



From concrete to nature: Green walls in Morelos

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Abstract

The main aim of this research is to demonstrate the implementation of green walls in Morelos through the analysis of various information sources. In the first place, the background of the topic is explored, understanding the origins of sustainability, its theoretical principles, and weighing its pros and cons in relation to sustainable development.

Furthermore, the proposal will be examined from a theoretical standpoint, gathering reliable and relevant data. Ultimately, as this study is explanatory in nature, the analysis will determine whether the objectives were met, allowing to assess if the implementation of green walls in Morelos will contribute to achieve sustainability goals.

Keywords: Green walls, sustainability, health, pollution, SDG.

Presentation and relevance of the study

According to data from the World Health Organization (WHO), nine out of ten people in the world breathe air with alarming levels of pollutants, a situation that affects both large cities and rural areas. Air pollution is one of the most serious public health problems of our time. It is estimated that 6.7 million premature deaths each year are related to exposure to polluted air, both outdoors and indoors. This figure reflects the devastating impact that air pollution has on our health, contributing to respiratory and cardiovascular diseases and lung cancer. According to data from the World Health Organization (WHO), nine out of ten people in the world breathe air with alarming levels of pollutants, a situation that affects both large cities and rural areas. Air pollution is one of the most serious public health problems of our time. It is estimated that 6.7 million premature deaths each year are related to exposure to polluted air, both outdoors and indoors. This figure reflects the devastating impact that air pollution has on our health, contributing to respiratory and cardiovascular diseases and lung cancer. (World Health Organization, 2024)

Problematic/ Social Justification

We can see how pollution is a big social problem for example:
-Air pollution is an important environmental risk to health of the people, in 2019 the OMS estimated that approximately 37% of premature deaths were associated to outdoor air pollution, such as lung diseases or acute infections (World Health Organization, 2024).

-March 2024, according to data from the Copernicus Climate Change Service, the hottest month ever observed in the world was recorded, due to climate change with a temperature of 0.73°C higher than the average. The last 7 years have been recorded as the hottest (Copernicus, 2024).

Methodological objective

Our methodological objective is to propose the planning, design, and implementation of green infrastructure in urban areas of Morelos, to improve air quality and social well-being and reduce pollution.

Possible outcomes of the project

The success of this project will be measured by the evaluation of quality compliance, that it achieves a good environmental impact, the achievement of social and aesthetic impact, economic benefits, durability and safety. The success of the walls can also be ensured thanks to the fact that in 2021 the global market size for walls was 713.070 million dollars and it is forecast that by 2031 it will reach 1491.69 million dollars. We believe that through a project that consists of incorporating green walls on the bridges of Morelos, starting with Cuernavaca, it would help not only improve the appearance of the place where we live, but it would also help eliminate pollutants from the air and the bacteria that are suspended in the air, which will contribute to providing us with clean oxygen, helping Morelos to achieve goal 11.6 of reducing the adverse environmental impact of cities, including paying special attention to air quality, such as part of SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable. The success of this project will be measured by air pollution statistics too.

Historical framework of sustainability

The term sustainability has been mentioned since ancient times, several thinkers discussed environmental problems caused by human economic activities such as deforestation, water salinization or soil degradation. During the Industrial Revolution, the consumption of natural resources increased greatly to the point of causing various continental crises. These environmental crises have caused many people to change their way of thinking and worry a little more about the responsible use of resources. In the 20th century, optimism arose due to technological advances, but also concern about the increase in the consumption of natural resources, especially after the Second World War. Later, in the 60s and 70s, research on environmental damage was published. These studies became popular, triggering concern which suggested the emergence of NGOs in defense of the environment; Also in these years,

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This was considered by the World Commission on Environment and Development of the United Nations Organizations. In 2000, 191 heads of State and Government agreed to work towards eight objectives and 17 goals to be met

by 2015. Among some of the objectives were: eradicating extreme poverty and hunger, achieving gender equality, reducing infant mortality, etc. In 2012 at the RIO+20 conference, a working group was established to develop a draft of sustainable development goals. Finally, in 2015, the UN sustainable development goals (SDGs) were created to be met by 2030.

They were 17 objectives to achieve three major changes: eradicate extreme poverty, combat inequality and injustice, and solve climate change.

We will focus on two of these number 11 and number 13. In goal number 11 which pursue to make cities and human settlements inclusive, safe, resilient and sustainable (UN Etxea – Basque Country Association for UNESCO, 2018). Good progress has been made, and the number of countries with national and local disaster risk reduction strategies has now doubled. However, the problems continue. Sustainable development cannot be achieved without transforming the way urban spaces are built and managed. Goal number 13 pursues to promote mechanisms to increase capacity for effective planning and management in relation to climate change in least developed countries and small island developing states, with particular emphasis on women, young people and local and marginalized communities (UN Etxea – Basque Country Association for UNESCO, 2018).

In December 2015, a significant step was taken by adopting the Paris Agreement, in which all countries committed to take action to address climate change. Companies and investors must ensure that emissions are reduced.

Historical framework of Civil Engineering

Civil Engineering has existed since prehistory since it was used to build their homes, transportation routes, workspaces and communication routes, such as the huts that nomads built to live in.

In the 17th century, the name civil engineering officially appeared, although records existed before, such as in the year 400 B.C. during the construction of the pyramids of Egypt, or the Great Wall of China, these structures were built with the techniques of ancient Civil Engineering. The Romans invented dams and aqueducts to protect their cities. After great civilizations began to emerge, Civil Engineering was developed at a military level, as they used it to build battle materials for war such as towers and catapults because the military and its armies wanted to expand the conquest with the help of Civil Engineering, they began to build roads and bridges as a means of transportation.

Civil Engineering emerged since ancient times but began to be analyzed on a scientific basis since the middle of the 18th century in France. Some important engineers and physicists began analyzing materials for construction using the principles of basic mechanics, calculation and matrix algebra. The first school of civil engineering called Ecole Nationale des ponts et Chaussées was created in 1747 in the city of Paris.

Civil engineering has gradually evolved from the ancient pyramids of Giza to the Burj Khalifa structure in Dubai. There are various advances that have allowed professionals in this area to build current structures faster and with better quality, new technologies such as drones, virtual reality, smart sensors and 3D printing have been very useful during this process, these tools have allowed engineers to build and create more efficient designs, improving the quality, safety and reducing costs of structures (Revista Construye, 2022).

Civil engineering has evolved significantly since current structures have been modified considering current problems such as climate change, resource shortages and urbanization. Tools have also been created that allow simulating natural disasters and thus building solid and efficient structures for prevention. of natural disasters and extreme weather conditions. Engineering has implemented new advances, for example in the future we will see the implementation of more sustainable structures that will have a lower impact on environmental pollution, it is expected that in the future we will have smart buildings, this means that we will be able to remotely monitor various devices such as light, climate, humidity, etc. Sustainable transportation will also be designed that generates less environmental impact on our society.

Theoretical framework of sustainability

The concept of sustainability comes from social and natural sciences. Social ones are the study of people's behaviors, and interactions with environments, while natural ones aim at the study of organisms and their interaction with the environment and their transformations. Among these sciences are disciplines such as ecology, which studies the interactions of organisms in ecosystems; economics, where societies and the use of their limited resources are studied; and the social, which studies man, individually or as a society. These disciplines must be verified, equitable and true, to establish precise and objective method. Therefore, sustainability refers to the ability to maintain a balance between economic growth and the protection of the environment and natural resources without compromising the capabilities of future generations.

Sustainability, defined by the United Nations, explains that it is what allows "to meet the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations Educational, Scientific and Cultural Organization, 2024). Currently, developing countries seek to meet their own needs, but due to climate change, efforts are being made to ensure that development does not affect future generations.

Despite having this definition, the Universidad Colegio Mayor de Cundinamarca mentions that the concept of sustainability is intertwined to call it sustainable, since the two concepts relate humanity and the planet in relation to the present

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and future, building a new culture for the individual within society (Zarta Ávila, 2018).

But they have in common that what sustainability seeks is to find a way for the economy to maintain or improve an environmental system.

State of art

There are several opinions about the SDG that are different but equal, we are going to focus on numbers 11 and 13, which are what this project is based on. Below are some examples of these opinions.

Let us remember that SDG number 11 pursues to “Make cities and human settlements inclusive, safe, resilient and sustainable” (UN Etxea – Basque Country Association for UNESCO, 2018). This objective is related to the ideas that Hamed Gholizadeh’s article about “Sustainable Urban Development: A Pathway to Resilient Cities” promote sustainability in urban development. He underlines the need for practices that not only respect the environment, but also improve the quality of life of citizens.

Another author is Saeed Bani Hashemi who is also known for his focus on sustainability and urban development. This author is also recognized for writing an article called “Sustainable Urban Planning: Strategies for Resilience and Inclusivity.” In which Bani Hashemi emphasizes that cities must be adaptable to climate change and socioeconomic challenges.

Now we are moving to SDG number 13 which focuses on climate action in which there are also different opinions, some examples by recognized authors are:

Joanne Chory who has spoken repeatedly about the importance of plants in climate change mitigation and how

they can be used to improve sustainability. It emphasized the need to develop crops that are more carbon efficient and can adapt to changing climate conditions. One of his most relevant publications is the article "Harnessing Plants for Climate Change Mitigation", which can be found in scientific journals such as Nature.

Bill McKibben is a well-known author and activist who has written extensively about climate change. In his book "The End of Nature", published in 1989, McKibben argues that climate change has transformed humanity's relationship with nature, emphasizing the urgency of taking drastic measures to address this problem.

Theoretical Framework of Civil Engineering

Currently, countries are suffering from various problems such as poverty, health and pollution due to urbanization and industrialization. That is why Engineering is one of the disciplines involved in solving that. Engineering is based on the exact sciences, which help us generate knowledge from the theoretical framework. Within the applied sciences we have engineering and technology. This area provides us with knowledge in the invention and use of techniques applied to solving real-world problems, as well as in the management of natural resources, the production of synthetic materials and the construction and development of machines, installations and systems. More specifically, we have Civil Engineering, helping us in the design and execution of structural works that serve the public, such as bridges, canals, roads, sewage systems and other infrastructure. That is why, with the help of this engineering, we can control the good infrastructure for green walls, helping to reduce the pollution problem.

Green infrastructure is an urban and environmental approach with the objective of integrating nature in cities to improve sustainability and quality of life, it seeks to

replicate the benefits of rural spaces in urban environments, with the objective of mitigating the effects of climate change. One of the examples of green infrastructure would be green walls and roofs, these exist in order to regulate temperature and rainwater filtration to avoid flooding. There are also parks and green areas, which are spaces that help absorb carbon dioxide, improving air quality and providing habitats for wildlife, supporting biodiversity within cities. Just as there are environmental benefits, there are also social benefits since it is scientifically proven that nature helps reduce stress.

State of art

Michael Mark Davis is an expert in sustainability and in projects that benefit it, he carried out a study on how 44% of the US population are exposed to noise levels that can harm health. With his study he demonstrated that plants have a positive effect for high frequencies when they are planted with a high density and developed a project to see the effect noise had on the green walls in a building and discover that this type of construction technology is suitable for reducing sound and is a design tool to improve the acoustics of interior spaces or urban squares (Marks, 2017).

Rebecca Collins, a specialist in green walls, conducted a study to estimate the economic value of these construction technologies, the experiment was carried out using three green infrastructure policies, (two green wall designs (living wall and "green facade") and an "alternative green policy" and these were compared with "there is no green policy". The results were that a higher level of utility was associated with the living wall, following the green facade. In both cases, the value of the green wall policies exceeded the costs that had been estimated from the investment, this means that the results suggest that the implementation would provide net economic improvement.

Deductive Method

Description of the project's implementation

For the installation of the green walls, a structure that supports the weight of the plants and the substrate, an automated irrigation system and a drainage system that controls excess water are required. In the case of Morelos, to carry out the implementation of a green wall, a detailed planning must be carried out that involves previous studies and the participation of professionals specialized in architecture, engineering, and botany.

a) Site analysis.

A field study will be conducted to determine which locations in Morelos are feasible for installing a green wall, considering the following:

- Location: Choose strategic places, meaning areas with heavy traffic, for example: Plan de Ayala Avenue, Paseo Cuauhnáhuac Boulevard, San Diego Street, CIVAC, and Domingo Diez Avenue.
- Orientation of the wall: A prior study will be conducted on the sun's orientation, considering where the sun rises and sets.
- Climate, wind, and rain: Since wind can damage the system depending on its direction, and excess rain can lead to material wear and plant detachment, it is important to consider periods of extreme temperatures.

b) Collection of materials and structure.

The most suitable species for the hot and dry climate of Morelos will be selected, ensuring that they are resistant and low maintenance. As a recommendation, native species of the region could be used, since they require less water, ensuring the adaptability of the plants. Some examples are bougainvilleas, vines and cacti. The selected plants should provide an attractive design that evenly covers the wall and offers an aesthetically pleasant look.

In addition, aspects such as resistance to common pests and diseases in the area will be considered, to reduce the need for chemical interventions and ensure more ecological management of the green wall. Priority will be given to plants that, in addition to being visually attractive, contribute to local biodiversity and favor the native fauna, such as birds and pollinators.

Another factor to consider will be the structure of the wall, which must be designed to support the weight of the plants and ensure a good drainage system to avoid problems of excessive humidity. Choosing an efficient irrigation system,

such as drip irrigation, will help reduce water consumption and keep plants healthy without wasting water resources.

With proper design and maintenance, the green wall will not only be a decorative element, but will also improve air quality, reduce ambient heat and provide a greater feeling of well-being in your environment.

c) Irrigation system design.

Install a drip irrigation system to ensure water reaches the roots and minimize waste. The walls should have this automated system, allowing regulation of the flow according to the needs of the wall. To ensure efficient and sustainable water supply for the plants, it is recommended to install humidity sensors to detect the water level in the substrate, activating irrigation only when necessary to avoid water waste. Another way to prevent water waste is by collecting rainwater, which can be redirected to a storage system or used for watering the plants during the driest times of the year.

d) Design and construction of the support structure.

The design and construction of a solid support structure for a green wall are essential to maximize its functionality, safety, and longevity. This type of structure must be strong enough to hold the weight of the plants, substrate, and irrigation system, especially when the plants are wet and the total weight increases. A poorly designed structure could lead to structural failures, such as substrate slippage or partial wall collapse, which would not only damage the installation but also put people's safety at risk.

In addition, a well-designed structure facilitates the even distribution and support of the irrigation system, which is crucial to ensure all plants receive the necessary amount of water. This enables the green wall to fulfill its ecological functions, such as temperature regulation, air quality improvement, and noise absorption.

e) Substrate selection and installation.

The selection and installation of the substrate in a green wall are essential components to ensure the system's success, as the substrate acts as the growing medium that supports the roots, stores water and provides the necessary nutrients for healthy plant growth. When choosing a substrate, it is important to consider factors such as moisture retention, porosity, stability, and weight. An ideal substrate should retain water well while allowing for adequate drainage to prevent waterlogging issues. Additionally, a substrate that is too heavy could overload the wall structure.

The composition of the substrate is also key and should include a mix of lightweight and nutrient- rich materials; an example of this is coconut fiber. Proper substrate installation also facilitates the maintenance of the green wall, as it reduces the frequency of interventions and long-term care costs.

f) Drainage system implementation.

The drainage system would consist of modular panels installed at the back of the wall, allowing water to pass through. Drainage channels would be installed horizontally at the base of the modules to direct water to pipes, which would be installed behind the solar panels to facilitate excess water evacuation.

It is important that the drainage system is slightly inclined toward an exit point, such as a drain, ensuring the water flows properly and doesn't pool in undesired areas.

g) Continuous monitoring and maintenance.

This step is crucial to ensure the durability and continued health of the green wall. Regular inspections of the drip irrigation system should be performed to ensure the humidity sensors are functioning correctly. Pruning should be done periodically to prevent excessive plant growth, ensuring that drainage channels do not get clogged and that plants grow healthily.

Regular inspections for pests should be conducted, and if any are detected, they should be controlled to prevent their spread. Organic methods should be used to avoid pesticides. Finally, it is important to clean the modules periodically to ensure that the plants receive enough light and air.

Pros and Cons of the three spheres of sustainability

Environmental pros

Green walls offer several ecological benefits. For example, they improve air quality by capturing pollutants and particles, and the plants used in them absorb up to 40% of carbon dioxide while releasing oxygen, thereby contributing to the reduction of greenhouse gases (World Health Organization, 2024). Additionally, they act as natural insulators, helping to reduce temperatures in urban areas and buildings by up to 5°C, which allows for less use of air conditioning and thus reduces energy consumption by 20%. They also provide habitats for birds, insects, and other species, promoting biodiversity. Green walls absorb and filter rainwater, reducing the risk of flooding. Furthermore, they serve as natural noise barriers, creating quieter environments, and protect building facades from solar radiation, rain, and other elements, thus extending their lifespan.

Environmental cons

Green walls offer various benefits, but they also present ecological drawbacks that must be considered. One of the main issues is their high-water consumption, which can reach up to 10 liters per square meter per day, especially in hot climates (Vital Arquitectura y Soluciones Ambientales, 2020). This water usage can be significant if efficient irrigation systems

are not implemented. Additionally, the CO₂ emissions associated with the manufacturing and maintenance of the materials used is another negative factor, with estimates suggesting that for every 100 m², annual emissions can range from 40 to 70 kg of CO₂ (Paisaje Sostenido, n.d.), due to the production processes of the panels, irrigation systems, and ongoing maintenance. Soil pollution can also occur if chemicals are not properly managed. Furthermore, their intensive maintenance requires resources and energy, with the risk of impacting ecosystems by modifying natural areas for installation.

Economical pros

Green walls offer several economic benefits, such as energy savings by improving the thermal insulation of buildings, which reduces heating and cooling costs. A study has shown that the surface of an exterior green wall can be up to 10°C cooler than a wall exposed to the sun, and indoors, they can lower the temperature by 3°C to 7°C, resulting in up to 20% savings on electricity bills (Ingeniería Natural, n.d.). They also reduce maintenance costs by protecting exterior facades from the elements. Additionally, green walls improve air quality, positively impacting public health and reducing expenses related to respiratory illnesses. They assist in stormwater management by decreasing runoff and associated drainage costs. Finally, they can qualify for government

incentives or insurance discounts, making them a profitable long-term investment.

Economical cons

The approximate price for installing a green wall or vertical garden is just over \$880 USD (about 18,000 Mexican pesos), with a minimum recommended size of 2x2 meters (4 square meters) (CNN en Español, 2022), as otherwise, the cost-benefit ratio would be excessive for the client. On the other hand, maintaining a green wall costs around \$60 to \$150 USD per square meter annually, as it requires regular watering, fertilization, and replacement of plants if necessary (CNN en Español, 2022). This means that, in addition to the initial investment in installation, buildings and companies face a significant expense to keep it functioning as intended. These factors can be a challenge when considering building a green wall and are not always financially viable, especially for large companies aiming to minimize costs.

Social pros

Green walls have a positive impact on the social realm by creating cooler and more modern spaces. A study published in the journal *Environment and Behavior* shows that these spaces help reduce stress and improve emotional well-being, as the presence of vegetation lowers cortisol levels (Bringslimark, Hartig, & Patil, 2018). In addition, green

walls are highly valued because they are attractive to live in and pleasant to the eye (UN Tourism, n.d.).

They also promote environmental education by raising awareness about the importance of plants and the environment. Since they can be installed on various infrastructures, green walls create spaces for community and recreation. They also act as barriers that reduce noise pollution. According to the World Health Organization (WHO), these walls can improve air quality by up to 25%, reduce temperature by up to 5°C, and decrease pollutants like nitrogen dioxide, which benefits public health and helps prevent respiratory diseases (WHO,2024).

Finally, due to their rarity, green walls are attractive to tourists, which benefits the local areas where they are located.

Social cons

In some communities, green walls may be perceived as a form of “superficial environmentalism,” seen more as a decorative measure than a real solution to urban issues such as poverty, lack of housing, or access to basic services. It has been found that 40% of urban residents in low-income areas view vertical gardens more as an aesthetic luxury than a solution to real environmental problems (Blanco, 2022), which can create a social disconnect with these green infrastructure projects. Furthermore, green walls can be expensive to install and maintain, leading to inequality in access to their benefits in cities. Poorer neighborhoods, due to high costs and a lack of resources for large-scale projects, often have less access to this type of infrastructure. In low-income areas, less than 10% of urban green spaces (including vertical gardens) are distributed equitably (U.S. Environmental Protection Agency, 2024), reinforcing inequality in access to benefits such as improved air quality or urban heat reduction.

Results

The plan to install green walls in Morelos combines sustainability, functionality, and aesthetics. Strategic sites like Plan de Ayala Avenue and CIVAC will be selected, considering climate, solar orientation, wind, and rain. Native species like bougainvilleas and cacti, adapted to the hot and dry climate, will be used to promote biodiversity and reduce maintenance. The structure will be solid, with lightweight and porous substrates, and an automated irrigation system with sensors and rainwater collection. An efficient drainage system will prevent water accumulation, while maintenance will include pruning, cleaning, and organic pest control. This project will improve air quality, reduce urban heat, and beautify the environment. The implementation of green walls has many strengths, weaknesses, benefits, risks, and threats for the three spheres of sustainability (ecological, social, and economic). Based on our research, we found that our project is not 100% sustainable, as there are certain details that prevent some aspects of these spheres from being fully met, such as the costs of implementing a green wall. However, our analysis shows that there are more benefits and positive effects on the environment than negative aspects. Finally, from this analysis, more information and further research should be considered if the project is to be implemented practically in the future, as many aspects need to be examined more specifically to ensure its complete and effective execution.

Goal fulfillment, limitations of the process and advice/ recommendations

According to our criteria, hypothetically speaking, this research shows that the project affects the economic sphere; that is, it does not impact social aspects and cares for the environment, but nevertheless, this system is expensive. However, this project can only be verified through real tests. In this regard, the first and greatest limitation we faced

was the difficulty in conducting research, as this project sometimes conflicted with others, and time was insufficient to complete it. Another point was that in Cuernavaca, there are no green walls like such, and those in the state are too far away to observe them adequately. Additionally, environmental education in Morelos is very poor, so not everyone knows what a green wall is, and those who do often have stereotypes about them. One of the main misconceptions is that they are only used for decoration. In this sense, studies on green walls in Morelos are also scarce. While the research on infrastructure was relatively simple, the challenge was finding ways to adapt it to the region. Moreover, another limitation is that implementing green walls requires specialized technical knowledge, making it difficult to find experts such as engineers or architects, though it was not impossible.

As for recommendations, since we only carried out the analysis for this project, a more in-depth study is required by architects, vertical gardeners, environmental engineers, hydraulic engineers, economists, among others, to conduct a more comprehensive study to confirm whether this project would be profitable and successful. However, according to the experts we interviewed, who have experience with green walls, one of them mentioned that they are indeed very profitable and successful.

As previously mentioned, environmental education in Morelos is virtually nonexistent. In this regard, government programs should aim to raise awareness through campaigns or by presenting the benefits of green walls and working to eliminate the stereotypes surrounding them.

Final reflection

First, it is essential to point out that undertaking a green wall project requires commitment, dedication, and time, as it involves extensive research, both theoretical and practical, as

well as an in-depth analysis of the information. Only in this way can a solid foundation be developed to support future initiatives and promote positive change in society.

With the completion of this project, it becomes clear that seeking and implementing sustainable alternatives, such as green walls, in all sectors is indispensable. In the face of the current environmental crisis, it is urgent to take measures to reduce pollution, counteract the effects of climate change, and manage resources efficiently. For this reason, it is crucial for communities, institutions, and governments to promote projects like this to transform their spaces into responsible and sustainable environments.

In conclusion, this project demonstrates that solutions such as green walls not only benefit the environment but also promote social equity and economic sustainability, which are fundamental pillars of sustainable development. As Lester R. Brown said, "Sustainability is not an option; it is a necessity." (Weaver, 2006)

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