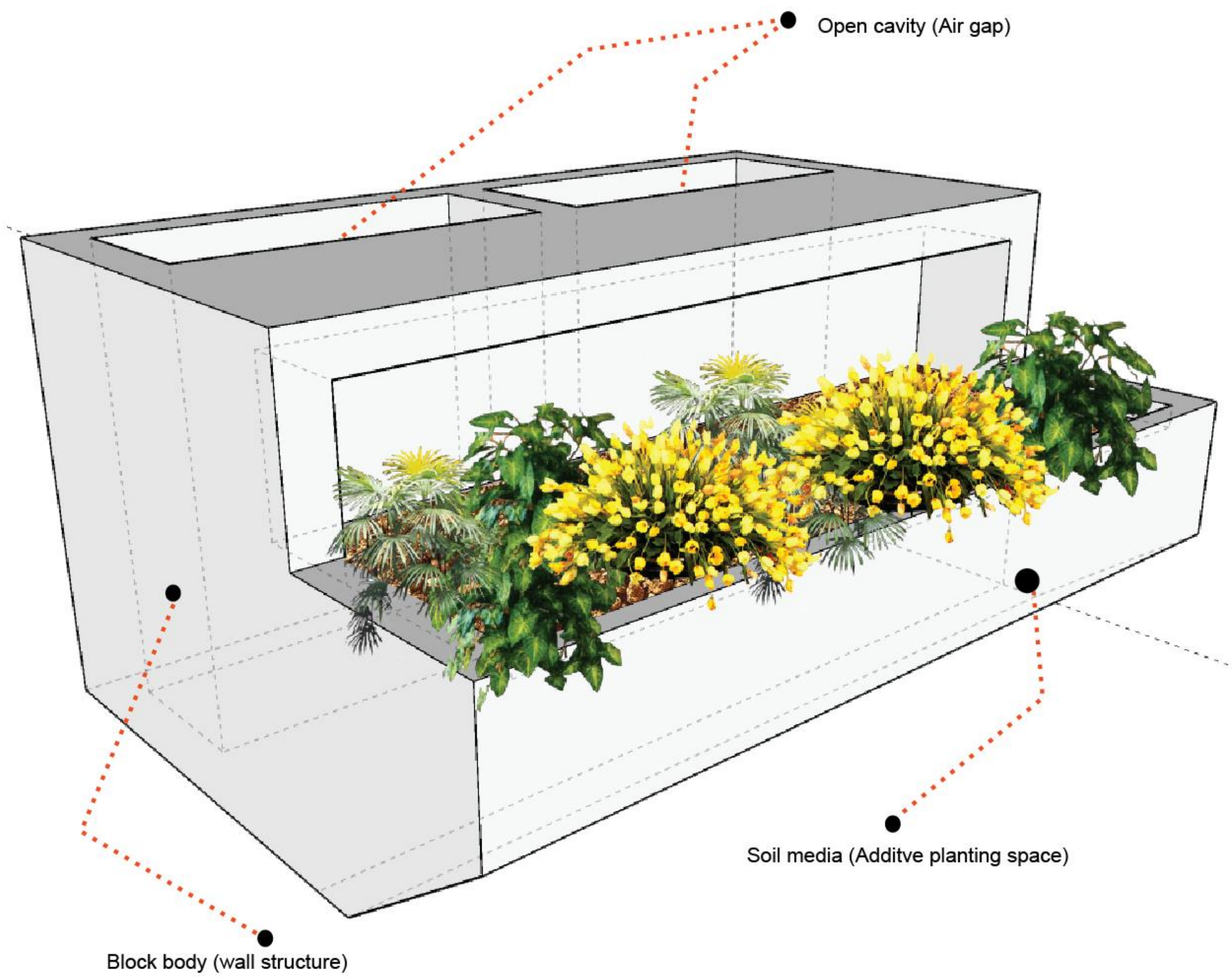

Fig. 49: Living block prototype "B", (Source: Author)

5.6.1 Physical Properties

Design, the prototype of the living block for the fences mainly consider their height, function and structural stability of the wall. The conventional dimensions not varied from the standard set for a hollow concrete block. The dimensions are 42cm x30cm x 20cm, which represents length, total width and a clear height of the living block.

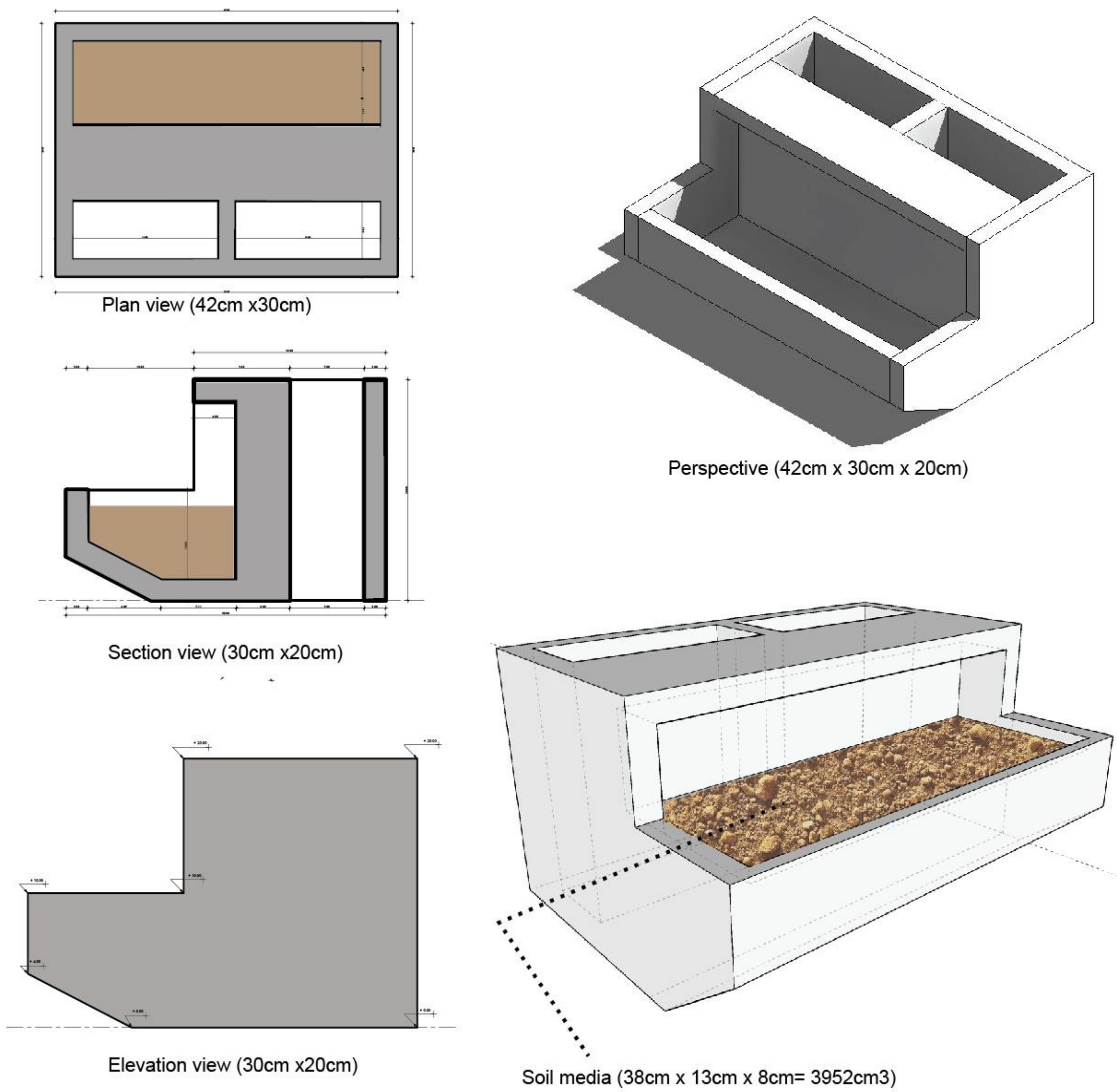

Fig. 50: Physical dimensions of Living block prototype “B”, (Source: Author)

5.6.2 Contribution

Living block design for fences provides spaces for vertical wall vegetation. The above Living block prototype has a total volume of $0.0027m^3$ space for soil as growing media for vertical wall vegetation. The size of the designed plantation space is 38cm x 7cm x 10 cm, which represents the length, width, and height respectively. Nevertheless, the design gives options for continuous space for plantation as shown in the figures above. The plantation space calculated based on a single block prototype.

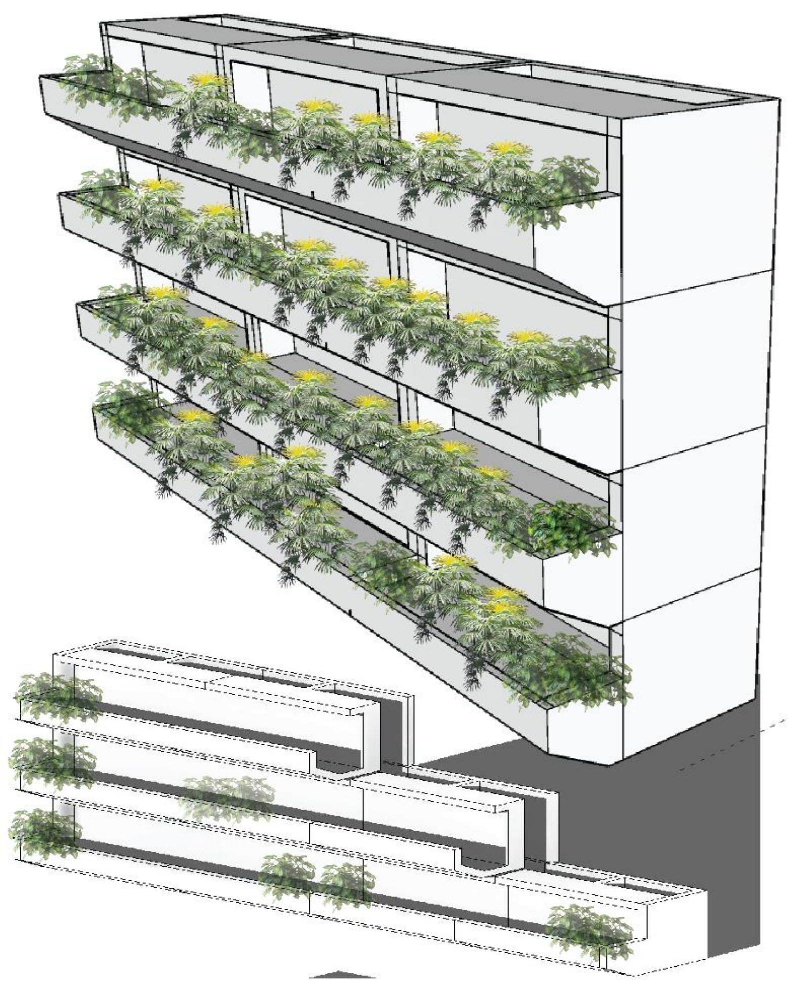

Fig. 51: Wall made up of Living block prototype “B”, (Source: Author)

5.7 Design Prototype "C"

The Third living block design proposed for shear wall and retail wall construction. The hollow concrete blocks for shear and retail walls has to reinforce for the sake of structural strength. In this design proposal, the living block has the space for reinforcement bars. The dimensions considered the nature of the wall and they are different from conventional the hollow concrete blocks.

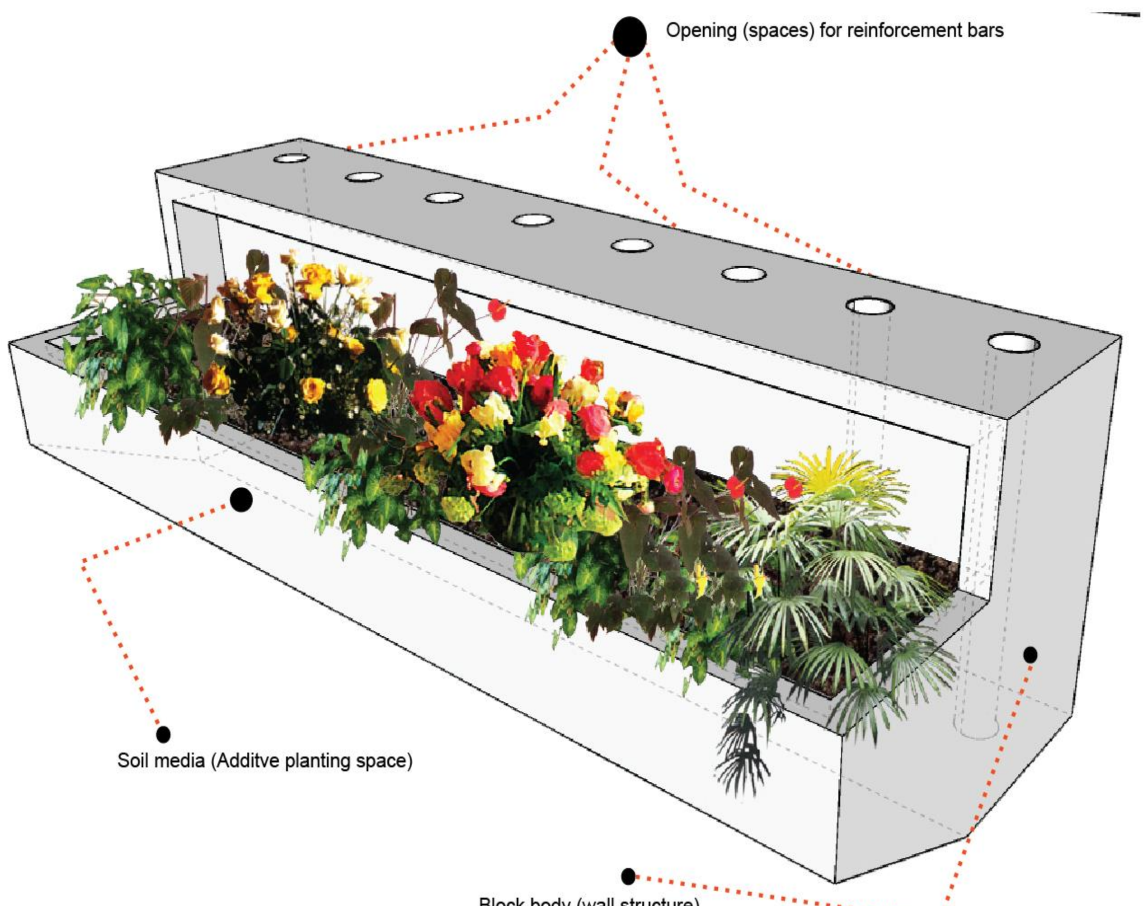

Fig. 52: Living block prototype "C", (Source: Author)

5.7.1 Physical Properties

The living block for shear wall and retail wall construction has nominal dimensions of 62 cm length, 20cm height, and 27cm width. The width of the living block has 13 cm length of the soil media, which is included on the overall width of the living block. Each block has six equally spaced circular holes with a 3cm diameter of reinforcement bars (Considering the Maximum bar diameter but it is subjected to change). The dimensions and layout of the block described below as figures and plans.

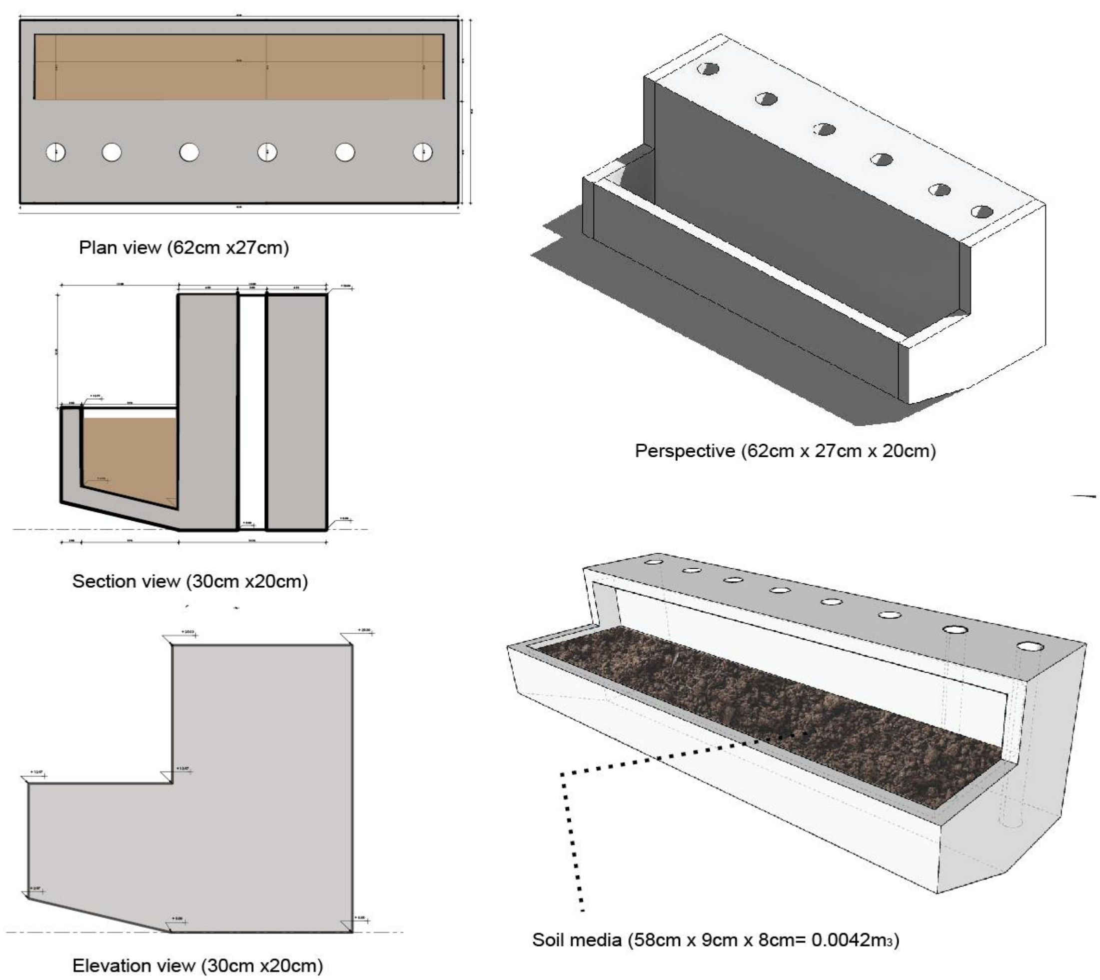

Fig. 53: Physical dimensions of living block prototype “C”, (Source: Author)

5.7.2 Contribution

The living block for shear wall and retail walls has a space for vegetation. The dimensions of the soil media are 58cm long, 9cm high and 8cm wide. The soil media can hold 0.0042m^3 of soil. Every single design of living block for reinforced block construction contribute 0.0042m^3 volume of space for vertical vegetation.

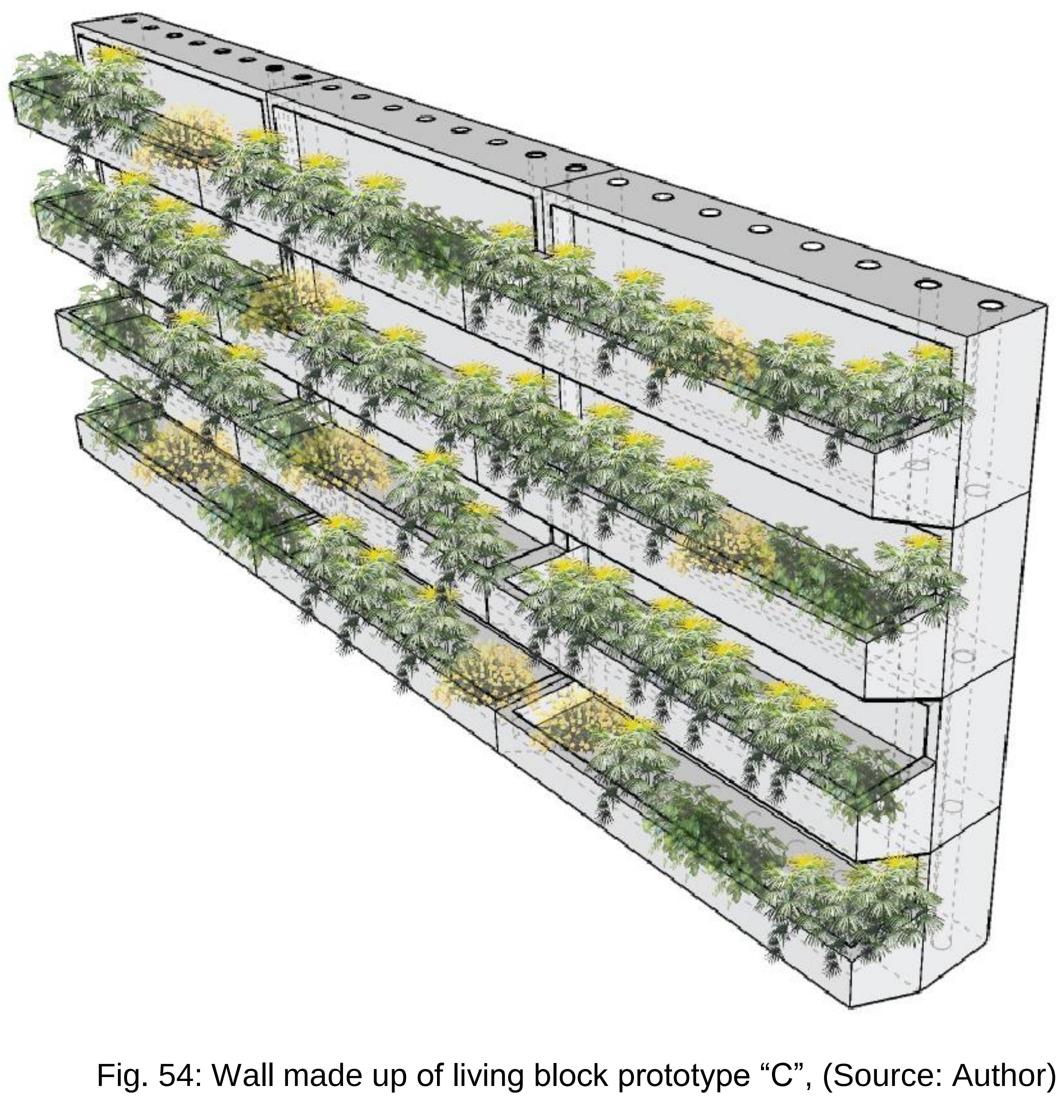

Fig. 54: Wall made up of living block prototype “C”, (Source: Author)

5.8 Design Scaling up

5.8.1 Introduction

Living walls can have a number of positive influences on the urban environment, including supporting biodiversity (provided that the plants used are either native or non-invasive), reducing the impact of rainfall runoff from buildings, reducing air pollution, and reducing the urban heat island effect by lowering the temperature of building walls. Living walls not only shield buildings from direct sunlight but 'evapotranspiration' (a combination of evaporation of water and release of water vapor) by plants also help cool walls. Covering walls with plants can significantly reduce the temperature of building walls during hot summer months. A recent study of three different types of these 'living walls' in Italy suggests that they can be 20°C cooler than a bare wall on sunny days (Mazzali, U., Peron, F., Romagnoni, P. et al. (2013).

Another study on living wall showed that living walls could cool buildings in warm climates by shading them, adding to the amount of exterior wall insulation, evaporating moisture from the growing substrate, and transpiring moisture from leaf surfaces. The thermal impact of eight different living wall systems in a Singapore study found that vertical vegetation reduced the surface temperature of building facades in a tropical climate by up to 11.58 °C (Wong, Tan, Chen, et al., 2010). In subtropical Hong Kong, vegetated cladding found to reduce interior temperatures by up to 14.5 °C by delaying the transfer of solar heat (Cheng, Cheung, & Chu, 2010). Consistent temperature reductions were also recorded in a study of green facades and living walls in Malaysia (Jaafar, Said, Reba, & Rasidi, 2013), and a model for estimating vertical vegetation systems' heat flux transmission that was developed and tested in Hong Kong (Jim & He, 2011) showed that south-facing living walls absorb large amounts of heat flux due to evapotranspiration.

The value of green walls to cool buildings recently cited for climatic zones with warm or hot summers. Living wall systems in China proven to reduce exterior wall temperatures by a maximum of 20.8°C, and interior wall by 7.7°C. Air layers between the wall and vegetation were on average 3.1°C cooler than ambient air (Chen Q, Li B, Lui X, 2013). Most studies focused on surface wall temperatures with maximum differences between vegetated and non-vegetated cited as 11.6°C Singapore (Wong NH, Tan AYK, Chen Y, et al, 2009), 18°C Japan (Hoyano A.,1988), 1.9°C to 8.3°C Greece (Eumorfopoulou EA, Kontoleon KJ., 2010), 15.2°C Spain (Perez G, Rincon L, Vila A, Gonzalez JM, Cabeza LF., 2011) and 12 to 20°C Italy (Mazzali U, Peron F, Romagnoni et. al,2013).

An additional fact about living wall is its capability of reducing the impact of rainfall runoff from buildings in urban areas. With more and more competition for the limited horizontal surface area in urbanized and urbanizing areas, the use of vertical surfaces for stormwater mitigation and evapotranspiration has attracted potential (Wein master 2009).

An experimental study was done in Pennsylvania to show the contribution of the green wall for urban stormwater management was based on a 16 planter box which has nominal dimensions of 38.1cm length, 30.48 cm width, and 12.7cm depth. The green wall has a total area of 1.8m^2. The planter boxes are installed in two directions Southeast and northeast with a daily drip irrigation system of watering and with four plant types: Sedum Angelina, Sedum Ternatum, Sempervivum tectorum, and Ajuga Reptans. Results of the study suggest that green walls can retain a significant amount of stormwater. On average, over the course of five months (May 15 to Oct 3, 2013) the green wall systems retained about 2.75 gallons of water a day. The southeast-facing green wall systems retained an average of 2.96 gallons of water a day, while the northwest-facing green wall systems retained an average of 2.51 gallons of water a day (Barry Kew, Eliza Penny packer, and Stuart Echols, 2013).

Based on the above scientific facts, scaling up the new design proposal to public buildings and public fences in the city of Addis Ababa will contribute both to the urban heat island effect and on the urban stormwater management effectiveness of the newly introduced living wall.

5.8.2 Site Selection for Testing the Scalability of the System

Considering the advantages of ownership, financial capability, and understanding of urban challenges, public buildings and institutional plots suggested by the researcher for scaling up the result of the research. The living block design for green wall construction is ideal for public buildings like condominiums, instructional buildings, and public infrastructures. Here the condominium site selected for scaling up the living block on the facades of the buildings to enhance the temperature and to utilize the rainwater runoff from the roof of the buildings.

5.8.3 Mechare Meda Condominium

Mechare Meda condominium is located at 8°59'58"N and 38°44'9"E coordinates and it found in the Lideta sub-city, Woreda 4 known with its local name of "SARBET". The condominium site has 18 building blocks and 720 households. Every single block has a total footprint of 328m^2 and 91.2m of the perimeter. The building blocks made up of HCB and their roof covered by CIS.

Fig. 55: Location map of Mechare Meda condominium site (Source: Author)

Based on GIS analysis and Rational method of runoff calculation, each building block generates 19.94 m^3 (19940Litres) average annual rainwater runoff from their roof. All the building blocks together generate about 358.92 m^3 (358920 Liters) annual rainwater runoff from their roof. In addition, the street, passing through the building blocks, which is also serving as a parking lot for the dwellers, is contributing to both surface runoff and the temperature increase during the warm season. The surface temperature of the walls and the street surface temperature contribute to the increase of UHI of the neighborhood. The site selected for upscaling of the living block design for living wall construction to reduce the temperature and stormwater runoff the site using living wall.

Fig. 56: Mechare Meda condominium site Building blocks, Street and Parking lot, (Source: Author)

5.8.4 Physical Character of Building Block

To assess the potentials of stormwater utilization and temperature reduction using the upscaling of living wall, the total external surface character and data interpretation of a building block presented as follows.

Table: 14 Physical analyses of Building block of Mechare Meda condominium

Building Elevation	Window and opening area (in m^2)	Blank/Bare wall area (in m^2)	Total surface area (in m^2)	Building block footprint)in m^2)	Potential for green wall using living block (in m^2)
Front	183	273	456	328	169.26
Left side	14	142.75	156.75		88.50
Right side	14	142.75	156.75		88.50
Rear	78	349.5	427.5		216.69
Total	289	908	1197		562.95

(Source: Author)

Fig. 57: Bare wall potentials for living wall, condominium block, (Source: Author)

From the above assessment, each building block of the condominium site has a significant role in reducing the surface temperature and utilize the stormwater runoff through their potential for vertical green wall and living walls.

5.8.5 Scaling Up Methods

The scaling up method for the condominium blocks suggested in two different ways. The first is to construct a green wall over the bare walls of the existing structures. This is as a technique of double wall construction with an air cavity in between. This technique of scaling up used for updating of existing bare walls with vertical living walls.

Fig. 58: Construction of green wall over bare walls, (Source: Author)

The second scaling up method for the living wall is to replace the existing bare walls and construct a new living wall using the provided living block. This method is reliable for new constructions of walls and for replacing of old walls.

Fig 59: New construction of living wall, (Source: Author)

5.8.6 Contribution

Scaling up the design proposal into the condominium building blocks has two main significances. These are the reduction of UHI and the Utilization of Stormwater Runoff. Recent experiments on living wall and green wall done in Singapore, which shares the same tropical zone with Ethiopia taken as a base for the temperature reduction using green walls. the study has focused on surface wall temperature, with maximum differences between vegetated and non-vegetated cited as $11.6^{o}C$ Singapore (Wong NH, Tan AYK, Chen Y, et al, 2009), based on this fact, each condominium block can reduce their surface temperature by $11.6^{o}C$ during the warm season.

Based on the experiment done for green walls, the study did a calculation of stormwater utilization capacity of the vegetated wall of each building block of the condominium site. The proposed living block for living wall can utilize 3,268 Liters of rainwater runoff each building block from its roof annually. This means each building has the potential of 16.4% of its roof rainwater runoff to utilize on its living walls when all the bare walls of the building block scaled up to living wall. Generally, here is the comparison between the vegetated building block and the bare wall-biding block in the table below.

Table 15: Comparison between Building blocks (living wall vs bare wall)

Building block Features	Building block with bare walls	Building block with living walls
Area of the footprint (in m^2)	328	328
Surface area (elevations)in m^2	1197	1197
Bare wall area in m^2	349.5	349
Green wall/ Living wall in m^2	None	562.95
Amount of roof runoff water utilized (in Liters)	None	3268
Surface temperature control (in ^{O}C)	None	7.7-11.6 (decrease surface temperature)

(Source: Author)

CHAPTER SIX

6. Result and Discussion

The results of the design proposal for a living block generally tried to provide vertical space for vegetation on vertical walls. Each prototype of living block design has different size and volume of space for vertical vegetation. The overall result of the design of prototypes living block is summarized as follows.

Table 16: Summary of Living block design

No.	Living Block prototype	Provided volume of space for vertical vegetation per living block (in m^3)	Provided volume of space for vertical vegetation per m^2 of the vertical wall (in m^3)	Area of provided space for vegetation per living block (in m^2)	Area of provided spaces for vegetation per m^2 (in m^2)
1	Prototype "A"	0.0046	0.0575	0.0494	0.6175
2	Prototype "B"	0.0027	0.0337	0.0266	0.3325
3	Prototype "C"	0.0042	0.0273	0.0522	0.3393

(Source: Author)

As indicated in the above table, the vertical space for vertical wall vegetation varies depending on the shape and size of the prototypes of living blocks. Design prototype 'A' has the potential of providing vertical vegetation, space of $0.61m^2$ per m^2 area of vertical walls, prototype 'B' also has the potential of $0.33m^2$ space for vertical vegetation and the third prototype has also similar potential as the second prototype of living block for vertical vegetation spaces on building's vertical bare walls. Based on the design result of the living block here the selected buildings from chapter four taken for discussion.

6.1 Urban Building

From the data assessment and interpretation chapter, the urban building has a total external surface assessed for vertical vegetation of 1180.55 m^2. From the analyzed surface 77.4 %(913.72m2) is a bare wall made up either of stone or hollow concrete block. In addition, the building has a total footprint of 1134.4m^2, which is consuming land by the structure of the building. The amount of available bare wall on the external surface of the building is 80.55 % of its footprint.

Using the living block design, prototype "A" which has the potential to provide 0.61m^2 per m^2 of the vertical wall, the urban building could have about 557.4m^2 of space for vertical vegetation on the external surface of the building. The provided space for vertical wall vegetation by the living block design, prototype "A" accounts about 49% of its footprint.

6.2 Library Building

Library building and its external wall assessed in the previous chapter to show the potential of the building for vertical greening and vertical wall vegetation. From the assessment, the building has a total external surface of 252.93m^2. 79% of the external wall, which is about 200.40m^2, is bare-wall. The building has a total footprint of 1015.60m^2 which is the land consumed by the building structure. The building has potentials of compensating 20% its footprint by vertical vegetation using its bare wall surface of the external faces of the building for different vertical greenery technologies.

Based on the design and development result of the research and using the living block design, prototype “A” to substitute (assumption) the bare walls found on the external walls of the building, it is possible to have 122.24 m^2 of space for vertical wall vegetation. This can help the building to compensate its footprint by 12% by changing the bare walls of the building to the vegetated surface.

6.3 Cafe and Dormitory Building

The café and dormitory building is among the selected buildings for the assessment of external surfaces for the vertical vegetated wall. As already mentioned in Chapter Four, the building has 1147m^2 of the total area of external surfaces and 869.61m^2 of the surfaces is free of any kind of opening. The building consumed 912.5m^2 of horizontal land for its structure.

Using one of the living block, which named as design proposal “A”, the building has the potential to have 530.50m^2 space for vertical vegetation. In addition, the living block will enable the building to compensate 58% of its footprint by having the vertical space for vertical wall vegetation.

6.4 Workshop Buildings

Both workshop buildings, which are taken from the external surface assessment of the potential for vertical greenery and vertical wall vegetation, have a total area of surfaces 513.40m^2. The buildings also consumed 634m^2 of land for their construction, known as building footprint. They have also 466.77m2 of bare wall surfaces according to the data interpretation done in chapter four. Considering their bare wall potential for vertical greenery, it is very important to compare the potential of the buildings using the living block proposal, already conducted in chapter five of the research.

Assuming the bare walls of the workshop buildings to be constructed with living block prototype “A”, it is possible to get 284.73m^2 of plantation space for vertical greenery and vertical vegetation. In other words, both buildings have the potential to recompense 45% of their footprint (the land consumed for their construction) by vertical greenery or vertical vegetated wall.

Generally, using the designed living blocks for bare wall construction, fence construction and shear wall and retail walls construction will help to get 0.0494m^2, 0.0266m^2 and 0.0522 m^2 from each single living block prototype “A”, “B” and “C” respectively. Comparing to the existing technologies of vertical greenery; such design proposals are preferable for their cost (costs 300 birr/m^2) and technique of construction (labor cost and less skilled manpower). The proposed technology of Living block is easily adaptive and can be an integral part of a wall which is totally different from the existing technologies which are fixed to a wall or structural support.

6.5 Scaling Up

From the scale-up strategy, the result showed that scaling up the living block as a living wall for different public buildings and the public institution will create visible change on the UHI of the city and on the urban stormwater management as well. Introducing the living wall to the building blocks of Mechare Meda condominium will retain about 16.4% of the roof rainwater runoff from each building block annually. In addition, the surface temperature of each building block decrease by 11.6^{o}C which directly decrease the UHI of the neighborhood as well.

CHAPTER SEVEN

7. Conclusion and Recommendation

7.1 Conclusion

The environmental challenges of urban areas are diverse and broad. The most common challenges are urban heat island effect and flooding. In the case of Ethiopian urban centers especially Addis Ababa, the uncontrolled rate of urban population growth has damaged the environment by degrading the resources found in the city. The green infrastructure of the city is one of the severely damaged resources. Several research reviews under this study show that all sub-cities of Addis Ababa failed to fulfill the suggested standard of green area, which is 7-12 m^2 per inhabitants. The value given to the green infrastructure of the city is low as a result, the imperviousness ratio increasing dramatically on both sub city scale and city scale.

The case study area, which is the Ethiopian Institute of Architecture Building construction and City Development (EiABC), is one of the academic institutions found in Addis Ababa. EiABC which was founded in 1954 has a total area of 7.8 hectares and located at latitudes 9˚0'45’’N - 9˚0'43’’N and longitudes 38˚43'44’’E -

38˚43'54''E within the Lideta sub-city. The research analyzed that the EiABC campus has an elevation difference of 34m and 39% of the total area lies within the gradient of 2-5%. The campus also has dominantly southwest and west aspect, which counts 79% of the site. The analysis also showed that the soil type of the research area is Eutric nitisols, known by its fertility property. The study area has the 27-39m depth to reach the level of groundwater.

In addition to the above natural potentials of the study area for green infrastructure practices, the research area has also rainfall ranging from 68-98mm annually. Even though these all potentials are there, the man-made challenges are visible in the research area due to the new construction and different developments on the site. To identify the challenges related to the man-made factors, the researcher analyzed the research area's land use and land cover. The area has 11-land use and land cover with different shares on the imperviousness of the area. These are bare land (1.2%), corrugated iron sheet (23.6%), concrete roof (0.9%), concrete road (2.6%), grass (8.6%), gravel (0.1%), paved stone (2.2%), playfield (8.6%), asphalt road (4.4%) and trees (37.2%). From the analysis, the result showed that 55.6% of the area of EiABC is impervious, 6.7% is semi pervious.

One of the investigation techniques for the study was: calculation of the generated runoff from the impervious surface of EiABC. The campus generates about 1757m^3 of water and 39.7% of this runoff water generated from the roof of the buildings found within the EiABC campus. The generated runoff is not utilized rather it causes damage to the pedestrian's walkways in the vicinity and also causing flooding on the lower catchment of Addis Ababa like Mekanisa area.

As the main objective of the research was to alleviate these challenges by increasing green infrastructure by taking the case of EiABC campus, the research used purposive sampling to select Five buildings for vertical bare walls assessment and their potential to be a vertical vegetated wall. The selected buildings were Urban building, Library building, café and dormitory building, and workshop buildings. The assessment showed that the urban building has a bare wall of 913.72m 2, Library building has bare wall area of 200.4m 2, café, dormitory building has 869.61m 2 bare wall, and the workshop buildings have bare wall area of 466.77m 2 of the bare wall on their external surfaces. The research investigated that the selected buildings have the potential of bare wall area 80.55%, 19.72%, 95.30% and 73.60% of their footprint on their external surfaces of the urban building, library building, café and dormitory building, and workshop buildings respectively. Finally, the research came up with different designs of innovative living block designs named as living block prototype “A”, Living block prototype “B” and living block prototype “C” which provided a space for vertical wall vegetation of $0.049m^2$, $0.026m^2$ and $0.052m^2$ form each living block respectively. The result of the living block design showed that by substituting the bare walls of the urban building, library building, café and dormitory building, and workshop buildings it is possible to have 557.4m2, 122.24m2, 530.50m2 and 284.73m2 of vertical spaces for vertical vegetation from each selected buildings respectively. The research did a comparison of the selected building’s potential of providing vertical space using the living block to their footprint. Moreover, the result showed that the urban building, library building, café and dormitory building, and the workshop buildings have the potential of compensating 49%, 12%, 58% and 45% of their footprint (land consumed in construction).

Generally, the research has identified bare walls on buildings, fences, shear walls and retail walls found in EiABC specifically and in Addis Ababa city level are the potentials of green infrastructure for urban settlements. Innovative and cost-effective living block design for vertical greenery is very important. The research provided living block technology as an option for the vertical greening of bare walls in cities.

7.2 Recommendations

The research investigated the problems and potentials of living wall design and development within the selected case study area. The identified problems from the findings of the study to increase of imperviousness which are main causes of flooding, damage to pedestrian walkways and streets. Urban Heat Island effect, which is also the main cause for discomfort in our cities due to increases in local temperature due to lack of Green infrastructure and public green spaces. Moreover, there is no attempt made to curb the above challenge using vertical greenery and other green technologies and practices in Addis Ababa. Finally, for a sustainable urban environment and resilient cities, the research has recommended the following strategies and suggestions.

- Vertical greenery practices have to be promoted as a means of increasing green infrastructure of urban areas for stormwater control.

- Every building, especially high-rise buildings in cities have to incorporate vertical greenery technologies for stormwater utilization and decrease the pressure on the drainage system of the cities.
- Bare walls of buildings, fences, shear walls and retaining walls found in urban areas have to change to green using vertical greening technologies.
- In Addis Ababa fences of institutional plots, public buildings and railway shear walls are ideal surfaces as potentials for vertical greening. Incorporating vertical green using living block technology to these structures will improve the quality of public spaces and livability of the city.
- The research provided three typologies of living block design for new bare walls construction. New constructions have to consider the advantages of the Living block during the construction process.
- Further design demonstrations and structural test of living blocks should be conducted.
- Buildings in urban areas have to compensate their footprint by introducing vertical greenery on their external facades.
- Regulations based on the need and existing amount of green infrastructures should formulate for vertical greenery practices for each building within the city.
- The research mainly worked on incorporating vegetation space for vertical greenery on the external facades of buildings. Moreover, the research recommends further researches on the irrigation system of living blocks and moisture protection technologies.

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