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A Suitability Analysis of Vertical Garden System: Cases in the City of San Fernando, Pampanga, Philippines

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ABSTRACT

Urban heat island refers to the phenomenon in which urbanized areas experience significantly higher temperatures compared to surrounding rural or natural landscapes. Vertical gardens and other greenery methods have emerged as potential solutions to mitigate the effects of urban heat islands and create sustainable cities that foster a livable and secure quality of life. This research study explores the suitability of implementing vertical garden systems in existing structures in the City of San Fernando, Pampanga, Philippines. The main objective is to create a checklist that can be used as a tool to assess and determine the appropriate design for the selected structures. Two vertical garden designs were provided: The Attached System and Free-Standing System, and these designed systems were modified depending on each case. A structured survey was also conducted among the participants, who are a residential structure owner, a commercial structure owner, and an institutional structure owner, to know the possible reason for adapting the system. The findings of this study provide valuable insights into the feasibility of vertical garden systems, which can significantly influence the extent to which these systems are embraced and integrated into existing structures.

Keywords: *Urban Heat Island, UHI Intervention System, Attached Vertical Garden, Free-Standing Vertical Garden*

1. Introduction

Rapid urbanization represents a remarkable societal change in human history, with cities playing an increasingly significant role in global progress through diverse social, economic, and environmental factors that extend across various spatial and temporal aspects (Bai et. al 2016). More than half of the population of the world currently lives in cities, indicating that cities have become an important component of human civilization as well as a crucial concern for sustainable development (Xu, Gao, Zhang & Fu 2019).

According to Khair, Lee, & Mokhtar (2020), this is in accordance with the idea of a sustainable city, which includes not just environmental mitigation, but also the active engagement of local citizens in interacting with authorities in order to attain a sustainable quality of life. Specifically, SDG 11 (Sustainable Cities and Communities) of the UN Sustainable Development Goals inspire urban sustainability, which demands cities to be livable and secure via integrated planning and management, and public engagement.

In recent years, the population of the world has significantly expanded, and both new and old megacities are becoming more populated (Mirzaei, 2015). Jain & Janakiram (2016) stated that a massive number of structures are being built globally, with many more to be added in the future. Because paved and impermeable surfaces absorb, collect, and retransmit more solar energy than vegetation, the replacement of vegetated surfaces in urban areas has raised temperature over time.

According to Dr. Hui (2011), a growing number of urbanized cities throughout the world are currently struggling with Urban Heat Island (UHI) issues and a shortage of green space due to industrialization and the transition of rural areas into urban areas. An urban heat island is a climatic occurrence in which cities experience higher air temperatures compared to their rural surroundings as a result of human activities altering land surfaces, large energy consumption, and the emission of waste heat as a result of these factors. Population growth is a major contributor to the establishment of urban heat islands (Tashnim & Anwar 2016).

As stated by Wu & Ren (2019), a strong association has been shown between high temperature and mortality, which poses serious health hazards such as respiratory tract infections and cardiovascular and cerebrovascular illnesses. Yin, Yuan, Lu, Huang, & Liu (2018) mentioned that excessive heat can reduce living comfort and increase health risks, particularly in the elderly (>65 years) and the very young (2 years), who are more susceptible to high temperatures.

The community needs an additional 5 to 10% of energy demand to make up for the impact of urban heat by increasing the energy demand for air conditioning or cooling by 1.5 to 2 percent for every 0.6°C increase in air temperatures (ranges of 20 to 25°C). As UHI raises the demand for energy, power plants must provide additional energy, and because they rely on fossil fuels for generating energy, greenhouse gas emissions and air pollutants increase (Rinkesh, 2016).

Several studies have been conducted in order to identify potential strategies for mitigating the Urban Heat Island (UHI) effect (Moore & Golrokh, 2018). As stated by Barron, Ruggier, & Branas (2018), a variety of researchers have shown a correlation between greenspace and lower urban temperatures. All types of vegetation, including grass, bushes, and trees, as well as bodies of water, contribute to cooling. Trees and shrubs can lower the maximum average UHI by 1.0 °C. Green walls have a maximum average mitigation performance value of 0.1 °C. Reflective roofs and pavements can minimize maximum UHI by 0.3 °C on average. Water has a significant cooling potential in dry environments. The maximum cooling potential while utilizing only one method is 0.4 °C on average. When two or more technologies are utilized simultaneously, the highest UHI reduction is 1.5 °C on average (Yenetti et. al 2020).

Ritu Jain and Janakiram (2016) assert that landscaping is the only way to convert gray walls into green ones, which is required in the modern world. Since there is no room for horizontal expansion, the only available space can be converted into vertical gardens.

Conforming to Moghaddam, Delgado, Dominguez, Mir & Mateu (2021), urban heat islands (UHI) and energy use, which is presently crucial owing to the global warming issue, may be reduced via vertical gardens and other greenery methods. Additionally, enhancing biodiversity and ecological value enhances the living conditions of building occupants by reducing environmental impact, boosting outdoor and indoor comfort, and improving air quality for city dwellers.
Vertical gardening is a popular method of designing buildings, structures, and interiors with growing plants. This style of landscaping receives special attention in urban areas owing to its perfect balance of functional, ecological, and aesthetic features (Chernova, Fedorovskaya, & Petukhov, 2020).

Ivanova, Ganzha, and Podkovyrov (2020) claim that it is widely utilized in contemporary cities for the window frames of low-rise and medium-rise buildings, as well as high-rise buildings and structures and their inner space atriums. Buildings and structural walls can be landscaped entirely, partially, or with accent wall coating.

As stated by Manso, Castro, & Gomez (2015), vertical gardens help to integrate vegetation into urban environments without taking up any roadway space. In actuality, covering buildings with vegetation on a large-scale metropolitan basis may enhance the urban environment.

Building exteriors may be made greener to enhance insulation, improve interior and outdoor climate, and lower greenhouse gas emissions such as carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen dioxide (NO2) (Jain & Janakiram, 2016).

Plants provide a natural solution for cleaning indoor air, creating cool interiors by shade, making the people less stressed and more productive in their presence, lowering background noise, and contributing to a healthy lifestyle.

As studied by Moghaddam, Delgado, Dominguez, Mir, & Mateu (2021), the surface temperatures of vertical gardening were up to 59.9 °F lower than those of bare facades, while those of internal walls were up to 35.06 °F lower. Cities are 1 to 7°F warmer during the day on average. This distinction lasts far into the night when cities can be as much as 5°F warmer than the surrounding environment (Gregory & Azarijafari 2021).

The City of San Fernando, which serves as both the provincial capital of Pampanga and the regional center for Central Luzon, was chosen as the study area because it has been influenced by land use, particularly where land is densely urbanized and has been converted to another land use from time to time due to various circumstances. It is a densely urbanized area with numerous leisure parks, malls, and residential neighborhoods. In addition, the city is expected to continue expanding its residential area in the next few years (Oliquino & Dungca 2021). It is also one of the cities that suffers from the extreme effects of Urban Heat Island. On the warmest day of the year, temperature in San Fernando normally varies from 25°C to 35.55°C (Weather Spark, 2022).

According to the City Government of San Fernando, Pampanga (2015), CSFP is a fast-growing city in terms of population and settlement growth. Built-up areas increased ten (10) times from 406 hectares in 1977 to 4,221 hectares in 2014. During the same time span, the population increased from 103,372 to 316,443.

By calculating the ratio of the total population to built-up area, the estimated urban densities in 1977, 2007, and 2014 were 255 people per hectare, 93 people per hectare, and 75 people per hectare, respectively. Declining urban density for CSFP might indicate urban sprawl. It is the consequence of investments in unfinished domestic, economic, and industrial real estate buildings.

Urbanization has become one of the most profound societal revolutions in human history. With more than 50% of people living in urban areas today. Through integrated planning and management, as well as public engagement, there is a need to mitigate the effects of urban heat islands and create sustainable cities that promote a livable and secure quality of life. The use of vertical gardens and other greenery techniques has been suggested as a way to improve air quality, lessen environmental impact, social and psychological well-being, and living circumstances for building occupants while also assisting in lowering the effects of urban heat islands and energy usage.

Despite the growing interest in vertical gardens, few studies have specifically addressed the practicality and feasibility of installing vertical gardens on existing buildings, including whether the structure of the building can support the weight of the vertical garden system, and if not, what alternative systems can be used. The feasibility of vertical garden systems on different types of existing structures is important because it could significantly influence the extent to which such systems are embraced on these structures.

3. Objectives of the Study

This study aims to assess the suitability of a vertical garden system in the City of San Fernando, Pampanga. Specifically, the purpose of this study is:

1. To develop a suitability checklist as an instrument in determining the appropriate design for the selected structures;
2. To design a vertical garden system based on the Load and Resistance Factor Design Method (LRFD); and
3. To conduct a survey in validation of the acceptability of designed vertical gardens to selected vertical structures in terms of environment; health; and cost.

4. Significance of the Study

The significance of this study lies in its potential to address the Urban Heat Island (UHI) effect in urban areas, specifically in the City of San Fernando, Pampanga. The UHI effect is a well-known phenomenon whereby urban regions suffer much higher temperatures than their neighboring rural areas. This has several negative effects on the environment, human health, and the economy. Vertical garden systems have garnered increasing attention in recent years as a potential solution to mitigate the Urban Heat Island (UHI) effect. This is due to their capacity to lower temperatures through shading and evapotranspiration.

This study contributes to the existing body of knowledge by analyzing the suitability of the designed vertical garden systems for existing buildings in the City of San Fernando, Pampanga. Through this study, the potential of vertical gardens as a practical and sustainable solution to mitigate the UHI effect in urban areas can be further explored. Furthermore, the study's findings may provide valuable insights for policymakers, urban planners, and building owners in adopting and implementing vertical garden systems as a viable urban heat mitigation strategy.

In addition, the study also highlights the importance of promoting and preserving green spaces in urban environments. The benefits of vertical garden systems extend beyond reducing urban temperatures, as they can also improve air quality, provide health benefits, and enhance the aesthetic appeal of the built environment. The findings of this study may encourage the incorporation of vertical garden systems in future urban design and planning initiatives, leading to the creation of healthier and more sustainable urban environments.

5. Scope and Limitations

The scope and limitations were divided into subcategories. This breakdown provided a clearer understanding of the specific aspects and constraints of the research study, both in terms of its focus and limitations.

Scope of Research

5.1 Topic Scope

The scope of the research study focuses on the suitability of the vertical garden system in existing buildings in the City of San Fernando, Pampanga, Philippines.

5.2 System Scope

The study specifically focused on outdoor vertical garden systems, excluding indoor vertical gardens. Consequently, the results and recommendations derived from this research may not be universally applicable to other cities or areas beyond the City of San Fernando, Pampanga, Philippines. Also, the study employed two design considerations for the system, namely the Attached and Free-Standing Vertical Garden System, to determine the most suitable design for buildings in the city.

6. Limitations of Research

6.1 Methodological Limitations

Due to non-participation constraints, researchers have limited control over the selection of buildings. Only participants who are qualified and have provided their consent to participate in the research are selected.

6.2 System Limitations

Plants: The plant chosen for the vertical garden is limited to moses-in-the-cradle unless mentioned in the recommendation under result and discussions for each case depending on the governing deciding factor parameters.

Soil: The vertical garden system is specifically designed to use loam soil as its designated soil type. Loam soil is an excellent choice for vertical gardening due to its ideal balance of water retention, drainage, nutrient availability, aeration, and workability. Its properties promote healthy plant growth, root development, and overall vertical garden success.

Maintenance: The system does not encompass the maintenance aspect of the vertical garden, as it concentrates on other specific factors. Nevertheless, the vertical garden system is intentionally designed to minimize maintenance requirements. This includes a thorough evaluation of plant species that are sturdy, resilient, and suitable for vertical growing conditions, require minimal maintenance and fertilization, and have notable resistance to diseases and pests. Furthermore, the automated irrigation of the system is intended to promote self-sustainability while reducing the need for manual intervention.

Costing: The costing of materials is based on average prices observed in the Philippine market. However, it acknowledges that these estimates may not accurately reflect current pricing due to market fluctuations. It is still recommended for people to conduct their own cost analysis, considering prevailing market conditions, for accurate pricing information.

Load Computation: The study focused only on the design of the vertical garden system and the load that the system will transfer to the supports. Other load calculations, including wall capacity, base plate design, and column design, are not covered.

Installation: The installation of the vertical garden was limited in this study. The focus of the study was not primarily on the installation process itself, but rather on other specific components of the system, aspects, and factors related to the vertical gardens. Therefore, the scope of the study did not extensively cover the installation procedures, techniques, or variations.

7. Definition of Terms

Heat Island. According to Merriam-1993 Webster's edition of the dictionary, Urban Heat Island is "an urban area in which significantly more heat is absorbed and retained than in surrounding areas." The phrase "an area that constantly experiences warmer temperatures than the surroundings, such as a city or industrial site, due to factors such as a lack of greenery, the poor absorption of asphalt and roofing materials, and the creation of waste heat by moving cars or structures" is used in this paper to denote Heat Island.

Participants. These are individuals or groups who are involved in the study by providing data or information through various means such as surveys, interviews, observations, or experiments. In this study, they are the owners or representatives of the buildings in three cases. They are chosen based on certain criteria that match the research objectives and the type of data needed.

Suitability. The dictionary definition of the term Suitability is “the quality or state of being especially suitable or fitting” (Merriam-Webster’s 1993). In this paper, the term suitability is used to mean “if something is appropriate or right for a specific goal or circumstance.”

8. Conceptual Framework

The study will be undertaken using a conceptual framework. Figure 1 entitled “The Research Paradigm” served as the conceptual paradigm of the study.

The study is divided into 3 parts: Part 1 is the general guidelines and procedures for this study. It consists of three (3) phases; Phase 1 – Suitability Checklist, Phase 2 – General Design, and Phase 3 – Design Validation. Followed by Part 2 in which procedures to classify three (3) different cases were undertaken. Lastly, under Part 3, all of the procedures in Phases I, II, and III from Part 1 are applied to the cases classified under Part 2.

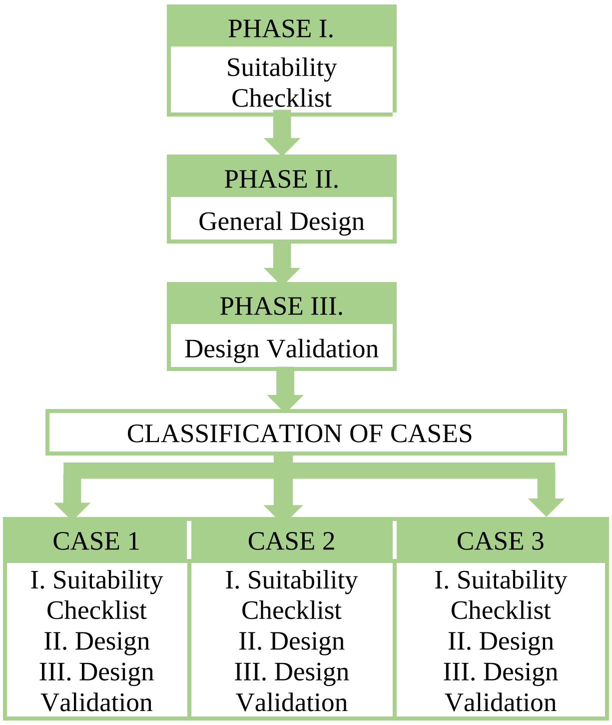


Figure-1: The Research Paradigm

9. Methodology

9.1 Suitability Checklist, General Design and Design Validation

This section presents the comprehensive set of general methods or guidelines to be followed.

9.1.1 Suitability Checklist

This phase includes the collection and analysis of data related to the various aspects that need to be taken into consideration when planning to install or construct a vertical garden by reviewing existing literature and conducting a comprehensive analysis.

9.1.2 General Design

After analyzing whether the structure will be suitable for the intervention system through the completion of the suitability checklist and structural analysis, the researchers will develop the design of a vertical garden that is suitable for the structure. This includes the steel bracing, planter, the chosen plant, and its installation. The design will be based on Load and Resistance Factor Design Method (LRFD).

Two (2) general designs, the attached system and the free-standing or offset system, will be illustrated through AutoCAD software. AutoCAD is a type of Computer-Aided Design (CAD) software which enables the creation of 2D and 3D models with greater efficiency and precision than could be achieved through manual drafting methods.

The designs were developed in adherence to the universal design of a vertical garden while considering the following:

9.1.2.1 Materials

Pambansang Bakal Corporation is a well-known distributor of steel in the Philippines having obtained steel projects locally and abroad from countries such as Korea, Taiwan, and China. Its website, https://www.pambansangbakal.com, contains information regarding the commonly available steel materials in the Philippines. This website was utilized to determine the materials to be used in creating the design of the system.

9.1.2.2 Loads

Applicable loads are identified and computed in accordance with the National Structural Code of the Philippines 2015. The following loads are used in Structural Analysis and Design Software (STAAD) to calculate the. STAAD is a well-known software application for analyzing and designing structures such as buildings, towers, bridges, industrial facilities, transportation infrastructure, and utility structures. The applicable loads used in analysis include the following:

Dead Load – A structural permanent load that includes the weight of the members, the supported structure, and any permanent attachments or accessories. This load remains constant and is unaffected by external influences like movement, vibration, or weather.

Live Load – A structural permanent load that includes the weight of the members, the supported structure, and any permanent attachments or accessories. This load remains constant and is unaffected by external influences like movement, vibration, or weather.

Wind Load – refers to the pressures or forces exerted by the wind on a building or structure.

Earthquake Load – Seismic load is the amount of seismic energy (energy waves that move through the ground) that a structure must endure in a certain geographic area.

9.1.2.3 Costing

Total costing of the materials used in structural framing, pot, soil mixture, plant, and irrigation to build a vertical garden is calculated. Costing is one of the considerations in choosing which vertical garden system suits your preference and budget. The costs of each material are retrieved from the prices present at Philippine market through Construct PH (https://constructph.com) and The Project Estimate (https://www.theprojectestimate.com/) websites.

9.1.3 Design Validation

9.1.3.1 Ethical Considerations

In a research process, adherence to research ethics, data privacy, and ethical underpinnings were critical. Permission letters were obtained in gathering the data. Consent letters were also distributed to solicit their participation, including their right to withdraw at any time if they felt they no longer wanted to participate, as articulated in the confidentiality disclaimer and data privacy notice appended to the copy of the research instrument. The references were correctly cited using the APA 7th edition format. Furthermore, no alterations or manipulations were made to the gathering. Similarly, the anonymity of the participants' identities and the confidentiality of the data gathered were treated with the utmost secrecy and professionalism.

9.1.3.2 Structured Survey Interview

Structured survey questionnaire is used for the determination which among the analyzed impacts – environment, health, and cost, of the vertical garden would be the factor why the owners will adopt the vertical garden system.

The 4-Point Likert Rating Scale is used to determine the level of importance of each of the deciding factors that the owners or representatives are considering in the applicability of the vertical garden system to a particular building.

Table-1: 4 – Point Likert Rating Scale

Strongly Disagree	Disagree	Agree	Strongly Disagree
4	3	2	1

9.1.3.3 Data Processing and Statistical Treatment of Data

The gathered data from the conducted survey are organized, tabulated, and listed for the analysis and interpretation using the following statistical technique:

9.1.3.3.1 Mean — average value of response in each of the deciding factors.

9.1.3.3.2 Likert — the scale that analyzes the value of each mean and provides interpretation.

Strongly Disagree (1-1.75)
Disagree (1.76-2.5)
Agree (2.6-3.25)
Strongly Agree (3.26-4)

9.2 Classification of Cases

The process used to classify cases is discussed in this section. This includes procedures employed to categorize cases based on specific criteria, as well as any relevant considerations or limitations encountered during the classification process.

The projected number of structures per barangay within the City of San Fernando, Pampanga, is requested to the Office of the City Building Official (OCBO), as this department is in charge of overall administrative control and supervision of all works related to buildings or structures in its area of responsibility, as well as the processing of all applications and certificates and the issuance of the necessary permits. The collected data on structures are divided into residential, commercial, industrial, and institutional. The three classifications of buildings that acquired the highest number are used in each case. Afterward, structures from different classification will be chosen and selected.

9.3 Three Cases

Section 3 provides the application of the aforementioned methods under Section 1; Phase I, II, and III, to the classified cases acquired from Section 2; Case 1, 2, and 3.

9.3.1 Suitability Checklist

The selected structure was assessed to gather specific data needed for the suitability checklist. The data is then used to fill in the developed suitability checklist. The particulars include the following:

For the structures that acquired 100% applicability
a. Wall Space
b. Unshaded wall portion
c. Type of Wall (based on material)
d. Type of Wall (based on purpose)
e. Height of the wall building
f. Width of the wall building

For the structures that acquired 0 – 50% applicability
a. Space beside the structure
b. Unshaded space
c. Structure's Height
d. Height of the wall
e. Width of the available space

9.3.2 Design

Modified Design was created based on the developed General Design and subsequently altered in accordance with the specifications of the buildings in each case being studied. In modifying the design, the following are set into considerations:

Table-2: Modified System Design Consideration

For Attached Vertical Garden System:	For Free-Standing or Offset Vertical Garden System
Height of the wall	Height of the Building
Width of the wall	Width of the Available Space

9.3.3 Design Validation

In compliance with ethical considerations, request letters were sent to the participants asking for their permission to answer the developed survey questionnaire prior to conducting the structured survey interview. Once permission was obtained, the survey questionnaire was administered and distributed to the participants in the form of printed copies. The data collected from the completed survey questionnaires were processed and statistically analyzed.

10. Result and Discussion

This chapter deals with the presentation, analysis, and interpretation of data relevant to the study.

10.1 General Method, Guidelines, and Design

10.1.1 Suitability Checklist

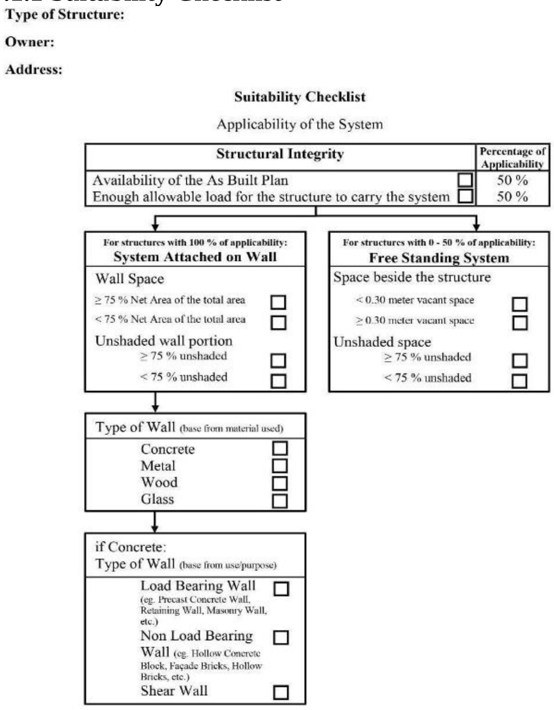


Figure-2: General Suitability Checklist (Applicability of the System)

Considerations in developing the Suitability Checklist: Applicability of the System

1. Availability of As-Built Plan

These plans are produced after construction is finished and are frequently utilized by architects, engineers, and builders to make it easier to modify or renovate the building in the future. Several studies have investigated the use of as-built plans in designing and modifying vertical gardens. In a study by Razzaghmanesh et al. (2018), as-built plans were used to design a green wall system for a building in Melbourne, Australia. The authors found that as-built plans were crucial in identifying potential challenges and ensuring the system's feasibility. Dávila et al. (2019) also utilized as-built plans in the design of a vertical garden for a building in Bogotá, Colombia. They concluded that the as-built plans played a critical role in guaranteeing the compatibility of the system with the building and ensuring that alterations could be carried out without posing a risk to the building's stability.

2. Enough Allowable Load

Knowing the enough allowable load for a building structure is critical in maintaining the safety and stability of the building and its occupants when installing a vertical garden system. The structure must support its own weight and additional loads such as furniture and people. Exceeding the maximum allowable load can cause structural damage, collapse, and potential harm to occupants. Designers must determine the type and size of the system and any necessary modifications to the structure to ensure that the additional weight of the system does not exceed the building's maximum capacity.

3. Wall Space

According to research by Grace and He (2016), the proportion of a vertical garden's total surface area that is covered by plants directly correlates with how well it reduces heat and improves air quality. According to the study, a vertical garden with at least 75% of its surface area covered can offer the greatest number of advantages.

4. Unshaded Wall Portion/Space

According to Matsuda, Ohashi-Kaneko, Fujiwara, Goto, and Kurata (2017), shade can have an impact on a plant's growth patterns and development, such as delaying flowering or diminishing fruit yield.

On the basis of this discovery, it is advised to make sure that the wall to which a vertical garden is attached receives enough sunlight for plant growth. While some plants may tolerate shadow, it is typically advised to provide at least 6 hours of direct sunlight per day for best growth (USDA, 2021). The 75% unshaded requirement could serve as a guide to make sure the plants get enough light for growth and development. It is crucial to take into account the particular lighting needs of the plant species being produced and to modify the shading accordingly.

5. Direction of the Available Space/Wall and Space beside the Structure

The study conducted by Safikhani and Baharvand (2017) stated that identifying the appropriate distance between the greenery and wall surface is important as it improves the thermal performance in temperature reduction and directly affects the system efficiency. The study concluded that the 150mm (15cm) and 300mm (30cm) space distance between the system and the wall area has a great impact on temperature reduction.

In addition, thermal performance between the living wall and the wall surface at distances of 150mm (15cm) and 300mm (30cm) varies in the morning and the afternoon. Thus, the direction of the wall and where the garden system will be applied is also crucial. Plants that are placed closer to the walls perform better because of the morning's high effectiveness of their cooling influence in decreasing temperature. On the other hand, a vertical garden is more successful in lowering the temperature in the afternoon when plants are exposed to direct sunlight.

6. Type of Wall (base from material used)

The suitability of various wall materials for mounting a vertical garden was examined in a study by Haddad and Kassem (2019). Due to their inadequate load-bearing capability and propensity for rusting, the study discovered that metal walls are typically not advised for mounting a vertical garden. Although some types of vertical garden systems may be acceptable for wooden walls, these walls can also be vulnerable to rot and insect damage. Due to the possibility of cracking or fracturing from the weight of the garden, glass walls might not be the best material to connect a vertical garden. On the other hand, Concrete walls are generally considered suitable for carrying attached vertical garden systems due to their high load-bearing capacity. Concrete is a strong and durable material that can handle the weight of a vertical garden without cracking or buckling. However, it is important to ensure that the wall is structurally sound and can support the additional weight of the garden system.

7. Type of Wall (based from use/purpose)
Several studies have investigated the design and installation of vertical gardens on different wall types, as outlined below:

a. Bearing Walls:
A study by Valipour et al. (2019) investigated the impact of vertical garden systems on bearing walls of high-rise buildings. The authors found that the weight of the vertical garden system could cause additional stress on the bearing walls, potentially leading to structural damage if the system is not properly designed and installed.

b. Non-bearing Walls:
In a study by Razzaghmanesh et al. (2018), the design and installation of a vertical garden system on a non-bearing wall was investigated. The authors found that the non-bearing wall was suitable for installing a lightweight vertical garden system, but additional reinforcement was necessary for larger systems.

c. Shear Walls:
A study by Hosseini et al. (2018) investigated the effect of installing a vertical garden system on shear walls of buildings. The authors found that the installation of a vertical garden system on a shear wall could lead to an increase in the wall's stiffness and strength, but also noted that additional analysis was necessary to ensure the system's safety and stability.

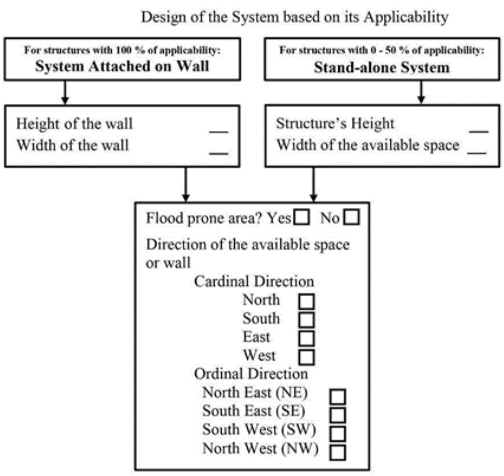


Figure-3: General Suitability Checklist (Design of System based on its Applicability)

Considerations in developing the Suitability Checklist: Design of the System based on its Applicability:

1. Height/Width of the Wall/Structure
Measuring the width and height of the wall, as well as the available space, is critical in designing an ideal vertical garden system. The wall must be able to accommodate the system's structural framework, including mounting brackets, framing, and irrigation. The available space must be measured to ensure a proper fit without interference with nearby structures or equipment, and with enough space for maintenance and plant access. These measurements will establish the system's proper width and height while maintaining plant growth and system stability.

2. Flood Prone Area
Assessing if the site for the vertical garden system is flood-prone is crucial as it can greatly affect its growth and structural integrity. Adjustments in design should be made to ensure the system can withstand flooding and continue to function properly after the flood subsides. Measures such as raising the system's height or adding drainage systems can be implemented to prevent waterlogging.

3. Direction of the available space or wall
The direction of the wall or open space where the vertical garden system will be built can have a significant impact on its performance.

Choosing a wall with a favorable orientation can enhance the thermal performance of the vertical garden system by minimizing heat gain and enhancing the system's overall energy efficiency. This is critical because it potentially minimizes the amount of energy required to cool the building, resulting in cheaper energy costs and a smaller carbon footprint.

4. Components of Vertical Garden System:
The components of vertical garden design, including plants, planters, soils, irrigation, and framing structures, remain consistent. The only variables that differ are the sizes of the structures and irrigation, and the number of plants, pot and planter incorporated.

5. Framing Structure
A blog from Frame it All (2023) states that a galvanized steel frame is ideal for a vertical garden because of its resilience and lifespan. Galvanization, which involves coating steel with zinc, protects against corrosion, rust, and environmental causes. It also stated that galvanized steel resists corrosion, has a long-life span, and has low maintenance requirements.

6. Plastic Planter
According to Plantlogic (2022), plastic pots provide various advantages for gardening, including price, lightweight and portability, moisture management, durability, and adaptability. They are ideal for vertical gardens because they are inexpensive, easy to handle and transport, effectively hold moisture while preventing

overwatering, survive a variety of weather conditions, and are available in a variety of sizes and styles for customization.

7. Plant
For this study, Moses-in-the-Cradle (Tradescantia Spathacea) will be the only plant used in the vertical garden. This plant was chosen considering its growth rate, heat resistance, and availability in the study area. The study conducted by Irfandi, Munir, Muslimsyah and Huda (2021) shows that the maximum temperature of Moses-in-the-Cradle was 37.5ºC while the maximum indoor temperature was over 50ºC. This means that the plant can indeed reduce the temperature. Another study conducted by Pahalagedara, Rupasinghe, Kumarasinghe, & Charminda (2022) showed that in their study, the highest temperature reduction of 3.14ºC was seen in Tradescantia Spathacea between the wall and the stem plant.

8. Soil
The soil used for this vertical garden is Loam Soil. According to Parvatha (2015), loam soil stores nutrients and has a texture that retains water long enough for plant roots to reach it, but it also drains well, which means that the water ultimately seeps away, preventing plant roots from rotting. Furthermore, loam soil supplies plants with medium-textured soil that allows air to circulate plant roots; air circulation protects against illnesses that are common in poorly draining compacted soils, and then the soil texture permits roots to spread swiftly, retain moisture, and absorb nutrients (Iannotti, 2023).

9. Irrigation
Mentioned by Daud, Indriyati, & Sari, (2022), in a vertical garden, the irrigation system serves an integral part since proper irrigation systems allow plants to grow well. Because it is more effective with a small discharge, may minimize runoff, and can reduce water loss due to evaporation, drip irrigation is one of the most extensively used irrigation systems and the greatest technique ever utilized.

10.1.2 Design

A. Attached Vertical Garden System

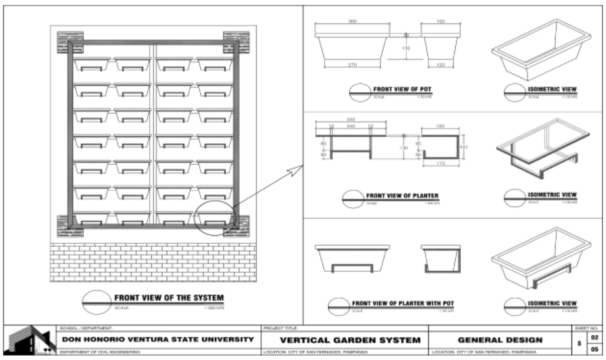


Figure-4: Pot and Planters: General Attached Vertical Garden System

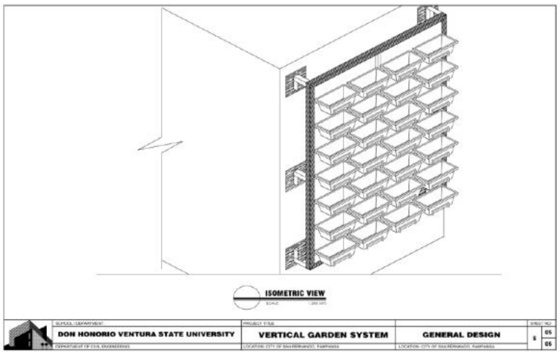


Figure-5: Isometric View: General Attached Vertical Garden System

A.1 Materials

Structure

Table-3: Structural Framing Materials: General Attached Vertical Garden System

Name of Materials	Size	Total Length
Galvanized Angle Bar Steel	50 x 50 x 6	7.52
Galvanized Angle Bar Steel	25 x 25 x 3	16.02
Stainless Steel Square Steel Bar	10 x 10	51.688

Plants and Planter

Table-4: Pot and Planter Materials: General Attached Vertical Garden System

Name of Materials	Total No. of Material Used
Pot and Soil	28
Plant	28

Irrigation

Table-5: Irrigation Materials: General Attached Vertical Garden System

Name of Materials	Size	Total No. of Material Used
Irrigation Tubing	3/4"	15
Irrigation Drip Emitter	16 x 16 x17	56
PVC Fittings: Elbow	3/4"	2
PVC Fittings: End Cap	3/4"	1
PVC Fittings: Tee	3/4"	7
Main Water Shut Off Gate Valve	3/4"	1
Hose Clamp	3/8"	29

A.2 Costing

Table-6: Total Cost of General Attached Vertical Garden System

Category	Amount
Structural Framing	4115.64
Pot and Planter	3334.000
Irrigation System	1587.00
Total Cost	9036.64

A.3 Loads

Dead Load

Total Dead Load = Total Load of the Structure + Total Load of Additional Materials

$$= 0.91\ kN + 0.549\ kN$$
$$= 1.459\ kN$$

Live Load

The National Structural Code of the Philippines (NSCP) 2015 does not specifically provide a minimum live load requirement for vertical gardens. However, in this study, twenty five percent (25%) of the minimum uniformly distributed live load for residential buildings will be used. Hence, a twenty five percent (25) of 1.9kN per square meter (kN/m^2) or 40 pounds per square foot (psf) is the live load that will apply in the planter. For the live load of each trellis, a load of 0.5kN multiplied by the width of the frame of the system will be used as the uniform distributed load. These live load considerations are for the irrigation system, and other additional components that are not considered as dead load.

Earthquake Load

To calculate the earthquake or seismic load of the system accurately, the following factors and variables must be considered, as they serve a critical role in determining the level of seismic activity and potential damage that may occur.

Table-7: Earthquake Load Variables: General Design

Earthquake Load Variables	
Total Height (m)	Soil Profile Type
Weight (kN)	Seismic Zone Factor, Z
Occupancy Category	Near Source Factor, Na
Seismic Zone Type	Near Source Factor, Nv
Seismic Source Type	Seismic Coefficient, Ca
Closest Distance (km)	Seismic Coefficient, Cv
Importance Factor, I	Response Modification Factor, R
Importance Factor, Ip	Steel Moment-Resisting Frames, Ct

B. Free-Standing or Offset Vertical Garden System

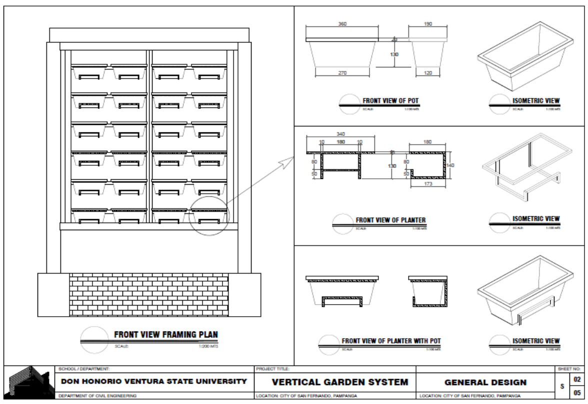


Figure-6: Pot and Planters: General Free-Standing or Offset Vertical Garden System

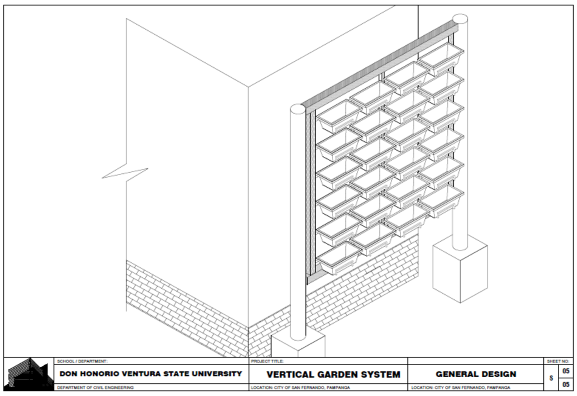


Figure-7: Pot and Planters: General Free-Standing or Offset Vertical Garden System

B.1 Materials

Structure

Table-8: Structural Framing Materials: General Free-Standing or Offset Vertical Garden System

Name of Materials	Size (mm)	Total Length (m)
Galvanized Angle Bar Steel (for Framing)	63.5 x 63.5 x 6.35	3.6
Galvanized Angle Bar Steel (for Trellis)	50.8 x 50.8 x 3.302	13.74
Galvanized Rectangular Tubular Steel	75 x 50 x 1.2	3.544
Galvanized Steel Round Pipe	141.22 Ø x 66.1	4.8
Stainless Steel Square Steel Bar	10 x 10	44.304

Plants and Planter

Table-9: Pot and Planter Materials: General Free-Standing or Offset Vertical Garden System

Name Of Materials	Total No. of Materials Used
Pot and Soil	24
Plant	24

Irrigation

Table-10: Irrigation Materials: General Free-Standing or Offset Vertical Garden System

Name of Materials	Size	Total No. of Material Used
Irrigation Tubing	3/4"	19
Irrigation Drip Emitter	16 x 16 x17	48
PVC Fittings: Elbow	3/4"	2
PVC Fittings: End Cap	3/4"	1
PVC Fittings: Tee	3/4"	6
Main Water Shut Off Gate Valve	3/4"	1
Hose Clamp	3/8"	28

B.2 Costing

Table 11: Total Cost of General Free-Standing or Offset Vertical Garden System

Category	Amount
Structural Framing	11600.00
Pot and Planter	2857.714
Irrigation System	1382.00
Total Cost	15839.71

B.3 Loads

Dead Load

$$Total\ Dead\ Load = Total\ Load\ of\ the\ Structure + Total\ Load\ of\ Additional\ Materials$$
$$= 1.81\ kN + 0.00\ kN$$
$$= 1.81\ kN$$

Live Load
The National Structural Code of the Philippines (NSCP) 2015 does not specifically provide a minimum live load requirement for vertical gardens. However, in this study, twenty five percent (25%) of the minimum uniformly distributed live load for residential buildings will be used. Hence, a twenty five percent (25%) of 1.9kN per square meter (kN/m^2) or 40 pounds per square foot (psf) is the live load that will apply in the planter. For the live load of each trellis, a load of 0.5kN multiplied by the width of the frame of the system will be used as the uniform distributed load. These live load considerations are for the irrigation system, and other additional components that are not considered as dead load.
Earthquake Load

In order to calculate the earthquake or seismic load of the system accurately, the following factors and variables must be considered, as they serve a critical role in determining the level of seismic activity and potential damage that may occur.

Table-12: Earthquake Load Variables: General Design

Earthquake Load Variables:	
Total Height (m)	Soil Profile Type
Weight (kN)	Seismic Zone Factor, Z
Occupancy Category	Near Source Factor, Na
Seismic Zone Type	Near Source Factor, Nv
Seismic Source Type	Seismic Coefficient, Ca
Closest Distance (km)	Seismic Coefficient, Cv
Importance Factor, I	Response Modification Factor, R
Importance Factor, Ip	Steel Moment-Resisting Frames, Ct

Wind Load

Table-13: Wind Load Variables: General Design

Occupancy Category	—
Basic Wind Speed	V
Wind Directionality Factor	Kd
Exposure Category	—
Topographic Factor	Kzt
Gust Factor	G
Internal Pressure Coefficient	Gcpi
Velocity Pressure Exposure Coefficient	Kz

10.1.3 Design Validation

When conducting a survey questionnaire, it is common to limit the number of parameters or variables to ensure a focused and manageable study. In evaluating the advantages of vertical gardens, the researchers have prioritized three distinct factors: cost, health, and environmental impact.

Environmental Impact: This parameter focuses on evaluating the positive effects of vertical gardens on the surrounding environment. It may cover topics including air purification, carbon dioxide absorption, reduction of urban heat island effect, and promotion of biodiversity. Assessing the environmental impact helps understand the contribution of vertical gardens to sustainable and ecologically-friendly practices.

Health Benefits: This parameter explores the potential positive impacts of vertical gardens on human health and well-being. Vertical gardens have been associated with improved indoor air quality, stress reduction, and enhanced mental health. By evaluating the health benefits, the survey intends to capture how vertical gardens can create healthier and more pleasant settings for individuals.

Cost Considerations: This parameter evaluates the financial aspects related to vertical gardens. It aims to assess the economic feasibility of implementing and maintaining vertical gardens, including financial aspects related to vertical gardens, including installation costs, maintenance expenses, and potential cost savings such as energy efficiency or reduced healthcare expenses. Understanding the cost implications helps decision-makers in evaluating the financial viability and long-term sustainability of vertical garden projects.

By selecting these three parameters, the survey questionnaire intends to collect information on the most important and pertinent aspects of vertical gardens for the target audience, which in this case is the owner/representative of the structure per case. It enables the researchers to gain insights into the environmental, health, and economic benefits perceived by the respondents.

10.2 Process to Classify Cases

Classification of Cases
The projected number of structures per barangay within the City of San Fernando, Pampanga according to the Office of the City Building Official in City of San Fernando, Pampanga is shown in the Appendix.

The data of structures collected are classified as; residential, commercial, industrial, and institutional. The three classifications of structures that acquired the highest number of structures are shown in Figure 21.

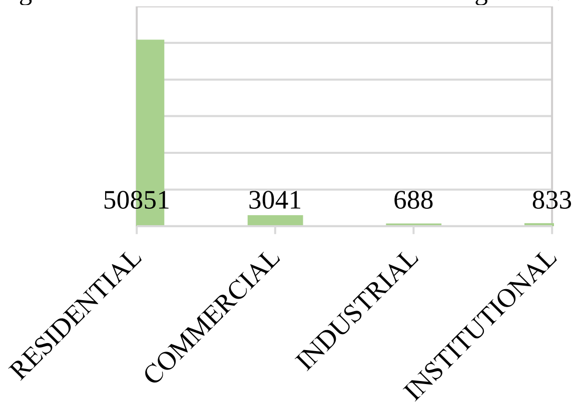


Figure-8: Total Number of Structure in the City of San Fernando, Pampanga

Based on Figure 8, it is evident that the residential category has the most significant number of structures with a total of 50851 within the City of San Fernando, Pampanga, followed by commercial and institutional with 3041 and 833 respectively. Hence, the three cases that were used in the study were the Residential Building, Commercial Building, and Institutional Building.

Table-14: Total Number of Buildings per Barangay

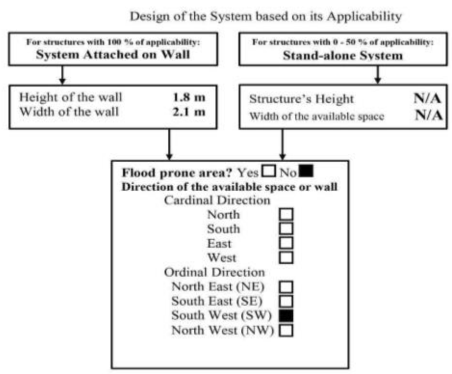
Barangay Name	Number of Buildings
Calulut	5578
Dolores	3546
San Agustin	3269
Sindalan	2357
Panipuan	2115
San Jose	1896
Sta. Lucia	1862
Del Rosario	1819
Maimpis	1819
San Nicolas	1779
Saguin	1844
San Isidro	1731
Malpitic	1742
Magliman	1661
Telebastagan	1517
Lara	1431
Pulung Bulu	1391
Malino	1327
San Pedro	1387
Sto. Nino	1205
Quebiawan	1108
Del Pilar	1027
Dela Paz Norte	1034
Bulaon	934
San Juan	869
San Felipe	1008
Del Carmen	927
Lourdes	565
Balita	484
Juliana	524
Dela Paz Zur	424
Poblacion	9
Alasas	406
Pandaras	157
Sta. Teresita	99

Table 14 shows that among the 35 barangays in the City of San Fernando, Pampanga, the three (3) barangays with the most total number of structures are Barangay Calulut (6061 buildings), Barangay Dolores (3909 buildings), and Barangay San Agustin (3633 buildings).

With the aforementioned data, 1 structure in each category; residential, commercial and institutional, located in either of the 3 barangays with highest number of structures; barangay Calulut, barangay Dolores, and barangay San Agustin has been selected and categorized as Case I, II, and III.

Table-15: Total Number of Structure per Barangay

Case Number	Type of Building	Name of the Structure	Address
CASE I	Residential	N/A	Villa Barosa Dolores, City of San Fernando, Pampanga, Philippines
CASE II	Commercial	A.D. Gonzales Jr. Construction and Trading Co. Inc	Morning Sun Village, City of San Fernando, Pampanga, Philippines
CASE III	Institutional	City Social Welfare and Development Office	San Agustin, City of San Fernando, Pampanga, Philippines



10.3 Application of general method, guidelines, and design to classified three cases.

Case 1: Residential Building – 2 Storey Residence

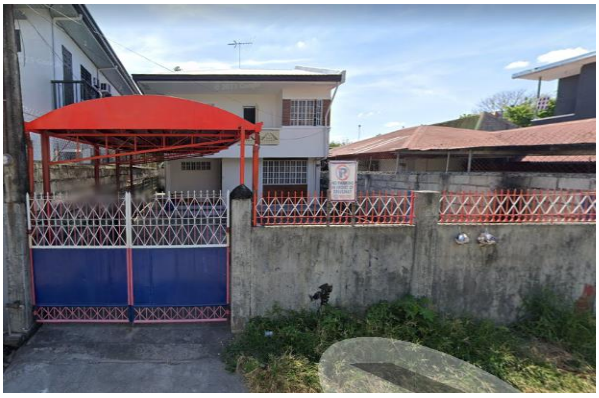


Figure-9: Selected Building for Case 1

10.3.1 Accomplished Suitability Checklist

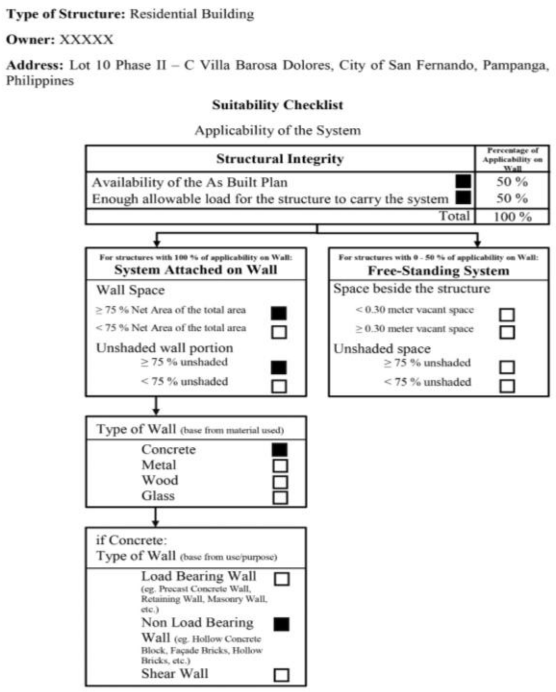


Figure-10: Suitability Checklist: Modified Design – Residential Building

10.3.2 Modified Design

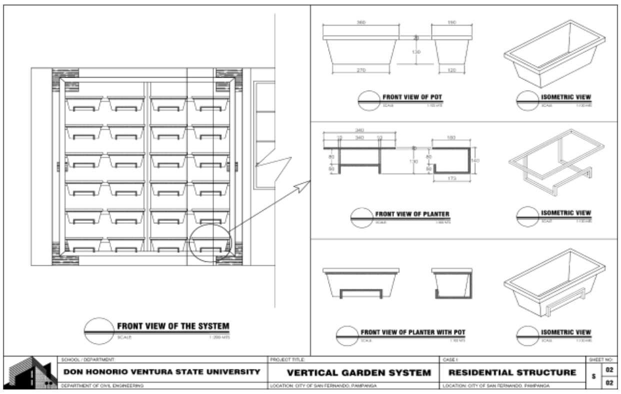


Figure-11: Plan View of the System: Residential Building Attached System

C.1 Materials

Structure

Table- 16: Structural Framing Materials: Residential Building Vertical Garden System

Name of Materials	Size (mm)	Total Length (m)
Galvanized Angle Bar Steel (for Framing)	50 x 50 x 6	6.92
Galvanized Angle Bar Steel (for Trellis)	25 x 25 x 3	13.76
Stainless Steel Square Steel Bar	10 x 10	44.304

Pot and Planter

Table-17: Pot and Planter Materials: Residential Building Vertical Garden System

Name of Materials	Total No. of Material Used
Pot and Soil	24
Plant	24

Irrigation

Table-18: Irrigation Materials: Residential Building Vertical Garden System

Name of Materials	Size	Total No. of Material Used
Irrigation Tubing	3/4"	14
Irrigation Drip Emitter	16 x 16 x17	48
PVC Fittings: Elbow	3/4"	2
PVC Fittings: End Cap	3/4"	1
PVC Fittings: Tee	3/4"	6
Main Water Shut Off Gate Valve	3/4"	1
Hose Clamp	3/8"	24

C.2 Costing

Table-19: Total Cost of Residential Building Vertical Garden System

Category	Amount
Structural Framing	3646.56
Pot and Plant	2857.714
Irrigation System	1447.00
Total Cost	7951.27

C.3 Load

Dead Load

Total Dead Load =Total Load of the Structure + Total Load of Additional Materials

$$= 0.80\ kN + 0.471\ kN$$
$$= 1.271\ kN$$

Live Load

Live Load for Planters:

$= 1.9\ kN \times 0.25\ kN$

$= 0.225 kN$

Live Load for Trellis:

= 0.5 kN × Length of the width of the system in meters

$= 0.5\ kN \times 1.66\ m$

$= 0.83\ kN/m$

Earthquake Load

Table-20: Earthquake Load Variables: Case 1 - Residential Building

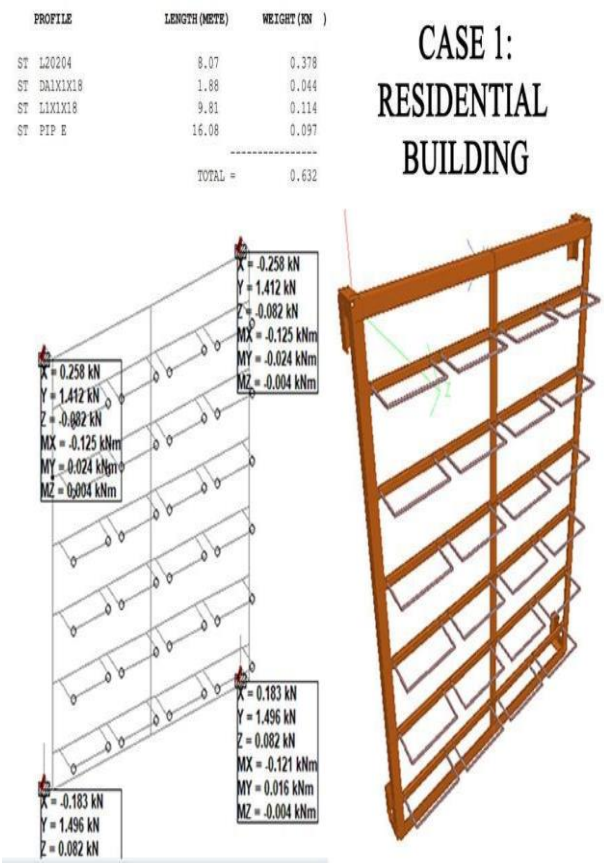
Earthquake Load Variables			
Total Height (m)	1.9	Soil Profile Type	SD
Weight (kN)	2.326	Seismic Zone Factor, Z	0.40
Occupancy Category	5	Near Source Factor, Na	1
Zone	4	Near Source Factor, Nv	1
Seismic Source Type	A	Seismic Coefficient, Ca	0.44
Closest Distance (km)	41.9	Seismic Coefficient, Cv	0.64
Importance Factor, I	1.0	R	3
Importance Factor, Ip	1.0	T (s)	0.0853

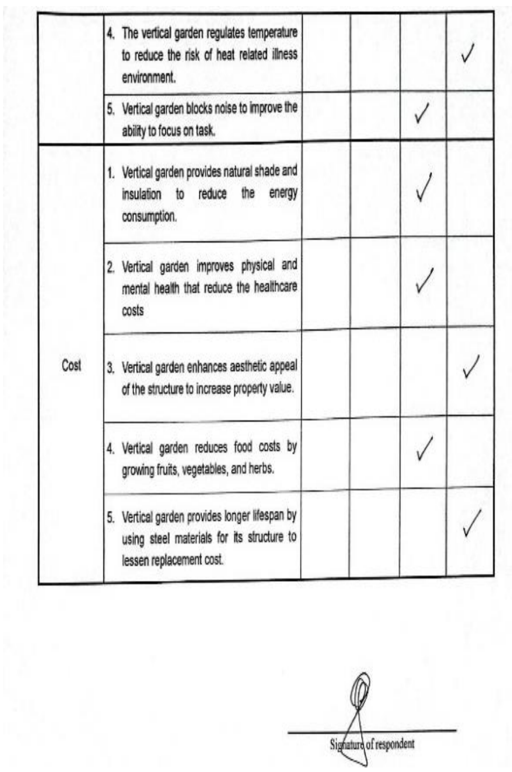
Wind Load

Table-21: Wind Load Variables: Residential Building

Occupancy Category	—	IV – Standard Occupancy Structures
Basic Wind Speed	V	260 km/hr – 72.22 m/s
Wind Directionality Factor	K_d	0.85
Exposure Category	—	B
Topographic Factor	K_{zt}	1
Enclosure Classification	—	Partially Enclosed Building
Internal Pressure Coefficient	GC_{pi}	0
Velocity Pressure Exposure Coefficient	K_z/K_h	0.70
Velocity Pressure	q_z/q_h	1902.359 N/m^2
Effective Wind Area of the C&C	—	3.0675 m^2
External Pressure Coefficient	GC_p	(-)0.71856312228
Design Wind Pressure	p	1.367 KPa

Figure-13: Design and Load Calculations from STAAD for Case 1





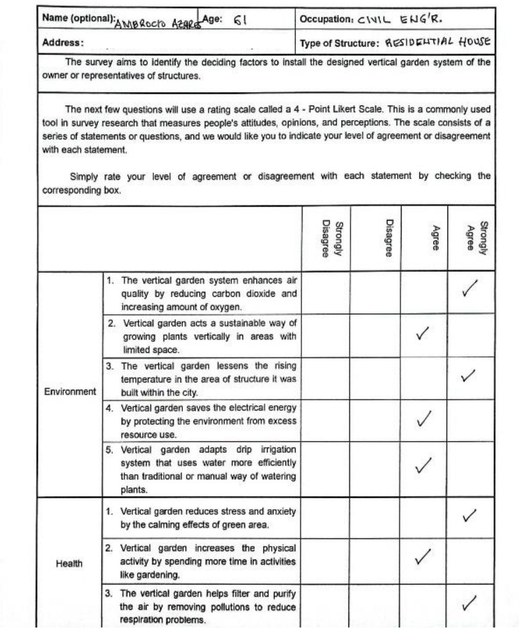
	4. The vertical garden regulates temperature to reduce the risk of heat related illness environment.				✓
	5. Vertical garden blocks noise to improve the ability to focus on task.			✓	
Cost	1. Vertical garden provides natural shade and insulation to reduce the energy consumption.			✓	
	2. Vertical garden improves physical and mental health that reduce the healthcare costs			✓	
	3. Vertical garden enhances aesthetic appeal of the structure to increase property value.				✓
	4. Vertical garden reduces food costs by growing fruits, vegetables, and herbs.			✓	
	5. Vertical garden provides longer lifespan by using steel materials for its structure to lessen replacement cost.				✓

Signature of respondent

Figure-12: Projected Design for Case 1

10.3.3 Design Validation

10.3.3.1 Accomplished Survey Interview



Name (optional): AMBROCIO AZARES	Age: 61	Occupation: CIVIL ENG'R.			
Address:		Type of Structure: RESIDENTIAL HOUSE			

The survey aims to identify the deciding factors to install the designed vertical garden system of the owner or representatives of structures.

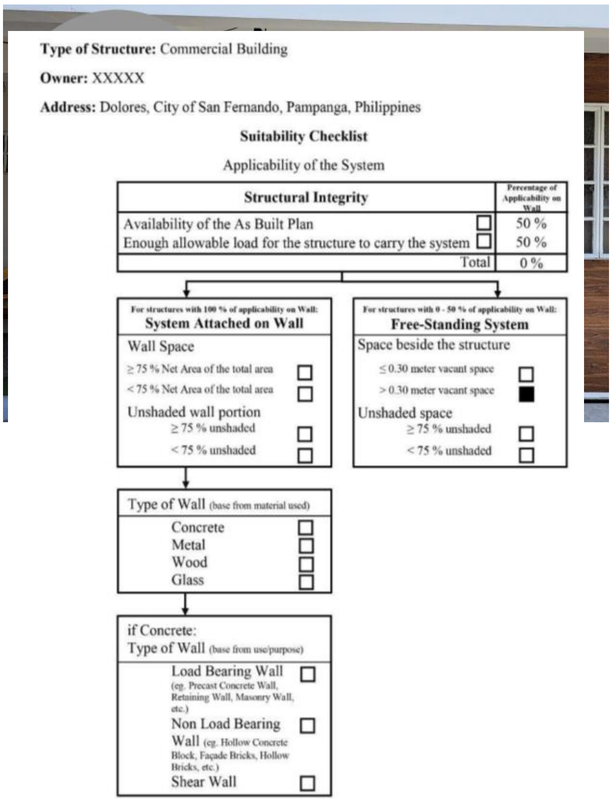
The next few questions will use a rating scale called a 4 - Point Likert Scale. This is a commonly used tool in survey research that measures people's attitudes, opinions, and perceptions. The scale consists of a series of statements or questions, and we would like you to indicate your level of agreement or disagreement with each statement.

Simply rate your level of agreement or disagreement with each statement by checking the corresponding box.

		Strongly Disagree	Disagree	Agree	Strongly Agree
Environment	1. The vertical garden system enhances air quality by reducing carbon dioxide and increasing amount of oxygen.				✓
	2. Vertical garden acts a sustainable way of growing plants vertically in areas with limited space.			✓	
	3. The vertical garden lessens the rising temperature in the area of structure it was built within the city.				✓
	4. Vertical garden saves the electrical energy by protecting the environment from excess resource use.			✓	
	5. Vertical garden adapts drip irrigation system that uses water more efficiently than traditional or manual way of watering plants.			✓	
Health	1. Vertical garden reduces stress and anxiety by the calming effects of green area.				✓
	2. Vertical garden increases the physical activity by spending more time in activities like gardening.			✓	
	3. The vertical garden helps filter and purify the air by removing pollutions to reduce respiration problems.				✓

Figure-14: Accomplished Survey Form from Case 1 Respondent

10.3.3.2 Data Processing and Statistical Treatment of Data



Type of Structure: Commercial Building

Owner: XXXXX

Address: Dolores, City of San Fernando, Pampanga, Philippines

Suitability Checklist

Applicability of the System

Structural Integrity		Percentage of Applicability on Wall
Availability of the As Built Plan	☐	50 %
Enough allowable load for the structure to carry the system	☐	50 %
Total		0 %

For structures with 100 % of applicability on Wall: **System Attached on Wall**

Wall Space
- ≥ 75 % Net Area of the total area ☐
- < 75 % Net Area of the total area ☐

Unshaded wall portion
- ≥ 75 % unshaded ☐
- < 75 % unshaded ☐

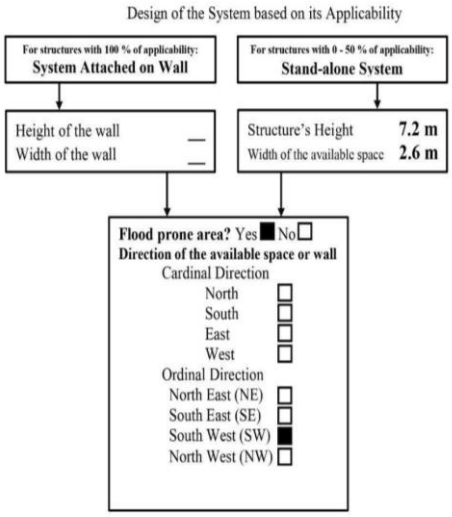
For structures with 0 - 50 % of applicability on Wall: **Free-Standing System**

Space beside the structure
- ≤ 0.30 meter vacant space ☐
- > 0.30 meter vacant space ■

Unshaded space
- ≥ 75 % unshaded ☐
- < 75 % unshaded ☐

Type of Wall (base from material used)
- Concrete ☐
- Metal ☐
- Wood ☐
- Glass ☐

if Concrete:
Type of Wall (base from use/purpose)
- Load Bearing Wall ☐ (eg. Precast Concrete Wall, Retaining Wall, Masonry Wall, etc.)
- Non Load Bearing Wall ☐ (eg. Hollow Concrete Block, Façade Bricks, Hollow Bricks, etc.)
- Shear Wall ☐



Design of the System based on its Applicability

For structures with 100 % of applicability: **System Attached on Wall**
- Height of the wall —
- Width of the wall —

For structures with 0 - 50 % of applicability: **Stand-alone System**
- Structure's Height 7.2 m
- Width of the available space 2.6 m

Flood prone area? Yes ■ No ☐

Direction of the available space or wall

Cardinal Direction
- North ☐
- South ☐
- East ☐
- West ☐

Ordinal Direction
- North East (NE) ☐
- South East (SE) ☐
- South West (SW) ■
- North West (NW) ☐

Table-22: Deciding Factors rated by the owner of the Residential Building in Dolores, City of San Fernando using the Likert Scale and Mean

Deciding Factors	Mean	Interpretation
Environmental Factor	3.4	Strongly Agree
Health Factor	3.6	Strongly Agree
Cost Effectiveness	3.4	Strongly Agree

Table 22 presents that Environmental Factor and Cost Effectiveness have a 3.4 meanwhile Health Factor has a 3.6 mean. The interpretation of data regarding the deciding factors is Strongly Agree which means that the Residential Building owner has a high acceptability rate of adopting the vertical garden. Also, the data shows that the Health Factor is the prime deciding factor in building the system.

The result shows that the governing factor for the adoption of vertical gardens is Health. Peppermint (Mentha Piperita) is one of many possible plants to be planted as it has a lot of health benefits. According to Dr. Neff of Neurodivergent Insights, the leaves of the peppermint plant are used to make the well-known herbal drink known as peppermint tea which has many health benefits, including calming effects and support for the digestive system. The aroma of peppermint tea has been said to be revitalizing and can lessen anxiety and depression. Additionally, peppermint can activate brain regions related to alertness, which can promote focus and attention (Vaezi, Parizi, and Tavangar, 2017).

Case 2: Commercial Building – Construction and Trading Company

Figure-15: Selected Building for Case 2

10.3.4 Accomplished Suitability Checklist

Figure-16: Suitability Checklist: Modified Design – Commercial Building

10.3.5 Modified Design

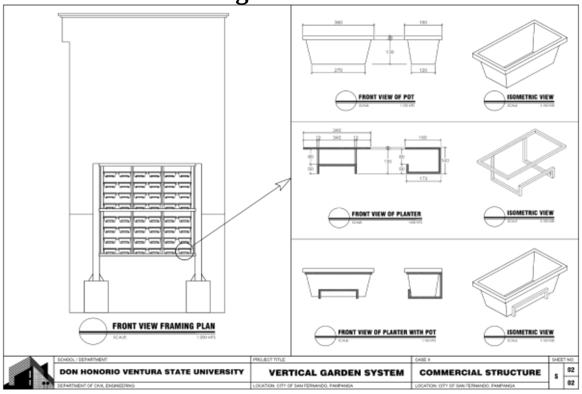


Figure-17: Plan View of the System: Commercial Building Attached System

D.1 Materials

Structure

Table-23: Structural Framing Materials: Commercial Building Vertical Garden System

Name of Materials	Size (mm)	Total Length (m)
Galvanized Angle Bar Steel (for Framing)	63.5 x 63.5 x 6.35	3.6
Galvanized Angle Bar Steel (for Trellis)	50.8 x 50.8 x 6.35	13.74
Galvanized Rectangular Tubular Steel	75 x 50 x 1.2	3.544
Galvanized Steel Round Pipe	141.22 Ø x 66.1	4.8
Stainless Steel Square Steel Bar	10 x 10	44.304

Plants

Table-24: Pot and Planter Materials: Commercial Building Vertical Garden System

Name of Materials	Total No. of Material Used
Pot and Soil	120
Plant	120

Irrigation

Table-25: Irrigation Materials: Commercial Building Vertical Garden System

Name of Materials	Size	Total No. of Material Used
Irrigation Tubing	3/4"	27
Irrigation Drip Emitter	16 x 16 x17	88
PVC Fittings: Elbow	3/4"	2
PVC Fittings: End Cap	3/4"	1
PVC Fittings: Tee	3/4"	8
Main Water Shut Off Gate Valve	3/4"	1
Hose Clamp	3/8"	40

D.2 Costing

Table-26: Total Cost of Commercial Building Vertical Garden System

Category	Amount
Structural Framing	20058.33
Irrigation System	5239.143
Structural Framing	1892.00
Total Cost	27189.48

D. 3 Load

Dead Load

Total Dead Load=Total Load of the Structure + Total Load of Additional Materials

$$= 7.28\ kN + 2.354\ kN$$
$$= 9.634\ kN$$

Live Load

Live Load for Planters:

$= 1.9\ kN \times 0.25\ kN$

$= 0.225 kN$

Live Load for Trellis:

$= 0.5\ kN \times$ *Length of the width of the system in meters*

$= 0.5\ kN \times 2.594\ m$

$= 1.297\ kN/m$

Earthquake Load

Table-27: Earthquake Load Variables: Commercial Building

Earthquake Load Variables			
Total Height (m)	2.55	Soil Profile Type	SD
Weight (kN)	10.932	Seismic Zone Factor, Z	0.40
Occupancy Category	5	Near Source Factor, Na	1
Zone	4	Near Source Factor, Nv	1
Seismic Source Type	A	Seismic Coefficient, Ca	0.44
Closest Distance (km)	41.9	Seismic Coefficient, Cv	0.64
Importance Factor, I	1.0	R	3
Importance Factor, Ip	1.0	T (s)	0.0853

Wind Load

Table-28: Wind Load Variables: Commercial Building

Occupancy Category	—	V – Miscellaneous
Basic Wind Speed	V	260 km/hr – 72.22 m/s
Wind Directionality Factor	K_d	0.85
Exposure Category	—	B
Topographic Factor	K_{zt}	1
Gust Factor	G	0.85
Internal Pressure Coefficient	GC_{pi}	0
Velocity Pressure Exposure Coefficient	K_z/K_h	0.572
Wind Velocity Pressure	q_z/q_h	1554.499 N/m^2

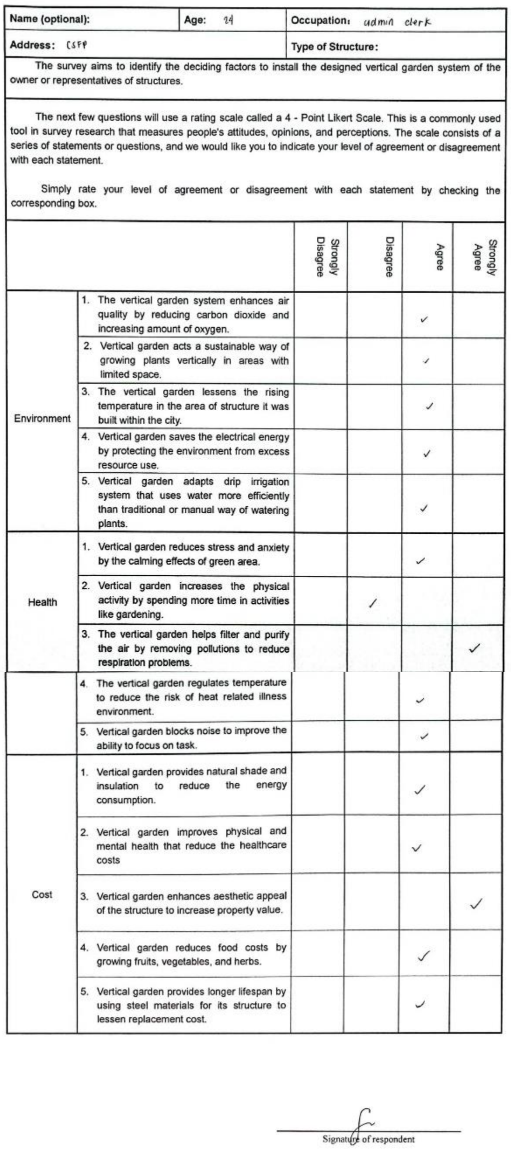
A. *B = 2.762 m* *H = 3.288 m* *S = 2.550 m* *s/h = 2.550/3.288* *= 0.7755474452* *= 0.776* *s/h<1, Case A/Case B* *Aspect Ratio B/s = 2.762/2.550* *= 1.08313725490196* *= 1.083* *B/s<2, Case C is not considered.*	*B.* *By interpolation (Figure207. D.4-1)* *Clearance Ratio = 0.776* *Aspect Ratio = 1.083* $cf = 1.65$	*C.* $F = q_h G C_f A_s$ $P = q_h G C_f$ $= 1554.499 \times 0.85 \times 1.65$ $= 2180.184848 /1000$ $= 2.180184848$ $P = 2.18\ KPa$

Figure-18: Design and Load Calculation from STAAD for Case 2

Figure-19: Projected Design for Case 2

10.3.6 Design Validation

10.3.6.1 Accomplished Survey Interview



Name (optional):	Age: 24	Occupation: admin clerk
Address: CSFP		Type of Structure:

The survey aims to identify the deciding factors to install the designed vertical garden system of the owner or representatives of structures.

The next few questions will use a rating scale called a 4 - Point Likert Scale. This is a commonly used tool in survey research that measures people's attitudes, opinions, and perceptions. The scale consists of a series of statements or questions, and we would like you to indicate your level of agreement or disagreement with each statement.

Simply rate your level of agreement or disagreement with each statement by checking the corresponding box.

		Strongly Disagree	Disagree	Agree	Strongly Agree
Environment	1. The vertical garden system enhances air quality by reducing carbon dioxide and increasing amount of oxygen.			✓	
	2. Vertical garden acts a sustainable way of growing plants vertically in areas with limited space.			✓	
	3. The vertical garden lessens the rising temperature in the area of structure it was built within the city.			✓	
	4. Vertical garden saves the electrical energy by protecting the environment from excess resource use.			✓	
	5. Vertical garden adapts drip irrigation system that uses water more efficiently than traditional or manual way of watering plants.			✓	
Health	1. Vertical garden reduces stress and anxiety by the calming effects of green area.			✓	
	2. Vertical garden increases the physical activity by spending more time in activities like gardening.		✓		
	3. The vertical garden helps filter and purify the air by removing pollutions to reduce respiration problems.				✓
	4. The vertical garden regulates temperature to reduce the risk of heat related illness environment.			✓	
	5. Vertical garden blocks noise to improve the ability to focus on task.			✓	
Cost	1. Vertical garden provides natural shade and insulation to reduce the energy consumption.			✓	
	2. Vertical garden improves physical and mental health that reduce the healthcare costs			✓	
	3. Vertical garden enhances aesthetic appeal of the structure to increase property value.				✓
	4. Vertical garden reduces food costs by growing fruits, vegetables, and herbs.			✓	
	5. Vertical garden provides longer lifespan by using steel materials for its structure to lessen replacement cost.			✓	

Signature of respondent

Figure-20: Accomplished Survey Form from Case 2 Respondent

10.3.6.2 Data Processing and Statistical Treatment of Data

Table-29: Deciding Factors rated by the owner of the Commercial Building in Dolores, City of San Fernando using the Likert Scale and Mean

Deciding Factors	Mean	Interpretation
Environmental Factor	3	Agree
Health Factor	3.25	Agree
Cost Effectiveness	3.2	Agree

Based on the table above, the Environmental Factor has a mean of 3, Health Factor has a mean of 3.25, and Cost Effectiveness has a mean of 3.2. The interpretation of the three factors is Agree which means the vertical garden is acceptable in Commercial Building. Furthermore, the gathered data shows that the Health Factor is the most considered deciding factor in adopting the system by the representative.

One of the possible reasons why the owner will adopt the vertical garden was the Cost factor, particularly the aesthetic appeal of the structure to increase the property value. In line with that, the viable solution for that is to choose the right plants to put in the vertical garden. Recommending to use a combination of flowering plants, such as mixing various plant habits, leaf textures and colors, and even herbal plants, can create a visually pleasing and colorful vertical garden.

Case 3: Institutional Building – City Child Development Center

Figure-21: Selected Building for Case 3

10.3.7 Accomplished Suitability Checklist

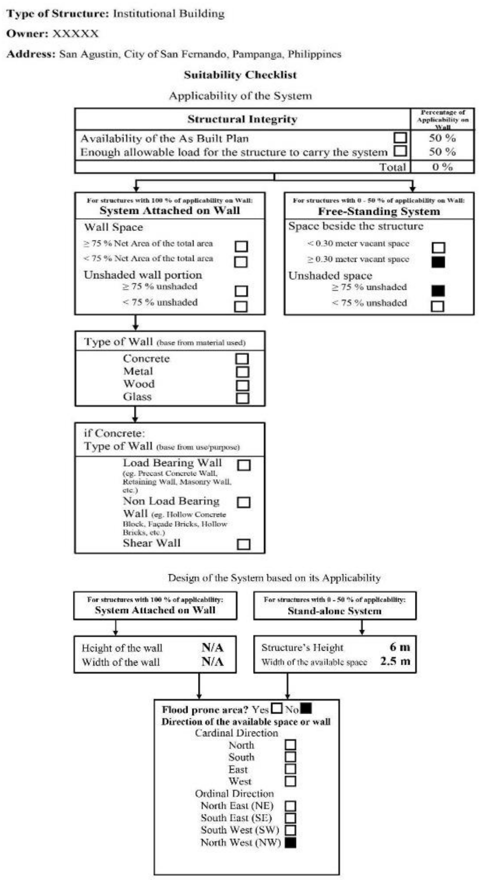


Figure-22: Suitability Checklist: Modified Design – Institutional Building

10.3.8 Modified Design

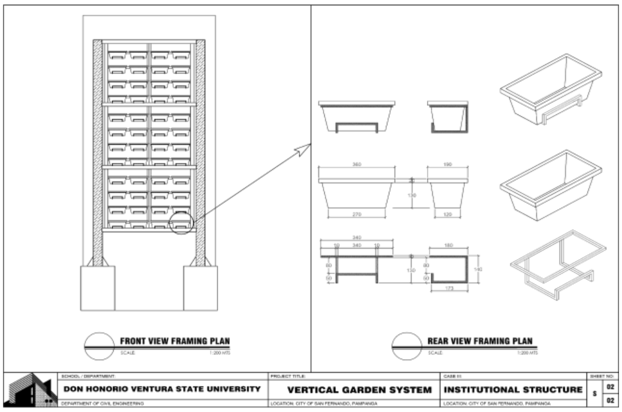


Figure-23: Front View and Rear View: Institutional Building – Free-Standing System

E.1 Materials

Structure

Table-30: Structural Framing Materials: Institutional Building Vertical Garden System

Name of Materials	Size (mm)	Total Length (m)
Galvanized Angle Bar Steel (for Framing)	63.5 x 63.5 x 6.35	3.6

Galvanized Angle Bar Steel (for Trellis)	50.8 x 50.8 x 6.604	13.74
Galvanized Rectangular Tubular Steel	75 x 50 x 1.2	3.544
Galvanized Steel Round Pipe	168.402 Ø x 66.1	4.8
Stainless Steel Square Steel Bar	10 x 10	44.304

Plants

Table-31: Pot and Planter Materials: Institutional Building Vertical Garden System

Name of Materials	Total Number of Material Used
Pot and Soil	48
Plant	48

Irrigation

Table-32: Irrigation System: Institutional Building Vertical Garden System

Name of Materials	Size	Total No. of Material Used
Irrigation Tubing	3/4"	27
Irrigation Drip Emitter	16 x 16 x17	88
PVC Fittings: Elbow	3/4"	2
PVC Fittings: End Cap	3/4"	1
PVC Fittings: Tee	3/4"	8
Main Water Shut Off Gate Valve	3/4"	1
Hose Clamp	3/8"	40

E. 2 Costing

Table-33:
Total Cost of Institutional Building Vertical Garden System

Category	Amount
Structural Framing	22233.33
Pot and Plant	5715.429
Structural Framing	1607.00
Total Cost	29555.76

E.3 Load

Dead Load

Total Dead Load=Total Load of the Structure + Total Load of Additional Materials

$$= 3.95\ kN + 0.941\ kN$$
$$= 4.891\ kN$$

Live Load

Live Load for Planters:

$= 1.9\ kN \times 0.25\ kN$

$= 0.225 kN$

Live Load for Trellis:

$= 0.5\ kN \times$ *Length of the width of the system in meters*

$= 0.5\ kN \times 1.77\ m$

$= 0.885\ kN/m$

Earthquake Load

Table-34: Earthquake Load Variables: Institutional Building

Earthquake Load Variables			
Total Height (m)	4.7504	Soil Profile Type	SD
Weight (kN)	5.776	Seismic Zone Factor, Z	0.4
Occupancy Category	5	Near Source Factor, Na	1
Zone	4	Near Source Factor, Nv	1
Seismic Source Type	A	Seismic Coefficient, Ca	0.44
Closest Distance (km)	47.8	Seismic Coefficient, Cv	0.64
Importance Factor, I	1.0	R	3
Importance Factor, Ip	1.0	T (s)	0.0853

Wind Load

Table-35: Wind Load Variables: Institutional Building

Occupancy Category	—	V – Miscellaneous
Basic Wind Speed	V	260 km/hr – 72.22 m/s
Wind Directionality Factor	K_d	0.85
Exposure Category	—	B
Topographic Factor	K_{zt}	1
Gust Factor	G	0.85
Internal Pressure Coefficient	GC_{pi}	0
Velocity Pressure Exposure Coefficient	K_z/K_h	0.572
Wind Velocity Pressure	q_z/q_h	1554.499 N/m^2

A. B = 1.940 m H = 4.713 m S = 3.825 m s/h = 3.825/4.713 = 0.8115849777 = 0.812 s/h<1, Case A/Case B Aspect Ratio B/s = 1.940 /3.825 = 0.5071895425 = 0.507 B/s<2, Case C is not considered.	B. By interpolation (Figure207. D.4-1) Clearance Ratio = 0.812 Aspect Ratio = 0.507 $cf = 1.534239678$ $cf = 1.534$	C. $F = q_h G C_f A_s$ $P = q_h G C_f$ $= 1554.499 \times 0.85 \times 1.534$ $= 2026.911246 /1000$ $= 2.026911246\ K$ $P = 2.03\ KPa$

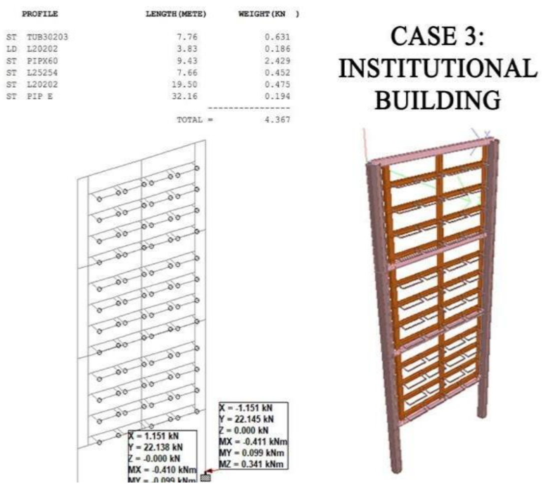
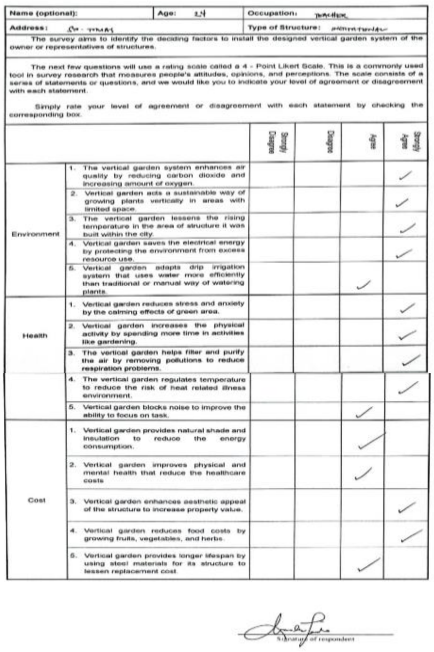


Figure-24: Design and Load Calculations from STAAD for Case 3

Figure-25: Projected Design for Case 3

10.3.9 Design Validation

10.3.9.1 Accomplished Survey Interview



Name (optional):	Age:	Occupation:
Address:		Type of Structure:

The survey aims to identify the deciding factors to install the designed vertical garden system of the owner or representatives of structures.

The next few questions will use a rating scale called a 4 - Point Likert Scale. This is a commonly used tool in survey research that measures people's attitudes, opinions, and perceptions. The scale consists of a series of statements or questions, and we would like you to indicate your level of agreement or disagreement with each statement.

Simply rate your level of agreement or disagreement with each statement by checking the corresponding box.

		Strongly Disagree	Disagree	Agree	Strongly Agree
Environment	1. The vertical garden system enhances air quality by reducing carbon dioxide and increasing amount of oxygen.				✓
	2. Vertical garden acts a sustainable way of growing plants vertically in areas with limited space.				✓
	3. The vertical garden lessens the rising temperature in the area of structure it was built within the city.				✓
	4. Vertical garden saves the electrical energy by protecting the environment from excess resource use.				✓
	5. Vertical garden adapts drip irrigation system that uses water more efficiently than traditional or manual way of watering plants.			✓	
Health	1. Vertical garden reduces stress and anxiety by the calming effects of green area.				✓
	2. Vertical garden increases the physical activity by spending more time in activities like gardening.				✓
	3. The vertical garden helps filter and purify the air by removing pollutions to reduce respiration problems.				✓
	4. The vertical garden regulates temperature to reduce the risk of heat related illness environment.				✓
	5. Vertical garden blocks noise to improve the ability to focus on task.			✓	
Cost	1. Vertical garden provides natural shade and insulation to reduce the energy consumption.			✓	
	2. Vertical garden improves physical and mental health that reduce the healthcare costs			✓	
	3. Vertical garden enhances aesthetic appeal of the structure to increase property value.				✓
	4. Vertical garden reduces food costs by growing fruits, vegetables, and herbs.				✓
	5. Vertical garden provides longer lifespan by using steel materials for its structure to lessen replacement cost.			✓	

Signature of respondent

Figure-26: Accomplished Survey Form from Case **3** Respondent

10.3.9.2 Data Processing and Statistical Treatment of Data

Table-36: Deciding Factors rated by the owner of the Institutional Building in San Agustin City of San Fernando using the Likert Scale and Mean

Deciding Factors	Mean	Interpretation
Environmental Factor	3.8	Strongly Agree
Health Factor	3.8	Strongly Agree
Cost Benefit Factor	3.4	Strongly Agree

Table 36 shows that the mean of the Environmental Factor and Health Factor is 3.8, while the mean of the Health Factor is 3.4. The data interpreted is Strongly Agree which means the Institutional Building accepts the vertical garden. Moreover, the data shows that the Environmental Factor is the most considered deciding factor in adopting the system.

Based on the result of the survey, the Environmental Factor is one of the two factors that appealed to the owner in adopting the vertical garden. Knowing this, the study recommends using Golden Pothos (Epipremnum Aureum) as a possible plant to put in the vertical garden. According to NASA Clean Air Study, Golden Pothos had the ability to remove benzene, formaldehyde, xylene, and toluene from the air. Furthermore, Pothos are tropical plants that enjoy humidity, but they can also increase the humidity levels inside the building (Moulton, 2021).

11. Conclusion

The primary objective of this study is to analyze the suitability of the vertical garden system in existing buildings with the use of the suitability checklist. Upon classifying the three (3) cases, the following procedures were done in each case: The collection of data, the application of the developed suitability checklist, the implementation of the methodology, and the interpretation of the acquired results.

The aforementioned observations led to the formulation of the following conclusions:

1. Majority of the existing structures in the City of San Fernando, Pampanga, do not have as-built plans, making it difficult and risky to just build a common attached vertical garden system. Therefore, an offset vertical garden system was purposely designed in order for the owner of a structure to still have a choice and be able to have one.

2. Upon gathering and interpreting the results, it was concluded that environmental and health factors prevailed in 2 out of 3 cases. This indicates that these factors hold the huge potential to be the reason for an owner of a building to consider the construction of a vertical garden system.

12. Recommendation

1. Based on the data and findings gathered from the study, the following recommendations are suggested for future researchers:

2. Modified Design: It is recommended that future researchers explore modified designs for each of the cases studied in order to improve the overall performance of the vertical garden system. By modifying the design, it may be possible to enhance the efficiency of the system and to address any limitations identified in the study.

3. Explore Other Materials: Another recommendation is to explore other materials that are available in the Philippines that can be used in constructing the vertical garden system. This may lead to cost savings or provide alternative options for construction that may be more suitable for local conditions.

4. Compute Base Plate and Footing/Column Design: Future researchers should also consider computing the base plate for both attached and free-standing design systems, as well as designing the footing and column for the free-standing design. This can help ensure the stability and safety of the vertical garden system.

5. Quantitative Approach: In order to test the performance of the vertical garden system in real-world applications, it is recommended that future researchers employ a quantitative approach. This can involve measuring factors such as plant growth rates, water consumption, and other relevant variables to determine the system's effectiveness.

6. Explore Plant Varieties: Finally, future researchers should explore the variety of plants that can be used in the vertical garden system. This can lead to more diverse and aesthetically pleasing installations, as well as providing additional benefits such as improved air quality and increased biodiversity.

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