Atmospheric Integuments:

A high-efficiency passive mesh facade system for integrated fog harvesting in Lima's vertical architecture

Yandira E Zuniga Mayta

A thesis

submited in partial fullfilment of the

requirements for the degree of

Masters of Architecture

University of Washington
2026

Committee:

Tyler Sprague

Myer Harrell

Program Authorized to Offer Degree:

Architecture

University of Washington

Abstract

Atmospheric Integuments:

A high-efficiency passive mesh facade system for integrated fog harvesting in Lima's vertical architecture

Yandira E Zuniga Mayta

Chair of the Supervisory Committee:

Tyler Sprague

Department of Architecture

Lima, Peru, faces significant water scarcity despite the frequent presence of coastal fog known as garúa. This thesis explores the potential of atmospheric water harvesting as an alternative source of non-potable water through the integration of fog-harvesting systems into existing high-rise buildings. Using a research-through-design methodology, the study combines literature review, precedent analysis, environmental research, and parametric design to investigate the relationship between fog collection technologies and architectural applications.

The research examines biomimicry, fog collection systems, mesh performance, and structural considerations associated with atmospheric water harvesting. Case studies were analyzed to understand how water collection technologies can be integrated into the built environment and inform architectural design strategies. Based on these findings, the Torre Banco de la Nación in Lima was selected as a case study to test the feasibility of a building-integrated fog-harvesting façade.

Through the development and evaluation of modular façade systems, the project investigates how existing buildings can function as environmental infrastructures that capture atmospheric moisture while responding to local climatic conditions. The thesis demonstrates the potential of integrating fog harvesting into urban architecture as a strategy for enhancing water resilience in arid coastal cities.

Keywords: atmospheric water harvesting, fog collection, biomimicry, façade systems, water scarcity, Lima, Peru, environmental infrastructure.

ACKNOWLEDGMENTS

I have greatly enjoyed my time at the University of Washington and am deeply grateful for the experiences, opportunities, and knowledge I have gained throughout this journey. I would like to express my sincere appreciation to all the instructors who provided me with the tools, guidance, and inspiration that helped shape me as a designer and thinker. Their dedication encouraged me to see architecture not only as a profession, but as an opportunity to create meaningful change and contribute positively to our environment.

I am especially thankful to my family for their unwavering support throughout my education. Their encouragement, patience, and belief in me made this achievement possible. I would like to give special thanks to my father, who faced many challenges and sacrifices yet never stopped supporting my educational goals. His perseverance, hard work, and commitment have been a constant source of motivation and inspiration.

I am also grateful to my friends, classmates, and colleagues who shared this journey with me. Their support, conversations, and encouragement helped make these years both rewarding and memorable.

Finally, I would like to thank everyone who contributed to my growth, both personally and professionally. This thesis represents not only the culmination of my academic studies but also the collective support, guidance, and encouragement of the many people who have helped me along the way.

Table of Contents:

INTRODUCTION

Thesis statement, goal and question:

Cities around the world are facing increasing pressure on their freshwater resources due to population growth, urbanization, and climate change. Lima, Peru, presents a unique paradox in which chronic water scarcity exists alongside persistent coastal fog generated by the Humboldt Current. Despite the abundance of atmospheric moisture, this resource remains largely untapped within the urban environment. At the same time, contemporary office buildings function primarily as consumers of water rather than contributors to resource generation. This condition presents an opportunity to reconsider the role of architecture in addressing environmental challenges.

This thesis proposes the integration of fog-water harvesting systems into the façades of existing office buildings in Lima, Peru, as a strategy for addressing urban water scarcity. By transforming the building envelope into an active environmental infrastructure, the project explores how atmospheric moisture can be captured, collected, and reused for non-potable applications. Through the retrofit of an existing office tower, the thesis investigates the potential of architecture to simultaneously respond to local climatic conditions, reduce dependence on municipal water resources, and contribute to a more resilient urban environment.

The purpose of this research is not only to examine the technical feasibility of fog harvesting but also to explore its architectural potential. Rather than treating water collection as a separate engineering system, the project investigates how environmental performance can be embedded directly within the building envelope. By integrating water collection, storage, and distribution into a façade intervention, the thesis seeks to demonstrate how existing buildings can become active participants in urban resource management.

The goal of this thesis is to design and evaluate a building-integrated fog-water harvesting façade for an existing office tower in Lima, Peru. The project seeks to demonstrate how architectural interventions can utilize the city's persistent fog conditions to generate an alternative water source while enhancing the environmental performance and resource efficiency of the building.

The research is guided by a central question that investigates the relationship between architecture, environmental systems, and water resilience. By focusing on an existing office tower in Lima, the project examines how atmospheric water harvesting can be integrated into the built environment while responding to the climatic conditions of the region.

How can the retrofit of an existing office building in Lima, Peru, integrate a fog-water harvesting façade system that captures atmospheric moisture and supplements non-potable water demands while contributing to urban water resilience?

Water Scarcity:

Water is a finite resource facing increasing pressure as global populations grow and economic development continues to intensify. As demand for water rises, many countries are struggling to ensure that their water resources and infrastructure can adequately support expanding populations and growing consumption needs.

Although approximately 75% of the Earth's surface is covered by water (NASA), only about 3% of the world's total water supply is freshwater. Of this limited amount, approximately 0.4% is readily accessible and suitable for human consumption, making it the primary source available to support the global population (Jyoti, 2019).

As a result, water scarcity has become one of the most significant challenges of the twenty-first century. More than two billion people currently live in regions experiencing water scarcity (Water, 2020), while approximately 2.7 billion people face water shortages for at least one month each year. Inadequate access to clean water and sanitation also contributes to serious public health concerns, exposing an estimated 2.4 billion people to waterborne diseases such as cholera and typhoid. Additionally, diarrheal diseases linked to unsafe water continue to affect millions worldwide, particularly children, and remain a leading cause of preventable illness and death (Jyoti, 2019).

Water scarcity is driven by a combination of factors, including population growth, increasing public water consumption, intensive agricultural practices, and the effects of climate change. As global demand continues to rise, pressure on freshwater resources has reached unprecedented levels. According to Jyoti (2019), humans consume approximately 321 billion gallons of water per day, in addition to 77 billion gallons of groundwater. These demands continue to increase alongside population growth, with the global population projected to reach approximately 8.24 billion people in 2025 (United Nations Population Division).

Agriculture is the largest consumer of freshwater worldwide and plays a significant role in global water scarcity. According to UN-Water (2025), approximately 70% of available freshwater is used for irrigation, while industrial and urban uses account for 20% and 10%, respectively. Current projections indicate that global water demand could exceed available supply by 40% by 2030. Beyond environmental consequences, water shortages also pose substantial economic risks. Fair's analysis estimates that the cost of inaction could range between $200 and $300 billion across multiple sectors, representing nearly five times the cost of implementing proactive water management strategies.

Groundwater depletion represents another critical concern. Groundwater currently supplies approximately 50% of domestic water use and more than 40% of irrigation water worldwide. However, many aquifers are being depleted at rates that exceed their natural recharge capacity, placing both drinking water supplies and agricultural production at increasing risk (UN, 2026).

Climate change is further intensifying water scarcity through rising temperatures, shifting precipitation patterns, and more frequent extreme weather events, including droughts, floods, and heat waves (Water, 2020). These changes are making water availability increasingly unpredictable while reducing terrestrial water storage, including water held in soil, snow, and ice (UN, 2024). As a result, many regions are experiencing greater water stress and disruption to social, economic, and ecological systems.

The consequences of climate change are particularly evident in vulnerable coastal regions. Rising sea levels threaten low-lying countries such as Bangladesh, where increased flooding is expected to reduce available land and place additional strain on water resources, infrastructure, and public health systems. These impacts demonstrate how climate change not only affects the quantity of available water but also disrupts natural water cycles and compromises water quality (Natural Disaster, 2014).

While water scarcity is a global challenge, its impacts are experienced differently across regions depending on climate, geography, infrastructure, and patterns of resource distribution. Peru presents a particularly complex case. Although the country possesses significant freshwater resources, these resources are unevenly distributed across its territory. The majority of Peru's water supply is located within the Amazon Basin, while a large portion of the population lives along the arid Pacific coast, where water availability is limited. This imbalance has created growing pressures on urban water systems, particularly in Lima, a city characterized by rapid population growth, high water demand, and increasing vulnerability to climate change. Understanding Peru's unique water conditions is therefore essential for exploring alternative strategies that can strengthen water resilience in the built environment.

Water Scarcity in Lima Peru:

Lima, Peru is the second-largest desert city in the world. The city's primary water sources are the Chillón, Rímac, and Lurín Rivers, which originate in the Andes Mountains and flow westward to the Pacific Ocean (The Nature Conservancy, Urban Water Blueprint). Despite access to these river systems, securing reliable and clean water remains a challenge for many residents. According to Weiss et al. (2015), approximately 11% of Lima's population lacks access to potable water.

Water scarcity in Lima is largely the result of the unequal distribution of water resources throughout Peru. While the Pacific watershed, where Lima is located, contains approximately 62.5% of the nation's population, it has access to only 1.76% of the country's available freshwater resources (Weiss et al., 2015). This geographic imbalance places significant pressure on existing water infrastructure and limits the city's ability to meet growing demand.

Rapid urbanization has further intensified these challenges. Since the 1950s, Lima has experienced substantial population growth driven by rural-to-urban migration. Many new residents settled in peripheral areas lacking formal infrastructure, creating informal settlements where access to water and sanitation remains limited. Extending water services to these communities is often difficult and costly, and legal barriers have historically complicated the provision of public utilities in these areas (Weiss et al., 2015).

Population growth is expected to continue in the coming decades, with projections estimating that Lima's population could reach 16 million residents by 2050 (Castro et al., 2010). As demand for water increases, the city faces mounting pressure to identify alternative and sustainable approaches to water management.

Fig 1.1: Lima's Hydraulic system, Source: Hoefsloot, Fenna I., Javier Martínez, and Karin Pfeffer. "An Emerging Knowledge System for Future Water Governance: Sowing Water for Lima." Territory, Politics, Governance, vol. 12, no. 6, 2024,

Efforts to manage and distribute water resources in Lima date back to the late nineteenth century. Beginning in 1876, dams constructed from stone masonry and concrete were developed primarily to support agriculture and hydroelectric production. By the mid-twentieth century, these systems were expanded to improve the drinking water supply for the rapidly growing metropolitan region (Weiss et al., 2015). As Lima's population continued to increase, additional dams, tunnels, and water conveyance systems were constructed to transfer water from Andean watersheds to the city. More recently, the Huachipa Water Treatment Plant, completed in 2011, was developed upstream of the La Atarjea treatment facility to increase the capacity of Lima's potable water network.

Today, water services in Lima are managed by Sedapal, the state-owned utility operating under the Ministry of Housing, Construction and Sanitation (Weiss et al., 2015). Sedapal is responsible for the provision of drinking water, sewerage, wastewater treatment, and water reuse services throughout the metropolitan area (GOB, 2024). The city's water supply is sourced primarily from the Rímac River and undergoes multiple stages of treatment before being distributed to residents (GOB.pe).

Despite decades of infrastructure investment and expansion, Lima continues to face significant challenges related to water availability, distribution, and future demand. Population growth, urban expansion, and increasing environmental pressures have highlighted the need for complementary strategies that can reduce dependence on centralized water systems and improve long-term urban water resilience.

Fig 1.2: Sedapal potable water distribution infrastructure in Lima and Callao. Source: "Sedapal distribuirá agua potable en Lima y Callao." Web 18, 11 Jan. 2024.

Fig 1.3: Drinking water and sewerage infrastructure improvements in northern Lima, including pipeline rehabilitation and network expansion. Source: Tedagua, Improvement of Drinking Water Supply and Sewerage Systems in Northern Lima, 2021.

Athmospheric oportunity:

Despite significant challenges related to water availability, Lima possesses a unique climatic condition that presents an opportunity for alternative water collection strategies. Although the city receives minimal annual rainfall, it experiences persistent coastal fog and high levels of atmospheric humidity throughout much of the year. This apparent contradiction suggests that while conventional freshwater resources are limited, atmospheric moisture may represent an underutilized source of water capable of supplementing existing supply systems. Understanding the climatic processes responsible for this phenomenon is therefore essential for evaluating the potential of atmospheric water harvesting within the urban environment

.

Lima's unique climatic conditions are largely shaped by its geographic location and surrounding topography. Situated along Peru's central Pacific coast, the city occupies an arid coastal desert bordered by the Pacific Ocean to the west and the Andes Mountains to the east. This setting creates a distinctive climate characterized by high atmospheric humidity, persistent fog, and extremely low annual rainfall.

Fig 1.4, 1.5: Location of Lima, Peru, within South America and its coastal setting along the Pacific Ocean. Image generated by the author using ChatGPT, 2026.

A primary contributor to these conditions is the Humboldt Current, a cold ocean current that flows northward along the western coast of South America. As warm air passes over the cold ocean surface, it cools and condenses, forming low clouds, mist, and coastal fog. At the same time, the Andes Mountains act as a barrier that prevents warm, moisture-laden air from the Amazon Basin from reaching the coast. Together, these factors create a subtropical desert climate where atmospheric moisture is abundant, yet precipitation remains scarce.

As a result, Lima receives less than 25 mm of rainfall annually, making it one of the driest capital cities in the world. Despite this lack of rainfall, average relative humidity levels remain above 80 percent throughout much of the year. During the winter months, from May to November, the city is frequently covered by a dense layer of fog and low clouds known locally as garúa. While this moisture rarely falls as rain, it represents a significant atmospheric water resource that remains largely untapped within the urban environment.

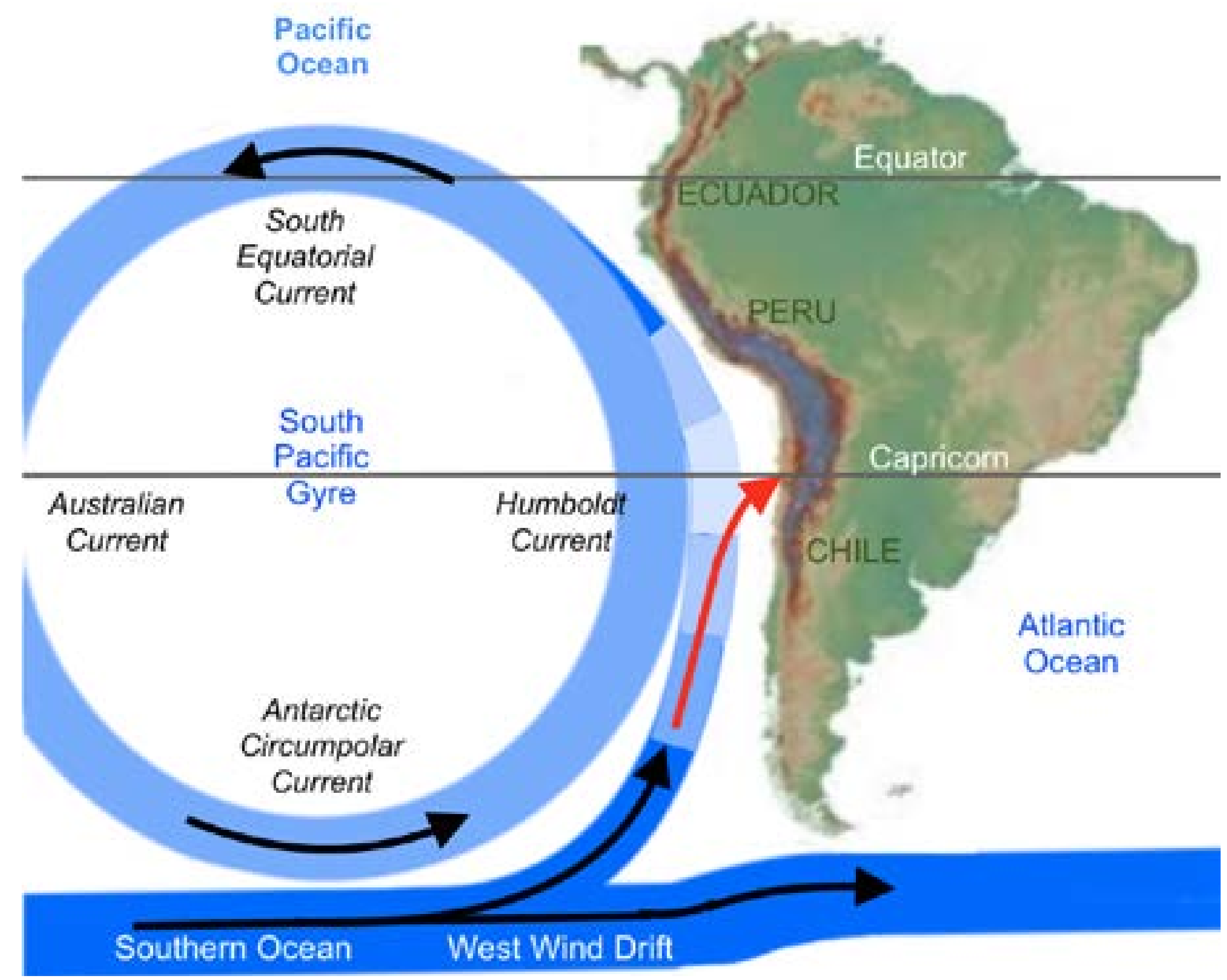


Fig 1.6: The Humboldt Current and its relationship to ocean circulation patterns along the western coast of South America. Source: "The Amazing Humboldt Current Course." NephiCode.com, 10 Dec. 2019.

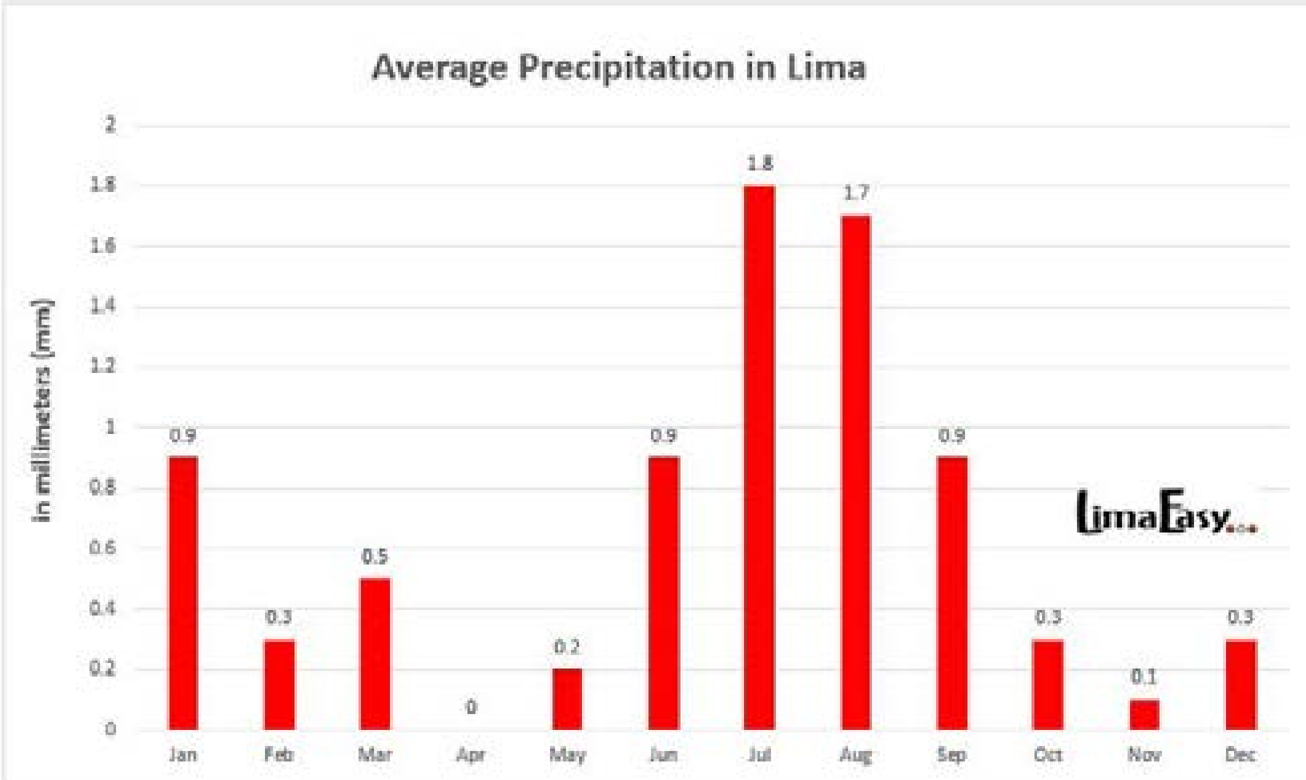


Fig 1.7: *Average monthly precipitation in Lima, Peru. Data source: SENAMHI (Peru's National Service of Meteorology and Hydrology); graphic reproduced from LimaEasy, 2023.*

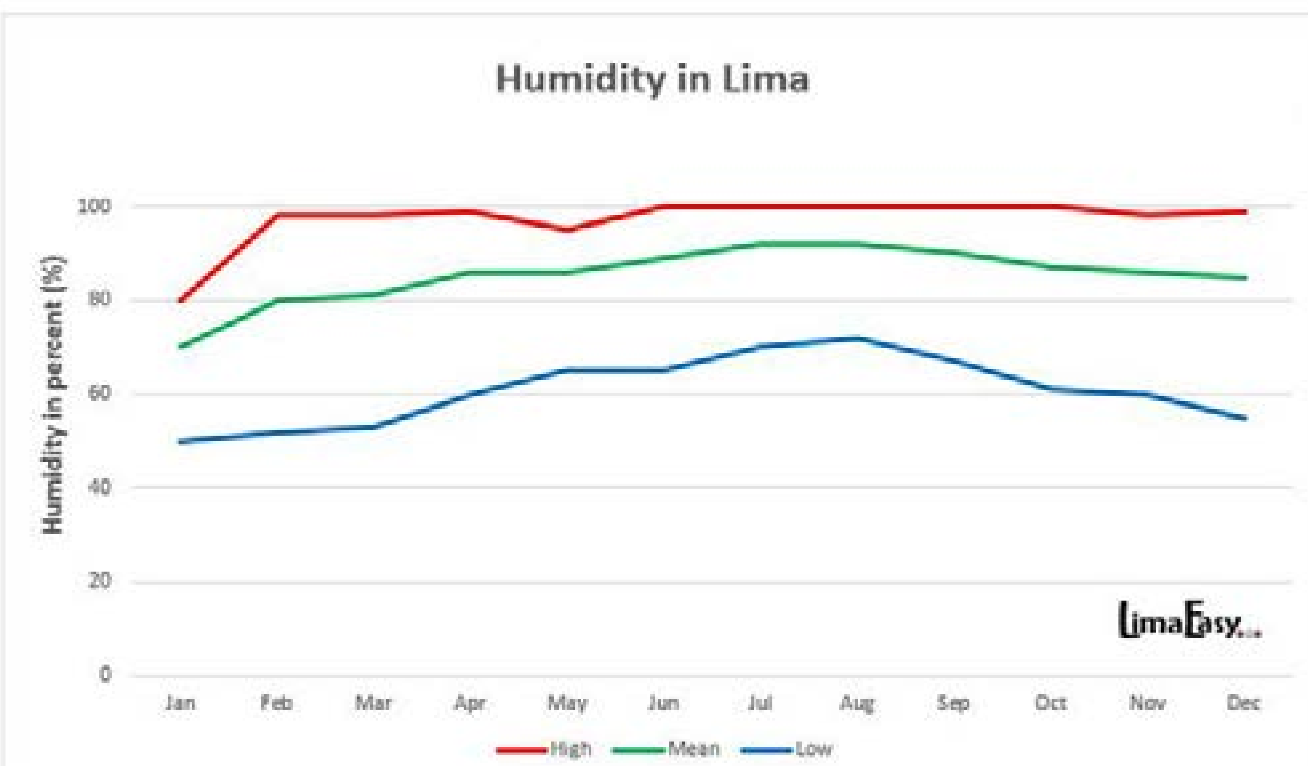


Fig 1.8: *Hunidity in Lima, Peru. Data source: SENAMHI (Peru's National Service of Meteorology and Hydrology); graphic reproduced from LimaEasy, 2023.*

GARUA- Lima's fog

Fog consists of tiny water droplets suspended in the air, along with gases and particles. It is a collection of water droplets or ice crystals that form near the earth surface, formed through condensation when water vapor in the air cools and condenses.
Fog can be formed everywhere, over land or water surfaces. Although it is not a climate-forming factor. It is of great meteorological importance, particularly due to its local character formation, its capability of reducing the temperature amplitude,and the fact that it is directed oriented to the humid parameters (Fog 2017).

La Garúa is a dense, cool, coastal fog or mist that appears along specific arid coastlines. The name is the Spanish word for drizzle or mist. This phenomenon represents a regular and substantial influx of moisture into environments that receive almost no rainfall. It acts as a lifeline, profoundly influencing the ecosystems and human settlements in these hyper-arid regions.

La Garúa is a persistent, low-lying stratus cloud that hugs the coastline. It is distinguished by the microscopic size of its water droplets, generally measuring between 1 and 40 microns across. These droplets are too fine to coalesce into raindrops capable of falling naturally. This high density of tiny water particles creates a thick, opaque blanket that dramatically reduces visibility, bathing the landscape in humidity as it drifts (Biologyinsighht,2026).

The most prominent manifestation of La Garúa occurs along the Pacific coast of South America, particularly in the desert regions of Peru and Chile. This moisture-laden fog defines the climate near the Atacama Desert and the Peruvian coastal plain. The phenomenon extends roughly 2,800 kilometers from southern Ecuador down into northern Chile. In Chile, this coastal fog is frequently referred to by the local name camanchaca. Similar fog-related moisture events also occur in other arid coastal areas globally, such as the Namib Desert in Africa and parts of Baja California (Biologyinsighht,2026).

While garúa is most commonly understood as a climatic phenomenon, its persistent presence along the Peruvian coast also presents a significant environmental opportunity. Although this fog rarely produces measurable rainfall, it contains substantial amounts of atmospheric moisture that can be captured and converted into usable water.

Fig 1.9: Fog (garúa) covering the Lima coastline and urban fabric. Source: Author-generated image created with ChatGPT (OpenAI), 2026.

LITERATURE REVIEW

Existing Harvesting Systems:

Rather than viewing fog solely as a climatic condition, researchers and designers have increasingly recognized it as a potential source of freshwater. Over the past several decades, various fog-harvesting systems have been developed to capture airborne water droplets and convert them into usable water supplies. These technologies have proven particularly effective in arid regions where conventional water resources are scarce. Many of the most successful collection strategies draw inspiration from natural organisms that have evolved to survive in water-limited environments, demonstrating how biological systems can inform innovative approaches to atmospheric water harvesting.

BIOMIMICKING- Namib Desert Beetle

One of the most widely studied examples of biomimetic water collection is the Namib Desert beetle (*Stenocara gracilipes*), which inhabits one of the driest regions in the world. Despite receiving very little annual rainfall, the beetle survives by harvesting moisture directly from fog. This ability is made possible through a specialized surface structure that efficiently captures, condenses, and transports water.

The beetle's shell consists of a series of hydrophilic bumps surrounded by hydrophobic, wax-coated valleys. When fog passes over the surface, water droplets accumulate on the hydrophilic protrusions where condensation occurs more readily. As the droplets grow in size, gravity causes them to roll off the bumps and travel along the hydrophobic channels toward the beetle's mouth. Research has shown that this combination of hydrophilic and hydrophobic surfaces is significantly more effective at collecting water than surfaces with uniform wetting properties.

To maximize water collection, the beetle adopts a characteristic "fog-basking" posture, positioning its body at an angle of approximately 23 degrees relative to the ground. This orientation allows fog-laden air to flow across its shell while facilitating the movement of condensed water droplets toward the insect's mouth. The beetle's ability to efficiently collect water through surface geometry and material differentiation has inspired numerous atmospheric water-harvesting technologies and continues to serve as a valuable precedent for biomimetic design (Uvarani,2024).

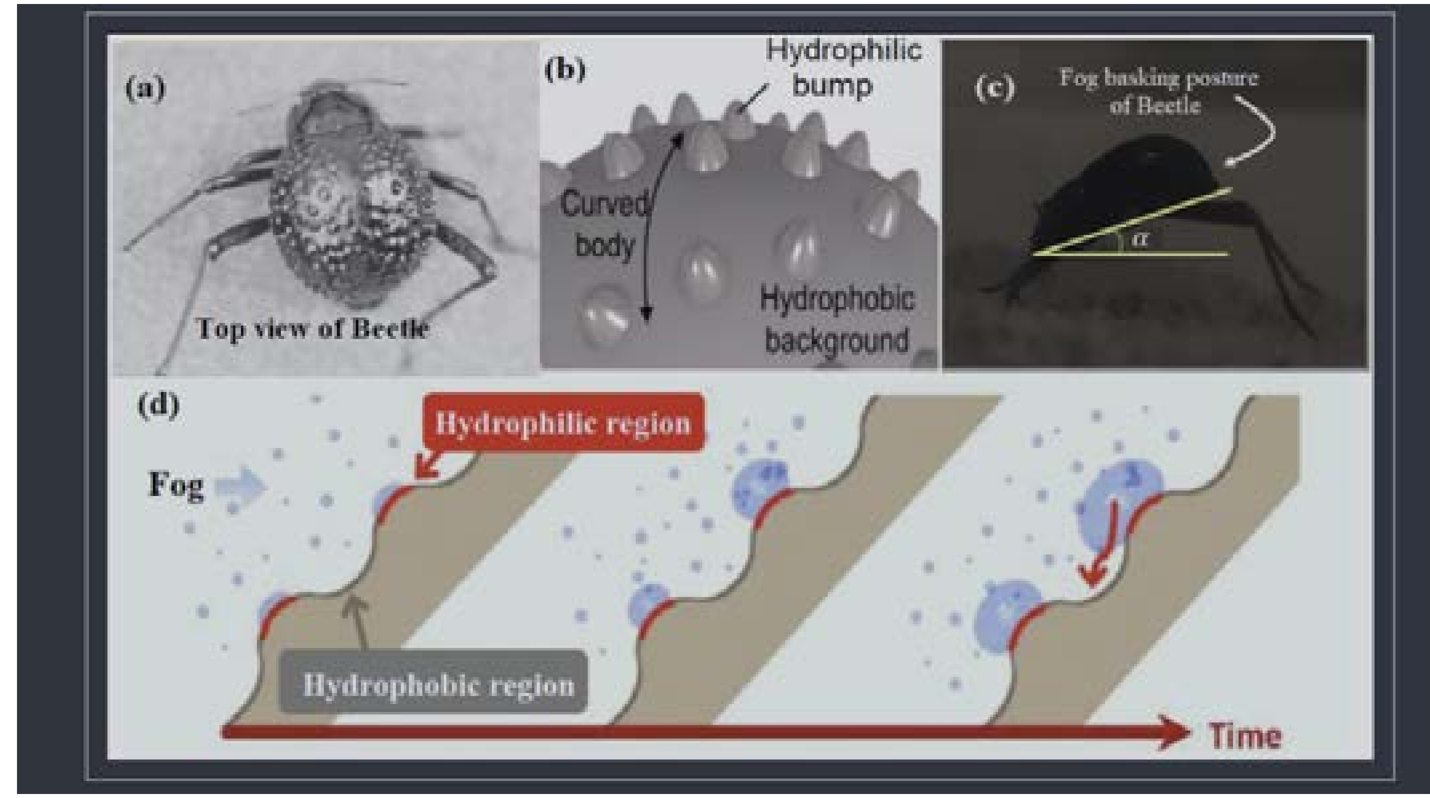


Fig 2.1: Biomimetic principles of fog collection inspired by the Namib Desert beetle. Hydrophilic bumps and hydrophobic regions on the beetle's shell facilitate water condensation and droplet transport, informing the design of engineered fog-harvesting surfaces. Source: Uvarani and Behura 8.

Fig 2.2: Namib Desert beetle (Stenocara sp.) collecting moisture from fog through a patterned shell surface, a biological strategy that has informed the design of modern fog-harvesting systems. Source: Parker and Lawrence.

BIOMIMICKING- Spider Silk

The Namib Desert beetle demonstrates how surface properties can enhance water capture and transport. Similar strategies can be observed in other organisms, such as cacti and spider webs, which utilize geometry and material characteristics to collect atmospheric moisture in arid environments.

Spider silk provides another remarkable example of natural atmospheric water collection. In humid and foggy environments, spider webs are capable of capturing microscopic water droplets suspended in the air. These tiny droplets accumulate on the silk fibers and gradually coalesce into larger droplets. Through a combination of surface chemistry and fiber geometry, the collected water is then transported along the silk strands toward specialized spindle-shaped knots.

Researchers have found that the alternating structure of joints and spindle knots creates differences in surface energy that drive the movement of water droplets. As droplets grow larger, they are naturally directed toward the knots, where they merge with additional moisture before continuing along the web. This passive transport mechanism allows spiders to efficiently collect and channel water without expending energy.

The ability of spider silk to capture, aggregate, and direct atmospheric moisture has inspired the development of advanced fog-harvesting materials and water-collection surfaces. Its combination of efficient droplet capture and controlled water transport offers valuable insights for the design of atmospheric water-harvesting systems and biomimetic architectural applications.

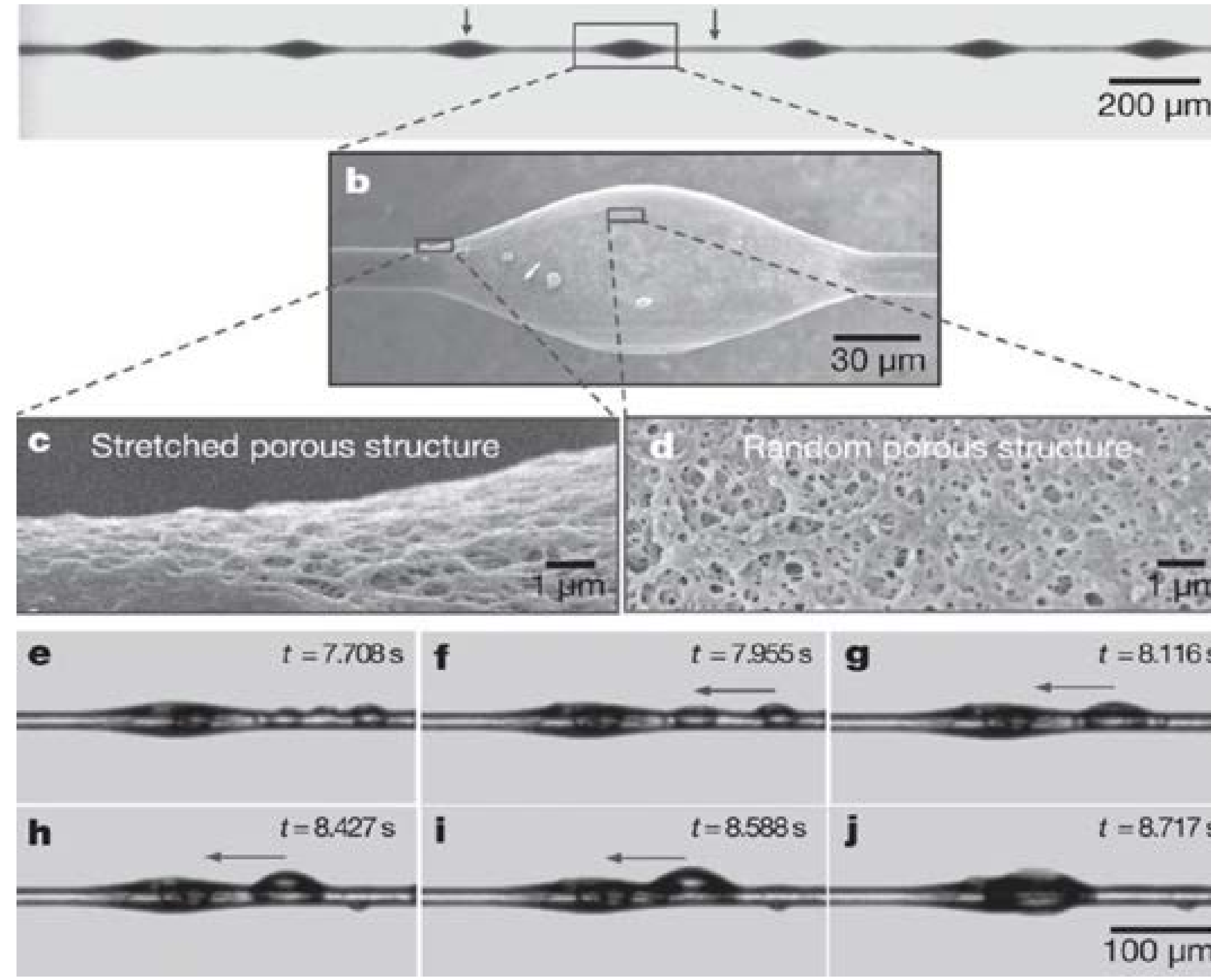


Fig 2.3: This diagram shows how spindle-shaped fibers inspired by spider silk collect and direct water droplets, improving passive water harvesting and transport. Source: Parker and Lawrence.

The study of biological water-harvesting systems demonstrates that efficient atmospheric water collection depends not only on the presence of moisture, but also on the geometry, surface properties, and organization of collection surfaces. Organisms such as the Namib Desert beetle and spider silk have evolved mechanisms that maximize water capture, condensation, and transport in arid environments. These natural strategies have inspired researchers to develop more efficient water-harvesting technologies and have contributed to a broader understanding of how atmospheric moisture can be transformed into a usable resource. While many contemporary systems continue to explore advanced biomimetic materials, the fundamental principles of water interception and transport remain central to the design of modern fog-harvesting technologies.

History of Fog Harvesting

Fog interception is a naturally occurring process through which airborne water droplets are captured by surfaces and converted into usable water. This phenomenon can be observed in fog-dependent ecosystems throughout the world. Along the Pacific coastal hills of Peru and Chile, for example, the lomas ecosystems survive almost entirely through the interception of moisture from advective fog despite receiving little to no annual rainfall (Fog, 2013). Similarly, certain plant species, particularly those with needle-like or highly textured surfaces, have evolved to efficiently capture water from fog, allowing them to survive in extremely arid conditions.

Human societies have also utilized fog collection for centuries. In the Canary Islands, inhabitants relied on trees such as laurels, junipers, and pines to capture atmospheric moisture, which served as an important source of drinking water for both humans and livestock. Similar practices were documented in Oman, where cisterns were constructed beneath trees to collect water dripping from fog-laden branches. Evidence of atmospheric water collection has also been found in the Atacama Desert and the Crimean Peninsula, where stone structures were used to condense and collect moisture during periods of low precipitation.

Fig 2.4: Traditional fog-water harvesting methods used in different regions of the world. Source: Author-generated image created with ChatGPT (OpenAI), 2026.

The scientific study of fog as a water resource began during the early twentieth century, with researchers investigating the potential of atmospheric moisture collection in arid environments. One of the first large-scale fog collection experiments was conducted in South Africa in 1969. The system consisted of two plastic mesh screens, each measuring 28 meters in length and 3.6 meters in height, positioned perpendicular to prevailing winds. Between October 1969 and December 1970, the installation collected an average of approximately 31 cubic meters of water per month, demonstrating the feasibility of harvesting atmospheric moisture as a reliable water source.

Building upon these early experiments, one of the most influential fog-water collection projects was implemented in 1987 in the fishing village of Chungungo, Chile. Located within the arid coastal region of northern Chile, the project utilized one hundred fog collectors, each measuring 12 meters by 4 meters, installed on a hillside overlooking the village. Water production varied according to weather conditions, reaching up to 20 liters per square meter per day during favorable fog events. The system successfully supplied approximately 33 liters of clean water per person per day for the village's 300 residents, demonstrating the potential of fog harvesting as a community-scale water supply strategy.

Fig 2.5: Fog-catching nets in Peña Blanca, Chile, harvesting atmospheric moisture from the Camanchaca fog. Since 2005, the system has been used to support native vegetation and provide an alternative water source in the Atacama Desert region. Source: Nick Lavars, "How Chile's Fogcatchers Are Bringing Water to the Driest Desert on Earth," New Atlas, 25 Aug. 2015

Strategies for Fog Collector Systems

Fog water harvesting has been studied and implemented for decades as a viable alternative source of freshwater in arid and semi-arid regions characterized by frequent and persistent fog events. In such locations, fog collection systems have demonstrated the ability to supplement conventional water supplies and provide access to freshwater in regions where rainfall is limited.

Among the most widely used technologies is the Large Fog Collector (LFC), a mesh-based system designed to intercept airborne water droplets and channel the collected moisture into storage systems. While LFCs have proven effective in numerous applications, their long-term performance is often affected by environmental conditions. Strong wind events, prolonged exposure to ultraviolet radiation, and material degradation can damage structural components and reduce collection efficiency. As a result, maintenance requirements and structural durability remain significant challenges for the widespread implementation of these systems.

The study "LFC: New Strategies for Fog Collection Efficiency and Structural Response to Wind Pressure" examines these limitations by analyzing the effects of wind loads on conventional fog collectors. Through the evaluation of existing case studies where structural damage and collapse occurred, the research identifies critical weaknesses in current designs and proposes strategies to improve both collection efficiency and structural performance. These findings highlight the importance of developing more resilient fog-harvesting systems capable of withstanding the environmental conditions commonly encountered in fog-prone regions.

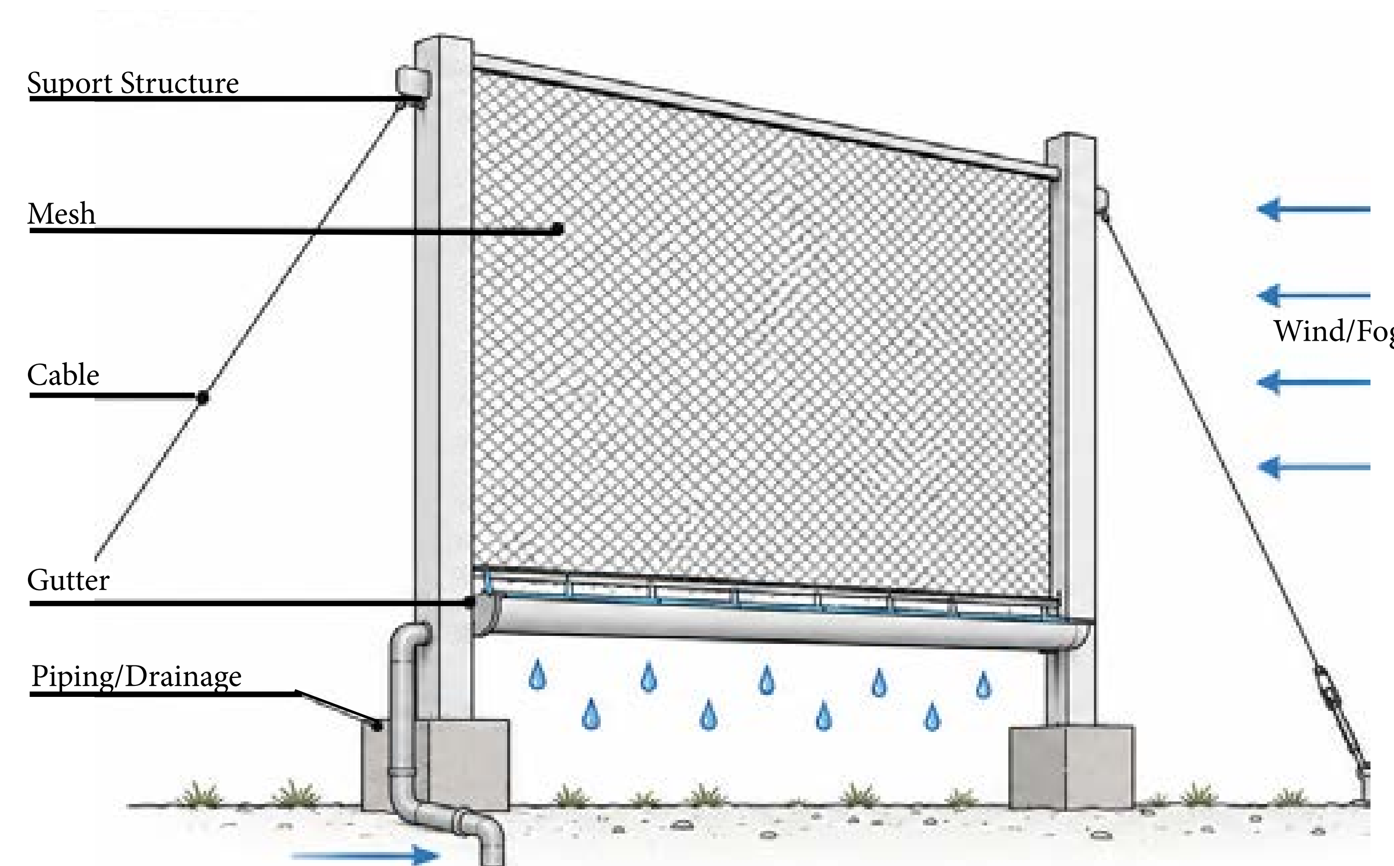


Fig 2.6: Components and operation of a standard fog collector, including the support structure, mesh panel, collection gutter, and drainage system. Diagram by the author.

Structure Strategies:

The structure of LFC's must withstand different types of forces:

1. Gravitational force, corresponding to the dead weight f the wet mesh, cable, through full of water and other structural elements.
2. Dynamic loads corresponding to erection and maintenance of the system.
3. sysmic loads in places like Chile, Peru (near subjuction Zones).
4. Largest, significant load is wind. Most frequently, LFC's are installed in wind places because only wind driven fog permits water collection.

Mesh Analysis:

The structural performance of fog collection meshes is strongly influenced by their knitting and weaving configurations. The orientation and directionality of fibers affect how loads are distributed throughout the mesh, particularly under wind pressure. This behavior is especially evident in Raschel mesh, whose asymmetrical knitted structure results in distinct mechanical responses when subjected to environmental forces.

Research on Large Fog Collectors (LFCs) has identified wind pressure as one of the primary factors affecting long-term system performance. Under strong wind conditions, two major forms of failure have been observed within the collection screen. The first is mesh deformation, which may occur as either elastic or plastic deformation and often results in sagging of the collection surface. The second is the concentration of stress in critical areas of the mesh, leading to localized tears or openings that can progressively expand and ultimately cause failure of the collection screen.

In some cases, these localized failures function as unintended release mechanisms that reduce wind pressure acting on the mesh. However, when the mesh is capable of resisting these stresses, the forces are transferred to the supporting structure and foundations, potentially causing structural damage elsewhere in the system.

Studies have also shown that mesh sagging increases with the distance from the perimeter attachment points and decreases as the stiffness of both the mesh and supporting structure increases. Consequently, larger collection surfaces with lower structural stiffness are more susceptible to deformation under wind loads. These findings highlight the importance of considering both material properties and structural support systems when designing fog-harvesting installations, particularly for large-scale applications and building-integrated systems.

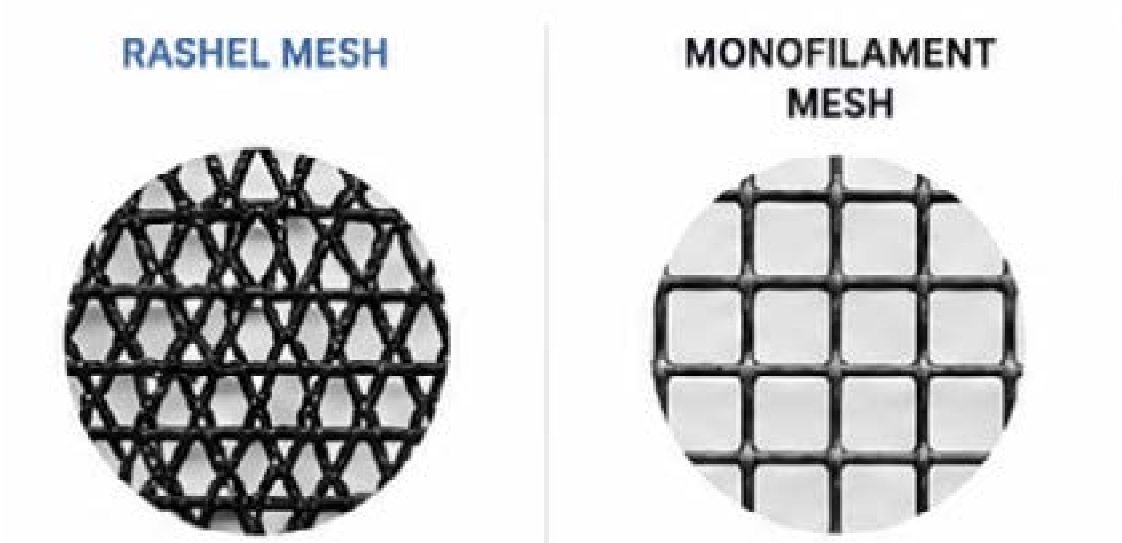


Fig 2.7: Raschel mesh and monofilament mesh used in fog-water collection systems.

Aerodynamic Collection Efficiency and Liquid Water Content:

Large Fog Collectors (LFCs) act as obstacles to the natural flow of wind. As air approaches the collection surface, a portion of the airflow passes through the mesh while the remainder is diverted around it. The proportion of air that passes through the mesh depends on several factors, including the mesh's resistance to airflow, its pressure drop coefficient (Co), aspect ratio, and overall three-dimensional geometry.

The pressure drop coefficient is influenced by the mesh shade coefficient, as well as the aerodynamic properties of the fibers and their weaving or knitting pattern. These characteristics directly affect both the structural performance of the collector under wind loads and its ability to capture water droplets from fog. Consequently, mesh design plays a critical role in balancing collection efficiency with structural stability.

Fog collection performance can be evaluated through three primary efficiency measures: aerodynamic collection efficiency (ACE), capture efficiency, and drainage efficiency. Aerodynamic collection efficiency refers to the proportion of airborne water droplets that are directed toward and collide with the mesh surface. This efficiency depends on factors such as the shade coefficient of the mesh, its resistance to airflow, and the drag forces generated by the collector. Capture efficiency describes the ability of the mesh fibers to retain droplets once contact occurs, while drainage efficiency measures how effectively the collected water is transported through the mesh and directed toward the collection system.

Together, these efficiencies determine the overall performance of a fog-harvesting system. Optimizing mesh geometry, fiber arrangement, and airflow characteristics is therefore essential for maximizing water collection while maintaining structural resilience under varying wind conditions.

$$\eta_{ac} = \frac{s}{1+\sqrt{\frac{C_0}{C_d}}} \qquad C_0 = 1.3s + \frac{s^2}{(1-s)^2}$$

Fig 2.8 2.9: Mathematical relationships for aerodynamic collection efficiency and pressure-drop coefficient used in the analysis of fog-harvesting mesh performance. Source: Elshennawy et al., 2023.

CASE STUDIES:

While conventional fog collectors have demonstrated the feasibility of atmospheric water harvesting, recent projects have expanded these principles beyond standalone collection devices and into the realm of architecture. By integrating water-harvesting technologies into buildings, towers, and public infrastructure, designers have begun exploring how the built environment can actively participate in resource generation. The following case studies examine projects that collect atmospheric moisture while simultaneously functioning as architectural interventions, offering important precedents for the development of building-integrated fog-harvesting systems.

The Namibian Univerity Water Science

The Namibia University Water Sciences Center was designed by British architect Matthew Parks and draws inspiration from the water-harvesting mechanisms of the Namib Desert beetle. Located near the Atlantic coast, the building responds to the region's fog-rich climate by incorporating atmospheric water collection directly into its architectural design.

A defining feature of the project is a large curved wall composed of nylon mesh that faces the ocean and intercepts moisture carried by coastal fog. Similar to the hydrophilic bumps found on the shell of the Namib beetle, the mesh surface incorporates a textured geometry designed to enhance the capture and condensation of airborne water droplets. Once collected, the water is directed through a network of channels integrated within the building's infrastructure and transported by gravity to underground storage reservoirs (Caldas,2018).

By combining biomimetic principles with architectural design, the Namibia University Water Sciences Center demonstrates how buildings can function as active environmental systems. Rather than serving solely as shelter, the building participates in water collection, storage, and management, illustrating the potential for architecture to contribute to resource generation in water-scarce environments.

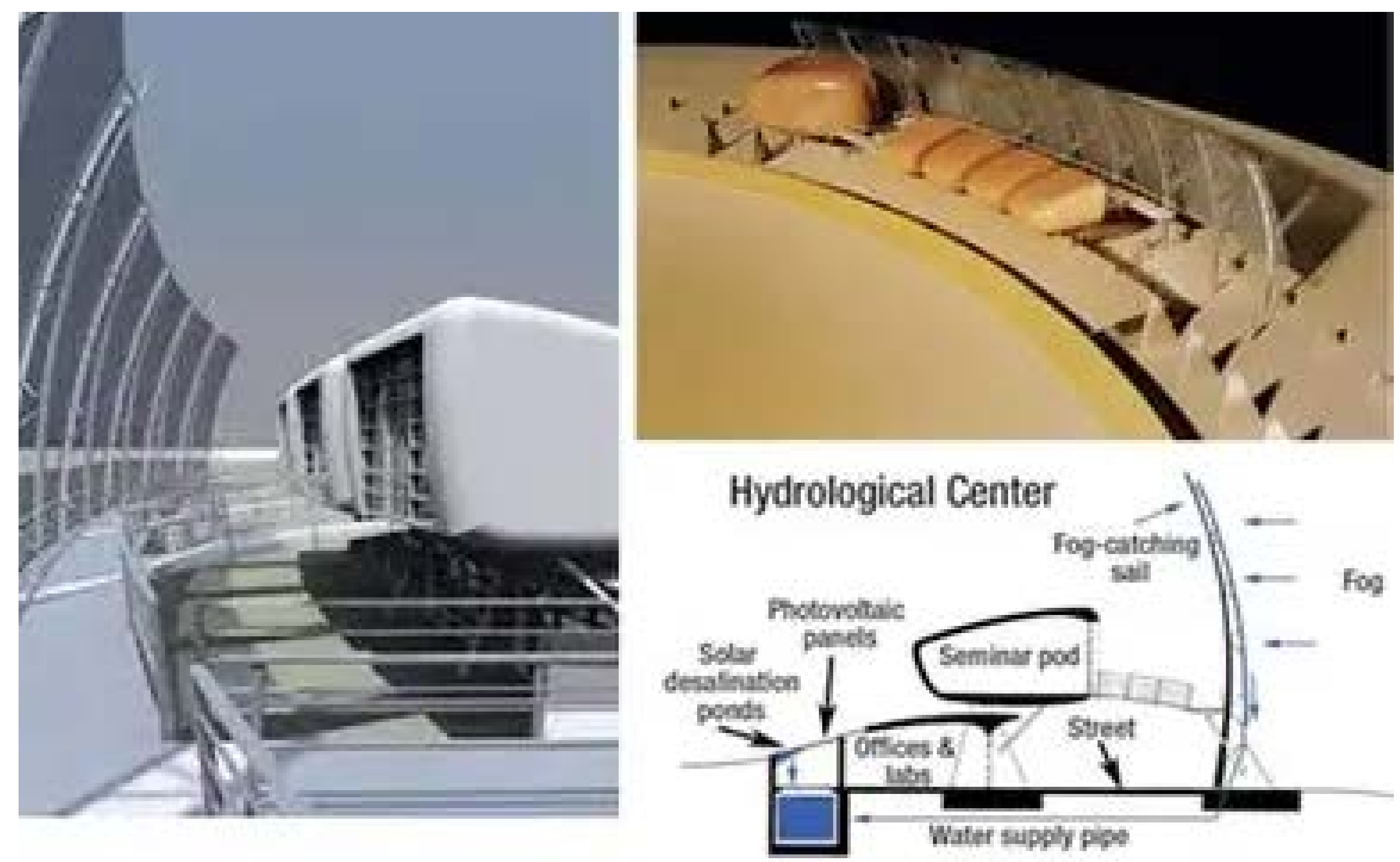


Fig 2.10: Hydrological Center for the University of Namibia. The building integrates fog-harvesting technologies and passive environmental systems inspired by biological processes, demonstrating the application of biomimicry in architectural design. Source: Kaya, Yücedağ, and Aşıkkutlu.

Warka Tower

The Warka Tower, proposed by architect Arturo Vittori, was conceived as an alternative method of providing water in regions facing limited access to freshwater resources. Inspired by natural water collection processes, the project utilizes simple materials and passive environmental strategies to harvest atmospheric moisture. The design emphasizes shape, geometry, and material performance rather than relying on complex engineering systems or energy-intensive technologies (Caldas,2018).

The tower operates without electrical power, pumps, or mechanical equipment. Instead, it relies on naturally occurring environmental processes, including fog interception, condensation, gravity, and evaporation, to collect and distribute water. Moisture from the atmosphere is captured by a lightweight mesh suspended within the tower's structural frame. The collected water droplets are then directed downward by gravity and stored for later use.

By employing a low-cost and low-tech approach, the Warka Tower demonstrates how atmospheric water harvesting can provide an alternative water source in resource-constrained environments. The project highlights the potential of passive environmental systems to address water scarcity while minimizing energy consumption and infrastructure requirements. As an architectural intervention, the tower serves as a precedent for integrating water collection strategies into built structures and illustrates how design can transform atmospheric moisture into a valuable resource.

Fig 2.11: Warka Water tower. Source: Arturo Vittori, Warka Water Project.

The literature review and case study analysis demonstrate that atmospheric water harvesting is a viable strategy for supplementing water resources in arid and water-stressed environments. Existing fog collection systems and architectural precedents have shown the potential of harvesting atmospheric moisture through passive technologies, material innovation, and climate-responsive design. However, despite these advancements, limited research has explored the integration of fog-harvesting systems into existing high-rise office buildings within dense urban environments such as Lima, Peru.

This gap presents an opportunity to investigate how atmospheric water collection can be incorporated into the building envelope as both an environmental and architectural intervention. Building upon the knowledge gained through the review of water scarcity, fog-harvesting technologies, biomimetic principles, material systems, and architectural precedents, the following chapter outlines the methodology used to develop and evaluate a building-integrated fog-harvesting façade for the Torre Banco de la Nación. Through environmental analysis, parametric modeling, and design exploration, this research seeks to assess the potential of transforming an existing office tower into an active water-generating infrastructure.

METHODOLOGY:

This thesis employs a research-through-design methodology to investigate the integration of atmospheric water harvesting systems into the façade of an existing office tower in Lima, Peru. The research process began with an extensive literature review focused on water scarcity, atmospheric water harvesting, biomimicry, fog collection technologies, and the structural and material characteristics of fog-harvesting systems. Particular attention was given to the performance of Raschel mesh, collection efficiency, wind behavior, and the integration of fog-harvesting technologies within the built environment.

Following the literature review, a series of architectural precedents were analyzed to understand how atmospheric water collection has been incorporated into buildings and environmental structures. Case studies including the Warka Tower, the Namibia University Water Sciences Center, and other fog-harvesting projects provided insights into water collection strategies, material systems, structural approaches, and environmental integration.

Based on this research, a case study building was selected in Lima, Peru. The chosen building, one of the tallest office towers in the city, was evaluated for its potential to support a building-integrated fog-harvesting system. Site conditions, climatic characteristics, and façade orientations were analyzed to determine opportunities for atmospheric water collection.

To assess the water-harvesting potential of the proposed intervention, environmental data related to Lima's fog conditions, humidity levels, and prevailing wind patterns were examined. A parametric workflow was then developed using Grasshopper to estimate the amount of water that could be collected across different façade orientations. The script evaluated collection potential based on surface area, climatic inputs, and wind directionality.

Two façade geometries were subsequently developed and tested. Each geometry responded differently to prevailing wind conditions and atmospheric moisture flows. The comparative analysis of these alternatives informed the final design proposal by identifying the configuration with the greatest water-harvesting potential while maintaining architectural and structural feasibility.

The results of this process were used to develop a building-integrated fog-harvesting façade that combines environmental performance, architectural expression, and water collection capacity. Through this methodology, the thesis explores how existing high-rise buildings can be transformed into active environmental infrastructures capable of contributing to urban water resilience.

Building Selection:

The Torre Banco de la Nación was selected as the primary case study for this research due to its prominence within Lima's urban environment and its potential to support a building-integrated fog-harvesting system. As one of the tallest office buildings in Peru, the tower provides a substantial façade surface area and significant exposure to prevailing coastal winds, both of which are critical factors for atmospheric water collection. Its height and visibility within the city make it an appropriate testing ground for evaluating the feasibility of integrating fog-harvesting technologies into existing high-rise structures.

The building was also selected because it represents a common office typology found within contemporary urban centers. Office buildings consume significant quantities of water for non-potable uses, including toilet flushing, landscape irrigation, cooling systems, and maintenance operations. As demand for water continues to increase in Lima, these buildings present an opportunity to supplement conventional water supplies through localized resource generation. By investigating the retrofit of an existing office tower, this thesis explores how commercial buildings can be transformed from passive consumers of resources into active environmental infrastructures capable of harvesting atmospheric moisture and contributing to urban water resilience.

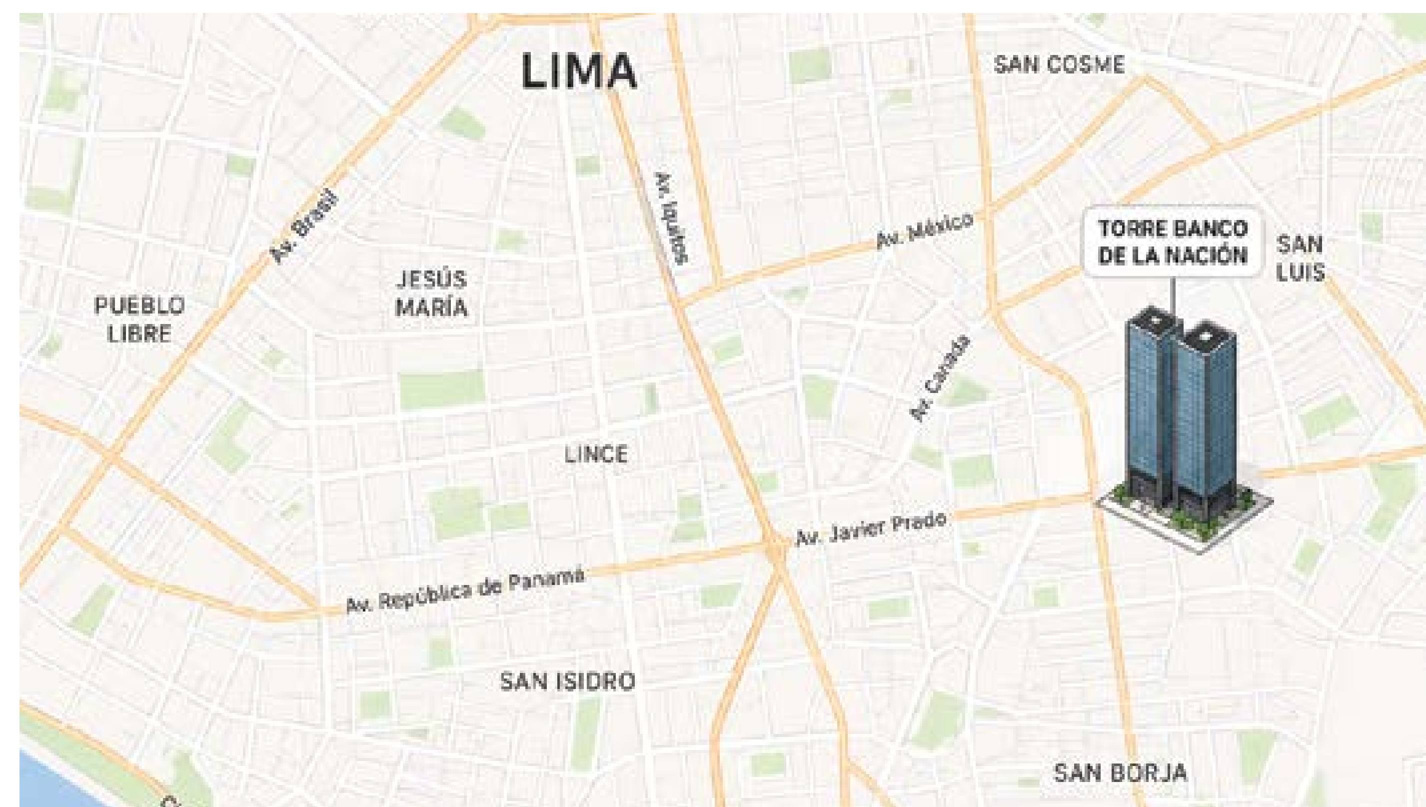


Fig 3.1: Torre Banco de la Nacion. Source: Google maps

Fig 3.2: Structural system of Torre Banco de la Nación, illustrating the reinforced concrete core, post-tensioned slabs, concrete columns, and podium structure. Source: Diagram by the author.

Fig 23: Existing Torre Banco de la Nacion Curtain wall system.

Fig 3.3: Curtain wall typycal section detail

BUILDING ANALYSIS:

Building: Torre Banco de la Nacion
Location: Lima, Peru
Designer: Arquitectonica
Year Built: 2016
Height: 140 m
Floors: 30 levels

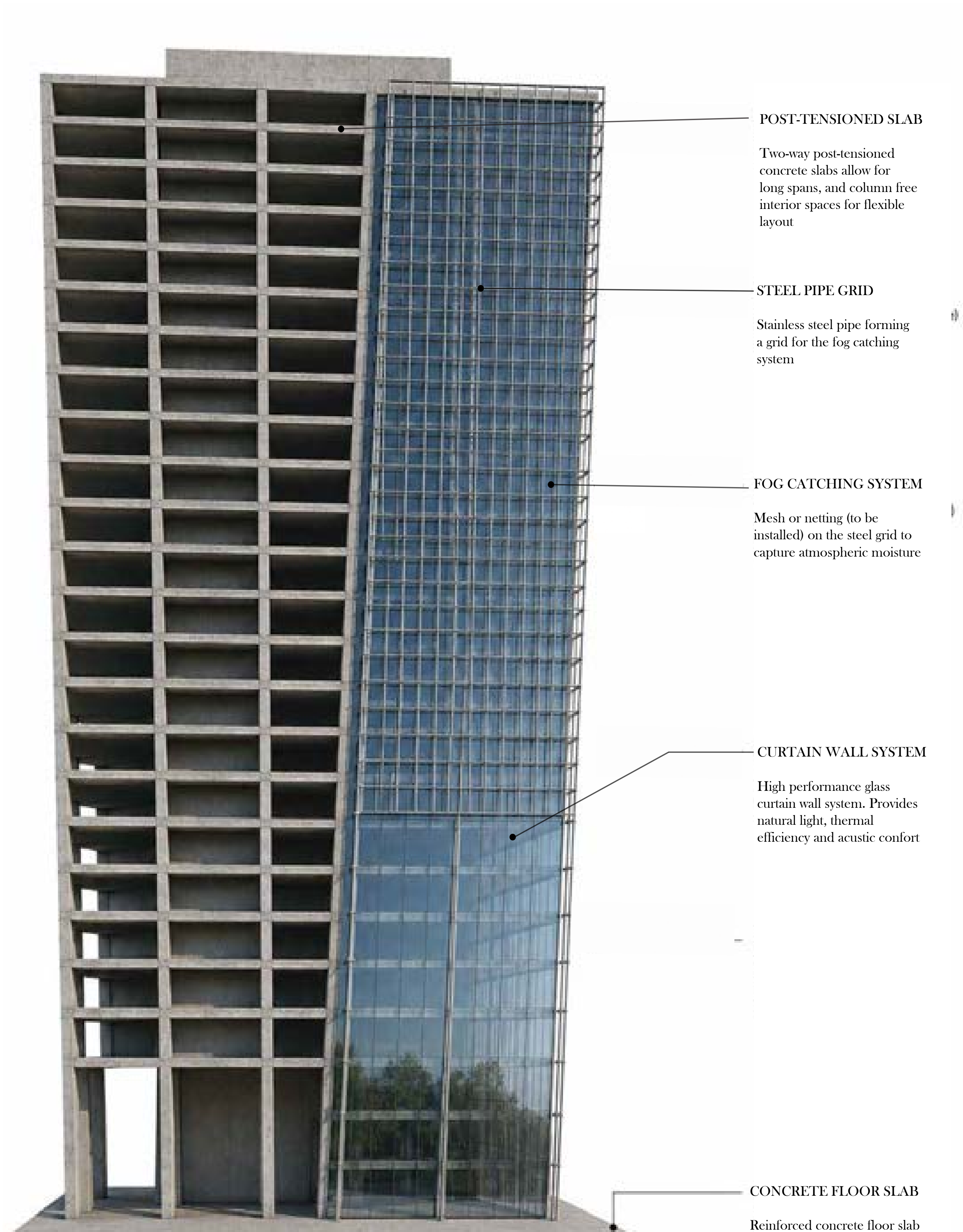


Fig 3.4: Proposed modular façade system attached to the existing Torre Banco de la Nación structure. The intervention consists of a stainless-steel pipe grid supporting a fog-harvesting mesh installed beyond the existing curtain wall, enabling atmospheric water collection while maintaining access to the building envelope.Source: Author

Building Integration:

This project proposes a secondary steel structure attached to the existing façade mullions of the Torre Banco de la Nación. The system serves as the primary support framework for a series of modular fog-harvesting panels positioned in front of the existing curtain wall. By utilizing the building's existing structural façade system, the intervention minimizes modifications to the tower while creating a platform for atmospheric water collection.

The decision to employ a modular system was informed by findings from the literature review regarding the performance of conventional Large Fog Collectors (LFCs). Previous studies have shown that large continuous mesh surfaces are highly susceptible to wind-induced deformation, sagging, material fatigue, and localized failures. Once damage occurs, tears can propagate across the mesh, reducing collection efficiency and increasing maintenance requirements.

To address these limitations, the proposed design divides the collection surface into a series of smaller modular units. This strategy reduces wind loads acting on individual panels, limits the spread of localized failures, and allows damaged modules to be replaced independently without disrupting the performance of the entire system. The modular approach also improves constructability, maintenance access, and adaptability while providing a more resilient framework for integrating fog-harvesting technology into an existing high-rise office building

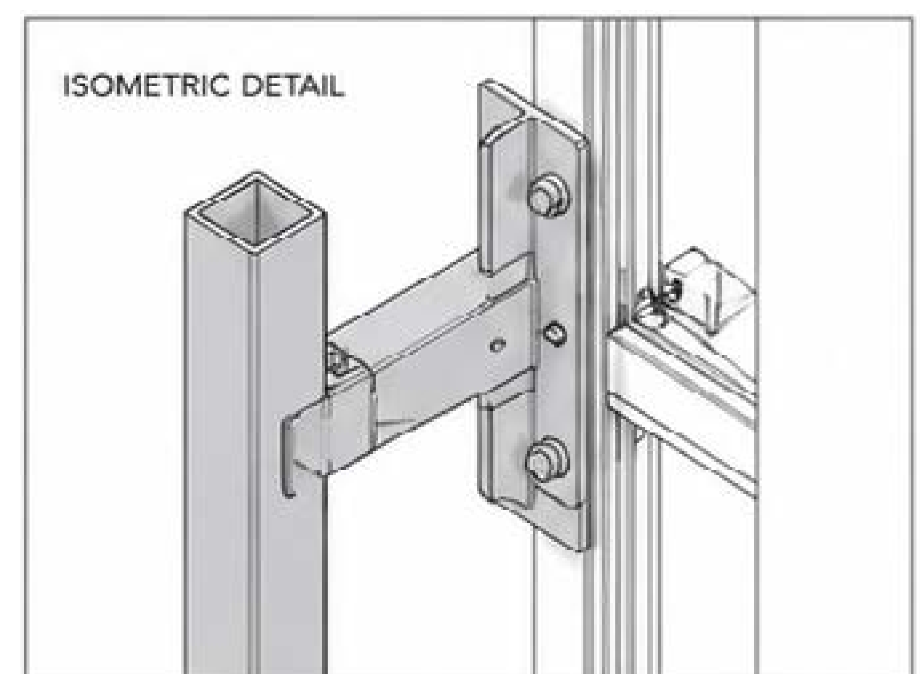


Fig 3.5: Typical connection detail between the proposed fog-harvesting support structure and the existing curtain wall mullio. Source: Diagramed by the Author

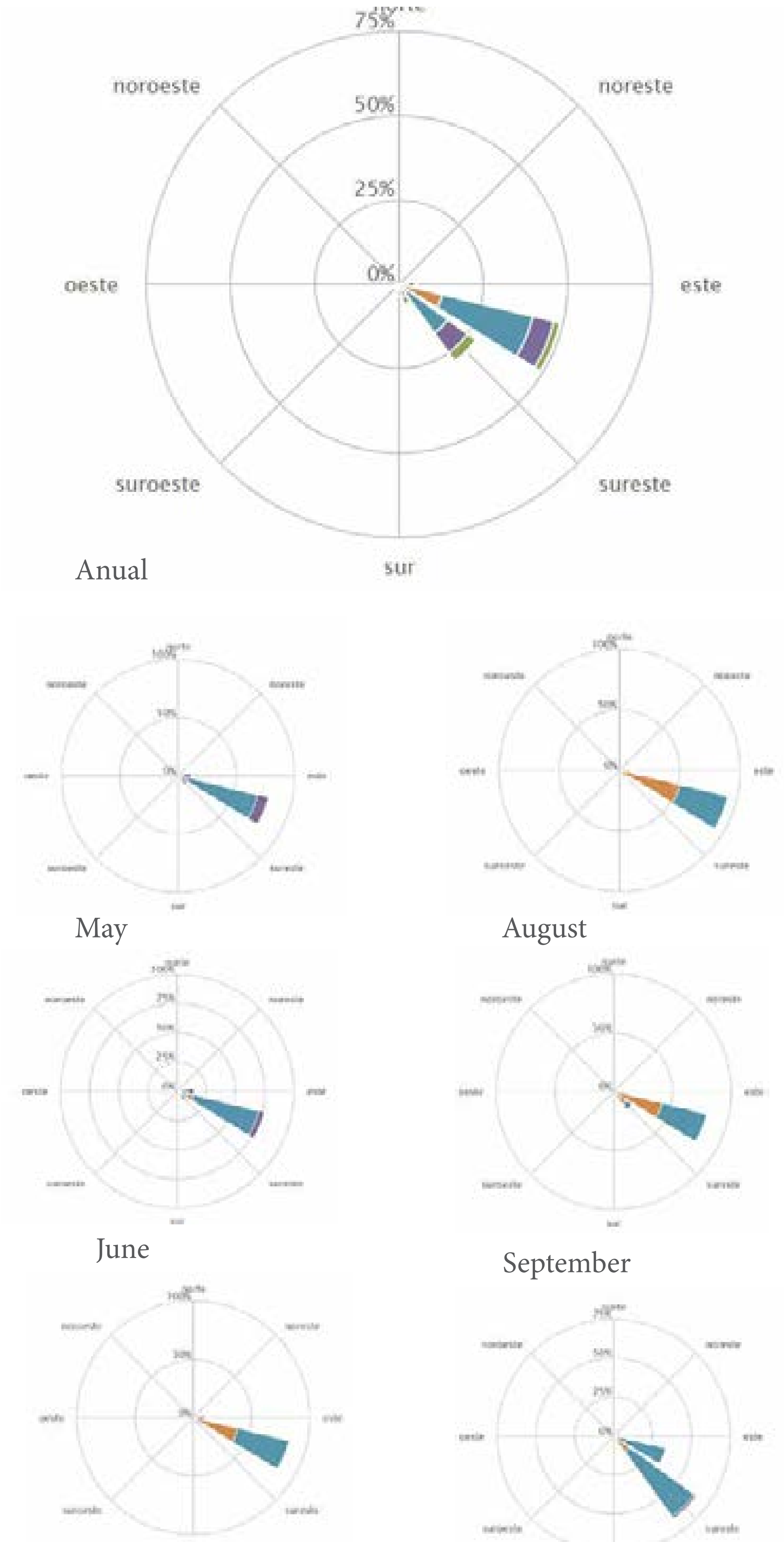


Fig 3.6: Lima;s Wind Rose. Source: MeteoCast.in

Fig 3.7: Building Wind analysis. Source: Author

Fig 30: Surfaces facing wind. Source: Author

Wind Analysis:

Annual wind rose analysis indicates that predominant wind movement originates from the southeast. These air currents carry fog inland from the coast, particularly during winter and transitional seasons. The selected façade orientation maximizes exposure to these prevailing winds, informing the placement of the thesis intervention as a mechanism for fog interception and environmental performance.

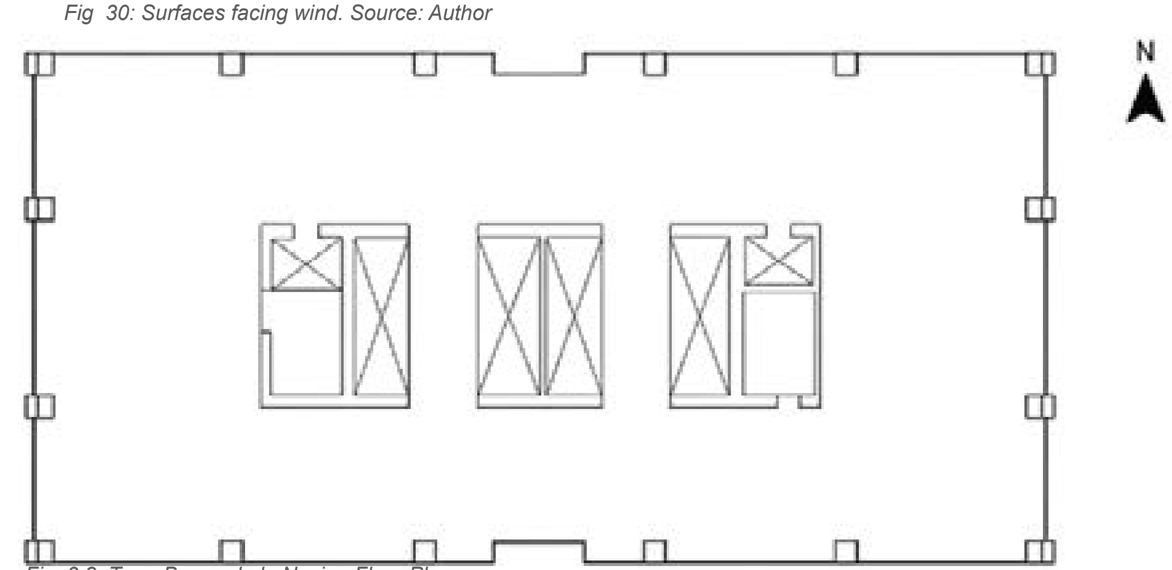


Fig 3.8: Torre Banco de la Nacion Floor Plan.

Fig 3.9: Analysis of a sigle mesh facade. Source: Illustration by the author, created with the assistance of ChatGPT.

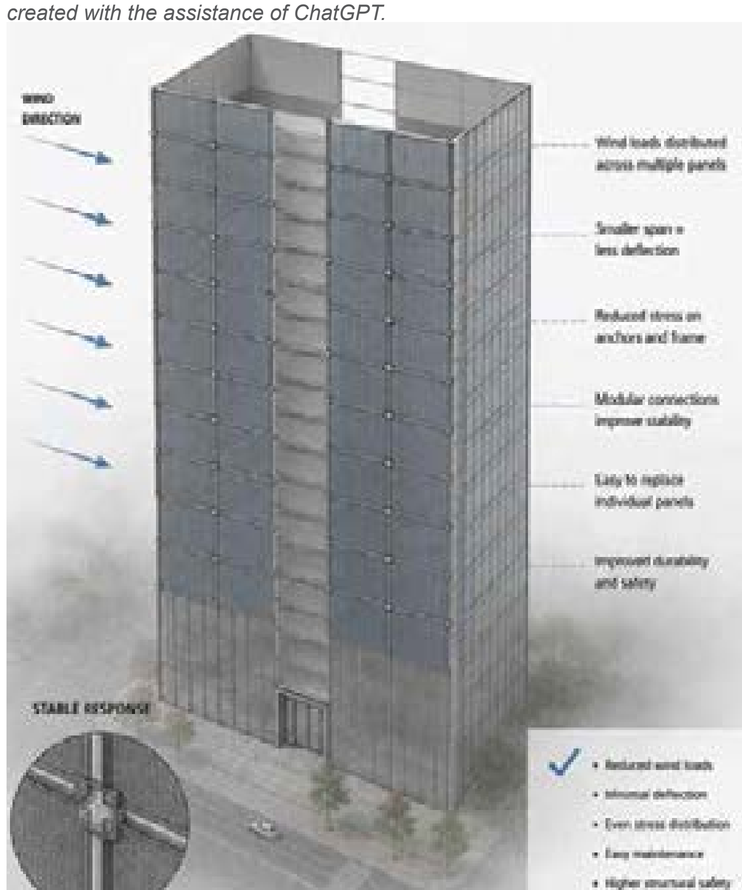


Fig 3.10: Proposed modular system. Source: Illustration by the author, created with the assistance of ChatGPT.

Facade Performance:

The design strategy begins by establishing the primary architectural framework of the tower and defining the façade as the interface between the building and its environment. To maximize atmospheric water collection, the fog-harvesting surfaces are oriented perpendicular to Lima's prevailing southeast winds. This orientation increases the interception of wind-driven fog originating from the Pacific coast, allowing the façade to capture and collect atmospheric moisture more effectively.

Initial investigations considered the use of large continuous mesh surfaces; however, the literature review identified several structural limitations associated with this approach. Large suspended mesh panels are subjected to significant wind pressures that can result in excessive deformation, increased stress at anchorage points, material fatigue, and potential system failure over time. These challenges become increasingly pronounced as collection surfaces grow in size.

To address these limitations, the proposed façade adopts a modular mesh system composed of smaller individual panels supported by a secondary steel structure. By subdividing the collection surface, wind loads are distributed more evenly across the façade, reducing stress concentrations and minimizing deformation caused by wind pressure. This strategy improves structural stability, increases durability, facilitates maintenance and replacement, and enhances the long-term performance of the fog-harvesting system. The modular approach also provides greater flexibility for integration within the existing building envelope while maintaining efficient atmospheric water collection.

Modular Analysis:

Design Iteration 01: Pyramidal Module

The first design iteration explores a three-dimensional pyramidal module generated by pulling the center of the mesh outward from the façade plane. This strategy increases the overall collection surface area while creating multiple angled faces capable of intercepting fog from different directions. The geometry is specifically designed to maximize exposure to Lima's prevailing southeast winds, increasing the potential for atmospheric moisture capture.

In addition to improving environmental performance, the pyramidal configuration enhances structural behavior through triangulation. The three-dimensional form increases rigidity, distributes wind loads more efficiently throughout the frame, and reduces deformation commonly associated with flat mesh surfaces. The modular nature of the system also simplifies maintenance and replacement while creating a consistent architectural language across the building façade. Through this approach, environmental performance becomes an integral component of the architectural expression.

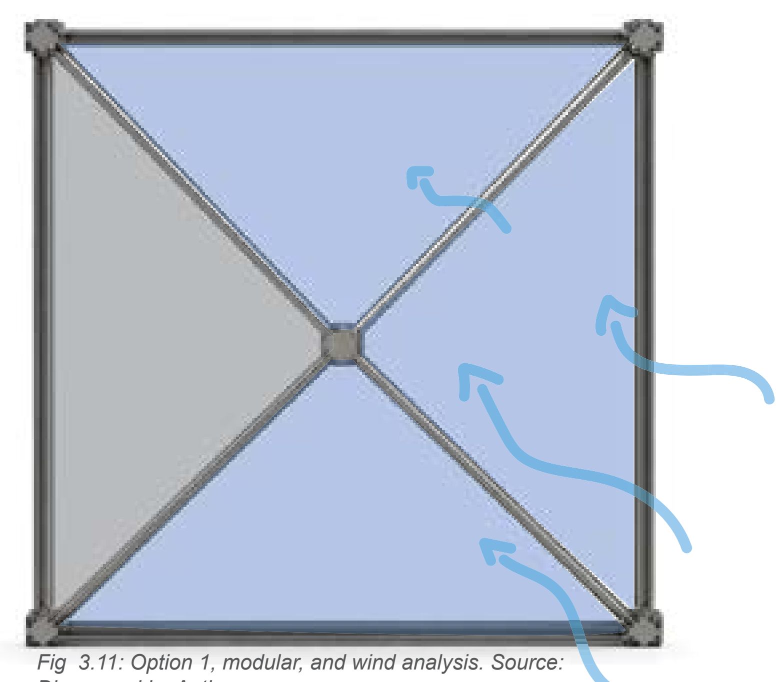


Fig 3.11: Option 1, modular, and wind analysis. Source: Diagramed by Author.

Fig 3.12: option 1 rendering

Design Iteration 02: Angled Module

The second design iteration investigates a simpler module that is rotated toward the southeast, directly aligning the collection surface with the prevailing wind direction. By positioning the mesh perpendicular to incoming airflow, the design maximizes direct fog interception and increases exposure to atmospheric moisture. Unlike the pyramidal module, which relies on increased surface area and multidirectional capture, the angled module prioritizes aerodynamic efficiency and directional responsiveness.

While the overall collection surface area is smaller than that of the pyramidal configuration, the module benefits from a more direct relationship with prevailing wind patterns. This approach creates a façade expression driven by climatic performance, where the orientation of each module responds specifically to local environmental conditions. The resulting system emphasizes simplicity, aerodynamic alignment, and efficient integration with the existing building envelope.

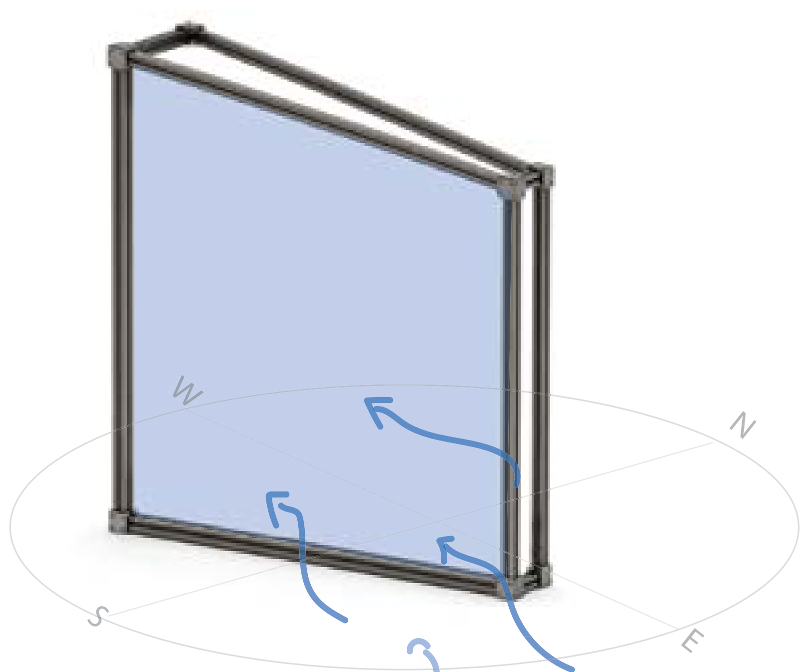


Fig 3.13: Option 2, modular, and wind analysis. Source: Diagramed by Author.

Fig 3.14: option 2 rendering

Mesh Analysis:

Three mesh materials were evaluated for the proposed fog-harvesting façade: Raschel mesh, stainless-steel mesh, and nylon mesh. The selection process considered factors such as collection efficiency, aerodynamic performance, structural behavior, durability, availability, and suitability for implementation in Lima.

Among the three options, Raschel mesh was selected as the most appropriate material due to its proven performance in existing fog-harvesting systems and its widespread use in Large Fog Collectors (LFCs). Its knitted structure provides an effective balance between fog interception and airflow, allowing for efficient water collection while reducing wind pressure on the system. In addition, Raschel mesh is readily available in Peru, making it a practical and cost-effective solution for installation, maintenance, and future replacement.

While stainless-steel mesh offers greater strength and durability, its increased weight and lower aerodynamic performance make it less suitable for large-scale façade applications. Nylon mesh was also considered; however, its limited availability in Peru reduces its feasibility for long-term implementation. Based on these factors, Raschel mesh was selected as the primary collection material for the proposed fog-harvesting façade.

Criteria	Raschel Mesh	Stainless Steel Mesh	Nylon Mesh
Shade Coefficient (G)	0.35	0.25	0.50
Shading Performance	Medium to high shading (typically 70%–90% depending on openness)	Medium shading (depends on wire diameter and spacing)	High shading (efficient for solar control and protection)
Drag Coefficient (Cd)	1.45	1.18	0.75
Wind Performance	High wind resistance due to light and porous structure	High wind resistance due to rigidity and weight	Lower wind resistance due to flexible and lightweight material
Durability	3–5 years	15–30 years	5–8 years
Accessibility in Lima, Peru	High	Medium	Low–Medium

Fig 3.15: Comparative evaluation of Raschel mesh, stainless steel mesh, and nylon mesh based on fog-harvesting performance, wind resistance, durability, and accessibility in Lima, Peru. Source: Illustration by the author, created with the assistance of ChatGPT.

Grasshoper Script to Analyse SE Wind Facing Surfaces of the Proposed Module:

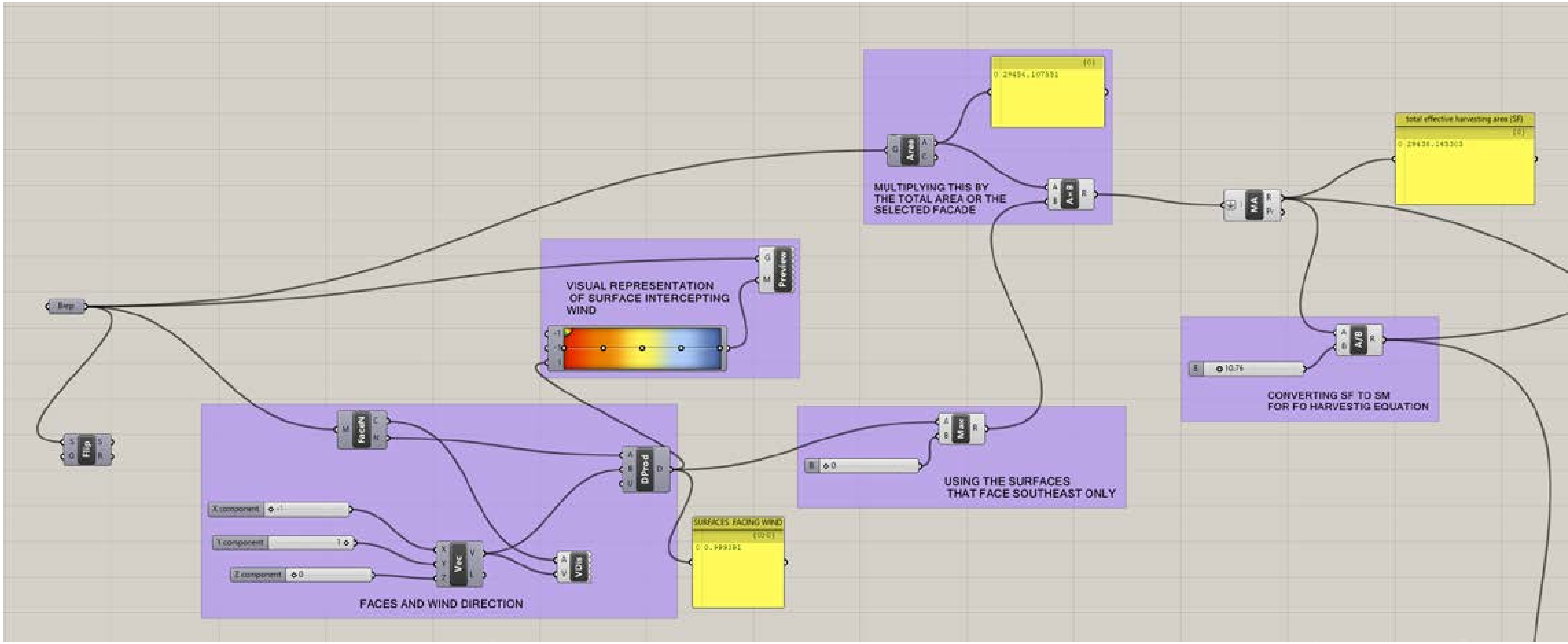


Fig 3.16: Grasshopper script analysing SE winf facing surfaces.

A Grasshopper script was developed to analyze the water-harvesting potential of each southeast-facing surface within the modular façade system. Since Lima's prevailing winds originate from the southeast, only surfaces oriented toward this direction were evaluated for fog collection. The script identifies the exposed collection areas of each module and calculates their potential water yield based on orientation, surface area, and environmental conditions. This analysis was used to compare different module geometries and determine which configuration maximized atmospheric water collection while maintaining architectural and structural feasibility.

AMARU Model

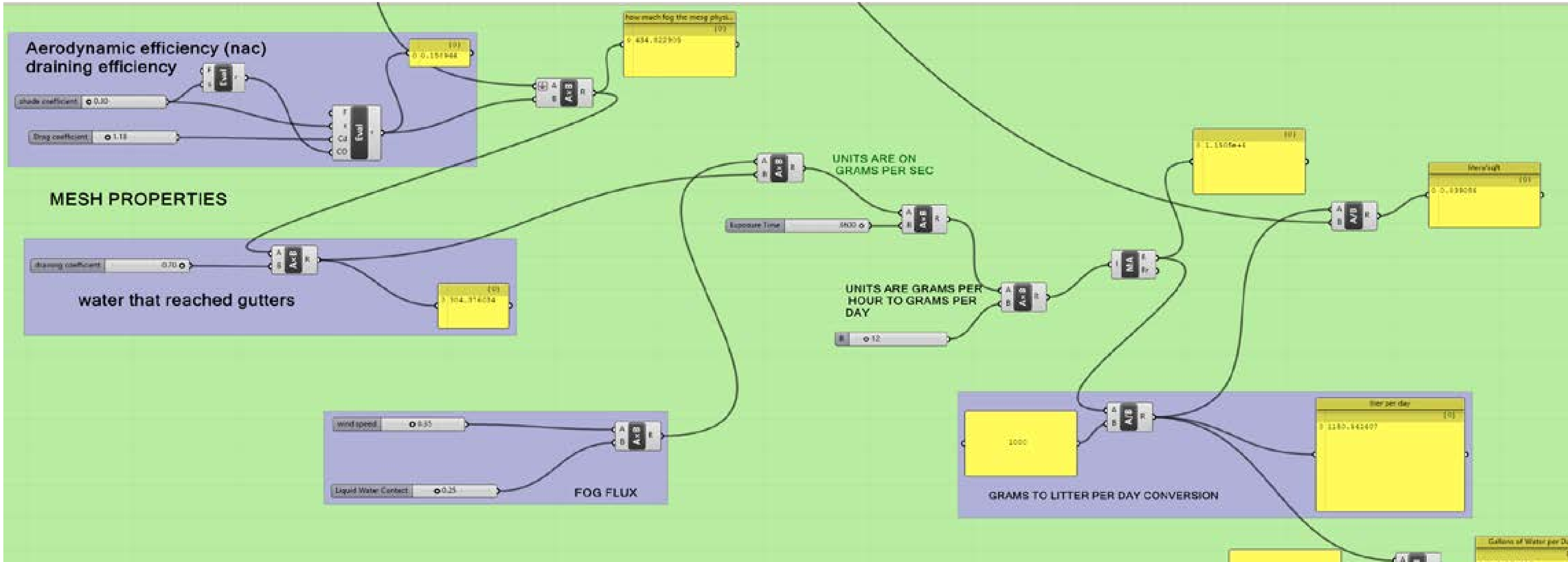


Fig 3.18: Grasshopper script analysing the total amount of water arvested per facade.

To evaluate the water-harvesting potential of the proposed façade system, a parametric workflow was developed using Grasshopper. The model analyzes the orientation and surface area of each fog-harvesting module to estimate the amount of water that can be collected under Lima's climatic conditions. Because the city's prevailing winds originate from the southeast, the script first identifies and isolates only the mesh surfaces that face this direction. These surfaces represent the areas most likely to intercept fog and capture atmospheric moisture.

The selected collection surfaces are then processed through the primary water-harvesting model, referred to as the Amaru Model. This model estimates water production by combining geometric and environmental parameters derived from the literature review and climate analysis. The effective collection area of each module is multiplied by the aerodynamic collection efficiency of the Raschel mesh, accounting for the percentage of fog droplets that successfully collide with and are retained by the collection surface. This value is then combined with the estimated fog flux, which represents the amount of atmospheric moisture transported across the façade by prevailing winds.

The resulting calculations generate an estimate of the volume of water collected by each individual module and façade orientation. These values are aggregated and converted into gallons per day, allowing the overall performance of the system to be evaluated and compared across different design iterations. Through this process, the model provides a quantitative method for assessing the relationship between façade geometry, environmental conditions, and water-harvesting performance.

The Amaru Model was used throughout the design process to compare alternative façade configurations and inform design decisions. By linking environmental data with parametric geometry, the workflow enabled the evaluation of multiple design options and helped identify the configuration with the greatest water-harvesting potential while maintaining architectural and structural feasibility.

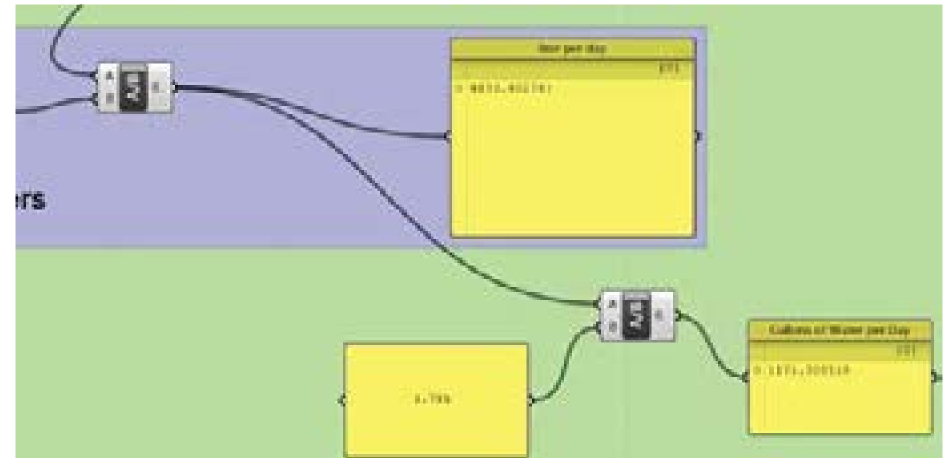
RESULTS:

Following the development of the first design iteration, the pyramidal module was evaluated using the Grasshopper water-harvesting model. The analysis estimated a total water collection capacity of approximately 3,640 gallons per day across the façade system. While the results demonstrated the potential of the design to harvest significant quantities of atmospheric moisture, the performance was lower than that of the second iteration.

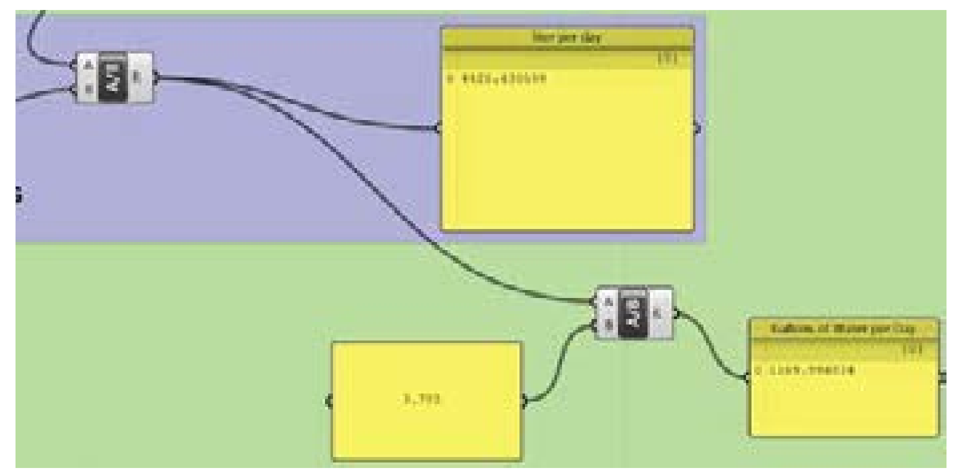
This outcome can be attributed to the geometry of the pyramidal module. Although the three-dimensional form increased the overall collection surface area and improved structural rigidity, not all surfaces were directly exposed to the prevailing southeast winds. As a result, portions of the mesh remained outside the primary path of fog-laden airflow, reducing the overall interception efficiency of the system. While some faces contributed to water collection, others had limited exposure to incoming fog and therefore produced lower yields.

The analysis revealed that maximizing surface area alone does not necessarily result in greater water collection performance. Surface orientation relative to prevailing wind direction plays a critical role in determining the effectiveness of fog interception. These findings informed the development and evaluation of the second design iteration, which prioritized direct alignment with the southeast winds in order to maximize exposure to atmospheric moisture and improve overall collection efficiency

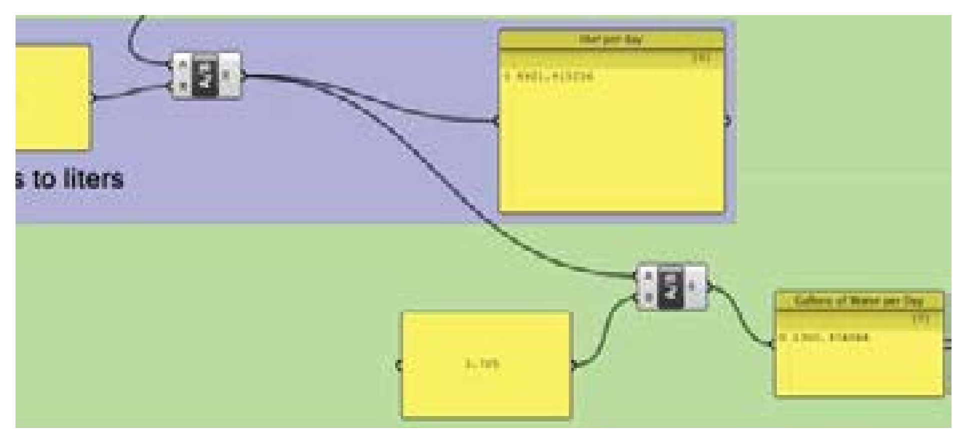
Pyramid Module Water Yield Analysis



South wall 1: 1171 gallons of water per day



South wall 2: 1169 gallons of water per day



East wall 2: 1300 gallons of water per day

Total amount of Water: 3640 galons of water a day

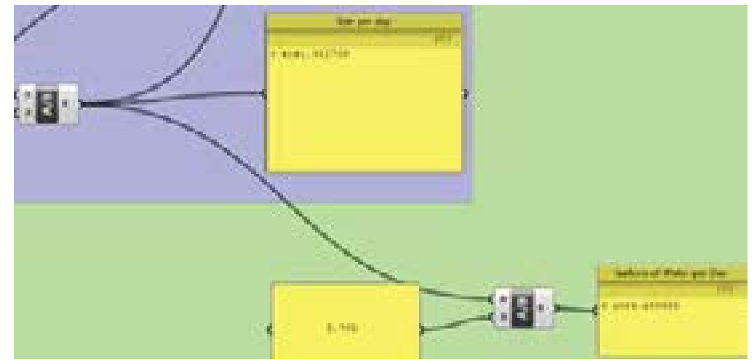
Fig 3.18, 19,20: describing the total amount of water harvested by facade.
Fig 3. 21: rendering of facade option

The second design iteration was also evaluated using the Grasshopper water-harvesting model and produced an estimated 3,719 gallons of water per day. This result exceeded the performance of the pyramidal module, which generated an estimated 3,640 gallons per day.

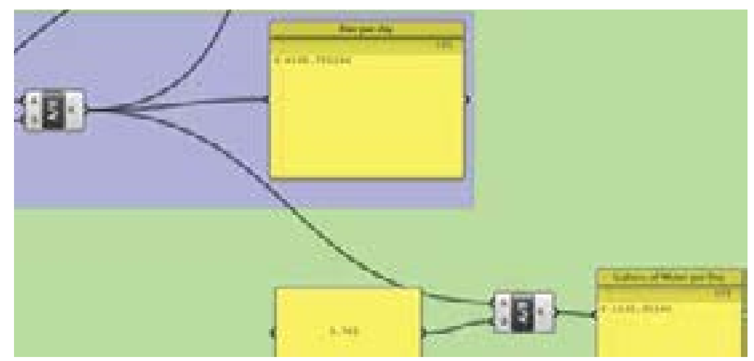
The improved performance of the second iteration can be attributed to the orientation of its collection surfaces. Unlike the pyramidal configuration, which included multiple faces with varying exposure to prevailing winds, the angled module positioned a greater proportion of its mesh surface perpendicular to Lima's southeast winds. This direct alignment increased the interception of fog-laden airflow and maximized the amount of atmospheric moisture captured by the system.

The results demonstrate the importance of surface orientation in fog-harvesting performance. While increased surface area can contribute to greater collection potential, the analysis suggests that surfaces oriented perpendicular to prevailing wind directions are more effective at intercepting fog and generating higher water yields. Among the two design options evaluated, the angled module produced the greatest volume of harvested water, making it the most effective configuration for atmospheric water collection. Based on these findings, the angled module was selected for further development due to its superior collection efficiency, higher water output, and stronger response to local climatic conditions.

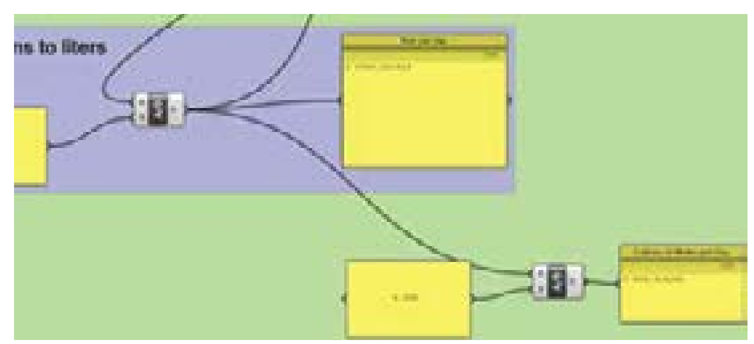
Angled Module Water Yield Analysis



South wall 1: 1094 gallons of water per day

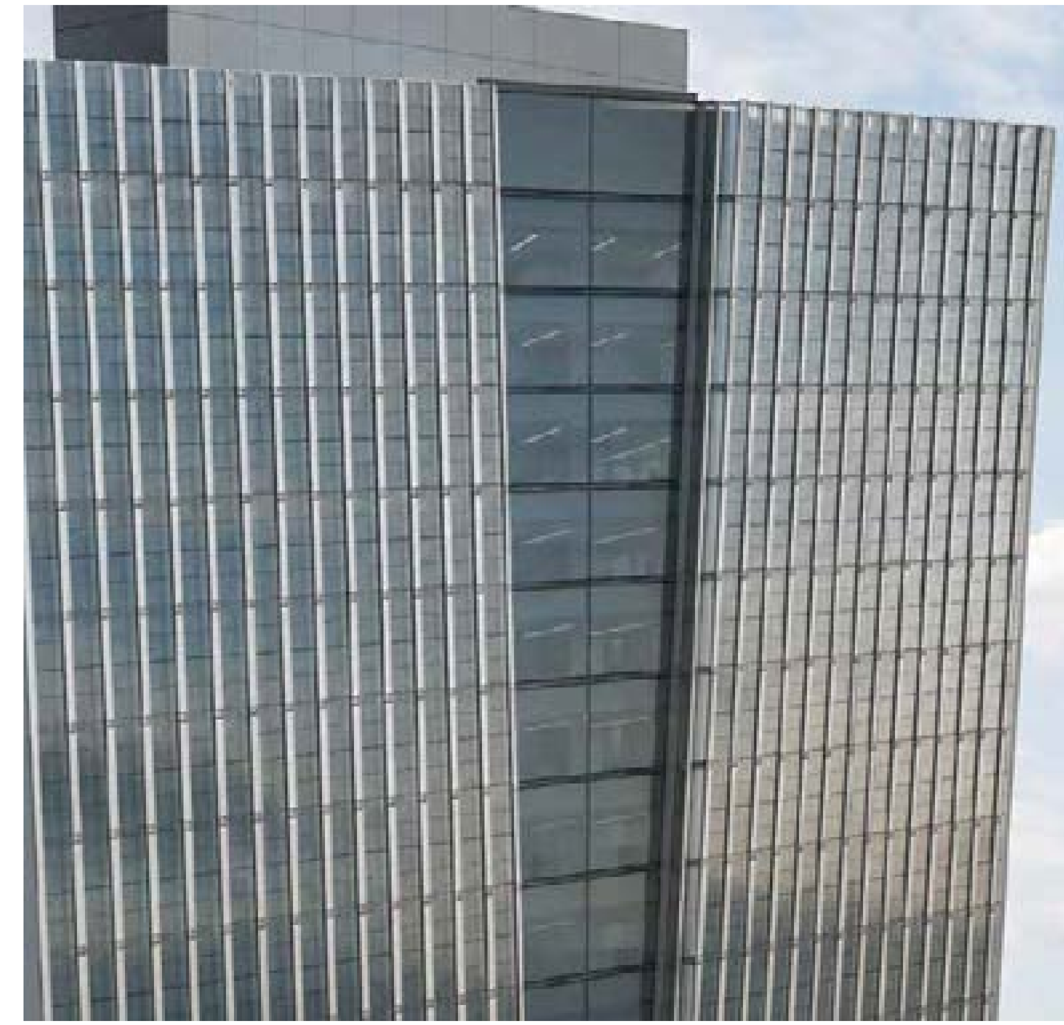


South wall 2: 1635 gallons of water per day



East wall 2: 990 gallons of water per day

Fig 3.22,23,24 describing the total amount of water harvested by facade.
Fig 3.25: rendering of facade option



Total amount of Water: 3719 galons of water a day

Water Channeling System:

The proposed design integrates water conveyance directly into the façade structure. Once moisture is collected by the Raschel mesh panels, the water is directed into a network of hollow steel tubes that serve a dual function as both structural members and drainage conduits.

Rather than introducing a separate piping system, the hollow steel framework channels the collected water downward through the façade and into storage reservoirs located in the building's basement. This integrated approach reduces the amount of additional infrastructure required on the building envelope while maintaining a clean and efficient architectural expression. By combining structural support and water conveyance within a single system, the design minimizes visual clutter, reduces material use, and improves overall system efficiency.

The collected water is ultimately stored in basement reservoirs where it can be retained for non-potable uses within the building. This strategy transforms the façade from a passive enclosure into an active environmental infrastructure capable of collecting, transporting, and storing atmospheric water while maintaining a high level of integration with the existing building structure.

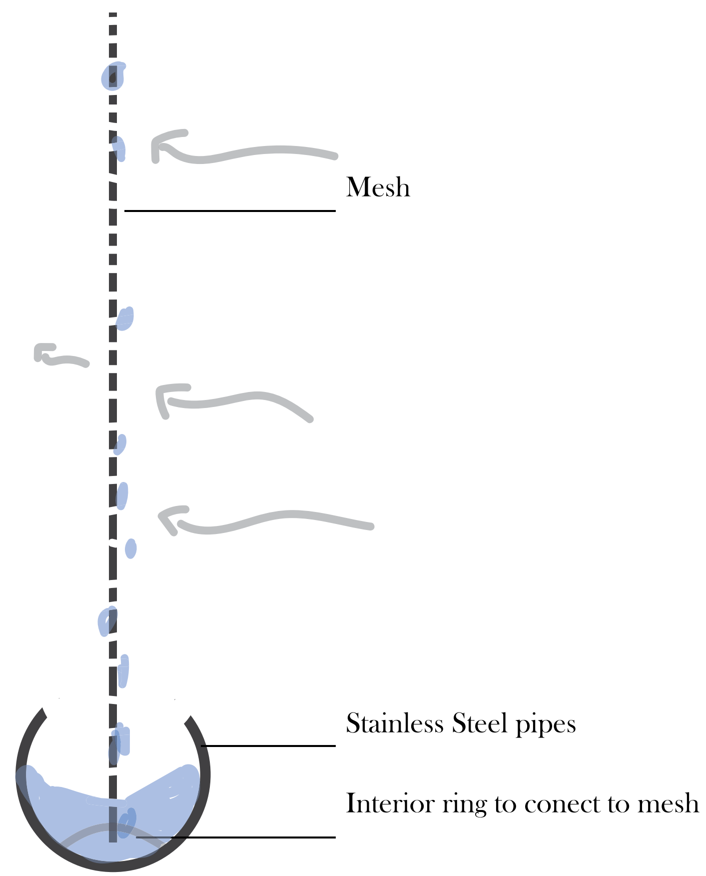


Fig 3.26 Section cut on mesh modula system, explainig mesh attachment.

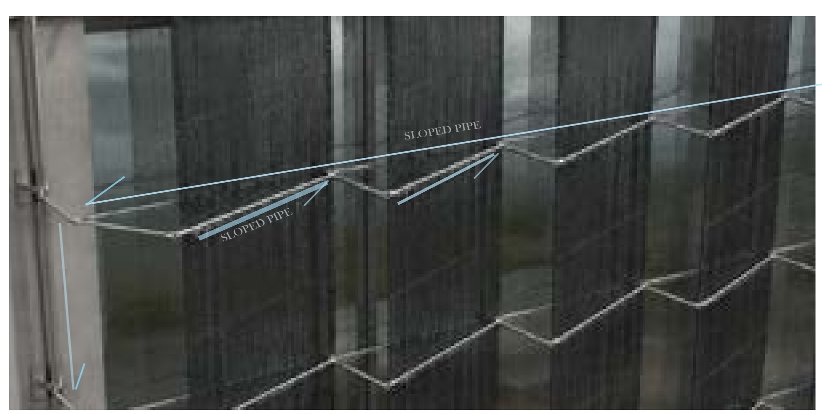


Fig 3.27: Water draingahe system, and piping directionality.

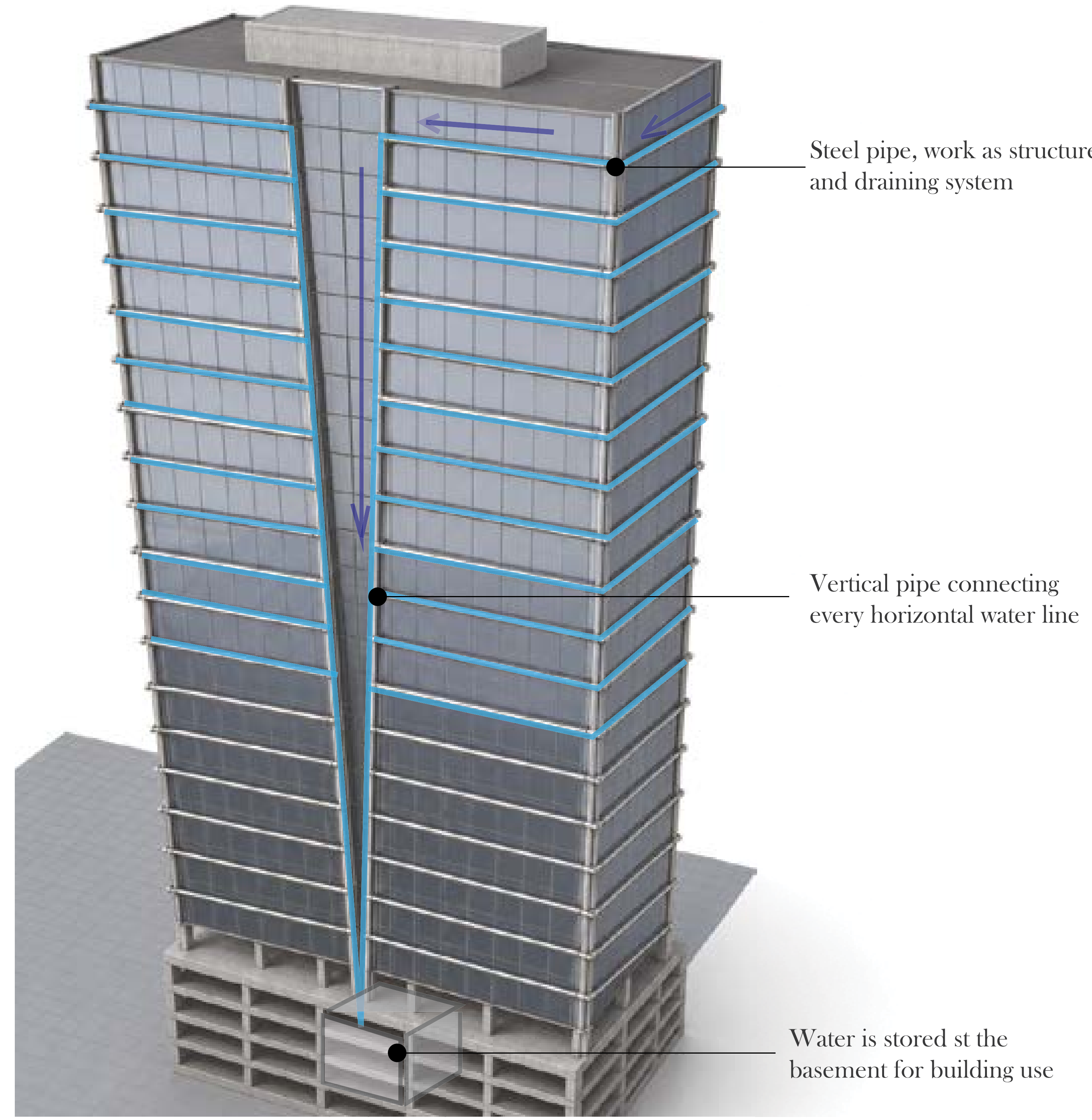


Fig 3.28: Overall building water drining and storing diagram.

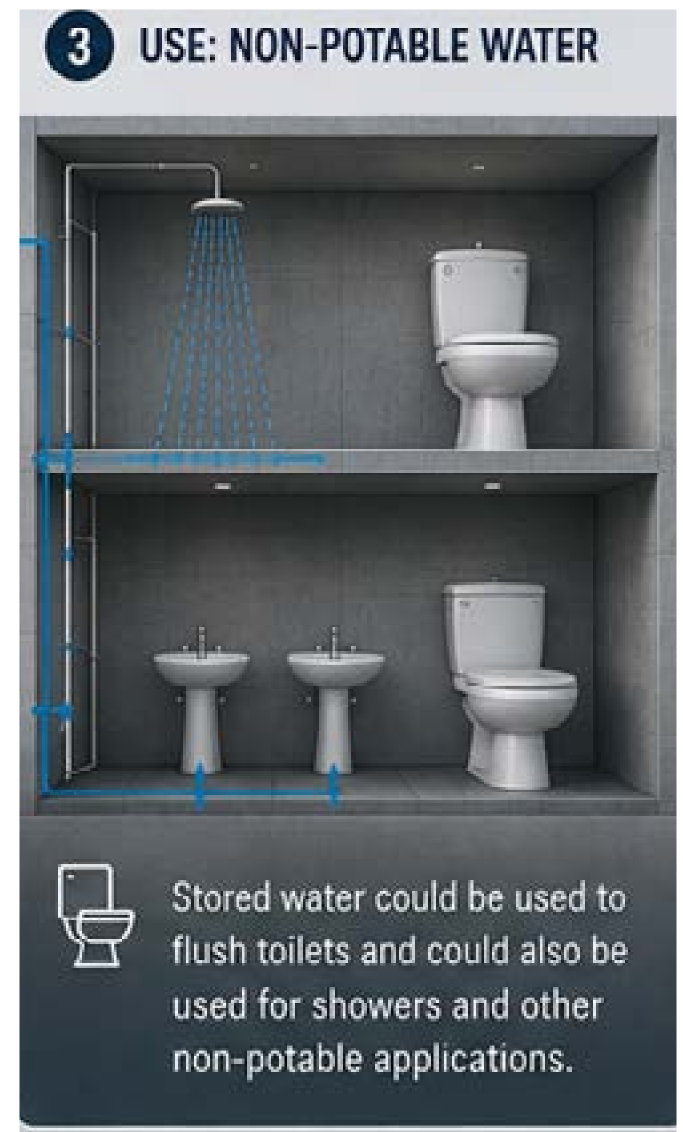
DESIGN OUTCOME:

Through this project, a building-integrated fog-harvesting system was developed and evaluated as a potential strategy for addressing water scarcity in Lima, Peru. By utilizing a passive collection system composed of Raschel mesh modules and an integrated drainage structure, the proposed façade was estimated to harvest approximately 3,719 gallons of water per day from atmospheric moisture.

This amount of water is significant when compared to the non-potable water demands of a typical office building. In Lima, office towers of a similar scale consume approximately 3,600 gallons of water per day for toilet flushing alone. The results suggest that the proposed system could potentially offset this demand by replacing potable municipal water with harvested fog water. By reducing the building's reliance on the city's freshwater supply, additional water resources could be redirected to areas of Lima where access to water remains limited.

Fig 4.1, 4.2, 4.3: illustration of the total of water harvested and its possible use. Source: Illustration by the author, created with the assistance of ChatGPT.

While this thesis focuses on a single building, the findings reveal the broader potential of atmospheric water harvesting within the urban environment. If one office tower can generate enough water to offset a substantial portion of its non-potable demand, the cumulative impact of implementing similar systems across multiple buildings could be considerable. Future research could expand this analysis to the district or city scale to evaluate the collective water-harvesting capacity of Lima's building stock and assess its contribution to urban water resilience. Such investigations could provide valuable insights into how architecture can play a more active role in resource generation and sustainable water management.



CONCLUSION:

Water scarcity is one of the most pressing environmental challenges facing cities around the world, and Lima presents a particularly unique condition. Despite its high levels of atmospheric humidity and persistent coastal fog, the city continues to rely heavily on limited freshwater resources to meet growing urban demands. This thesis explored the potential of atmospheric water harvesting as an alternative strategy for increasing water resilience within the urban environment.

Through a research-through-design methodology, the study examined the relationship between Lima's climatic conditions, fog-harvesting technologies, biomimetic principles, and architectural integration. By analyzing existing fog collection systems, material performance, and architectural precedents, a building-integrated fog-harvesting façade was developed for the Torre Banco de la Nación. The proposed system utilizes modular Raschel mesh panels supported by a secondary steel structure that simultaneously functions as a water conveyance network, creating an integrated environmental infrastructure within the building envelope.

Using a parametric Grasshopper workflow, the proposal was evaluated based on façade orientation, prevailing wind conditions, and fog collection efficiency. The final design was estimated to harvest approximately 3,719 gallons of water per day, an amount capable of offsetting the building's non-potable water demand for toilet flushing. These findings demonstrate that atmospheric moisture can serve as a valuable and underutilized water resource within Lima's urban context.

Beyond the scale of a single building, this thesis highlights the potential for architecture to move beyond its traditional role as a consumer of resources and instead become an active participant in their generation and management. The integration of fog-harvesting systems into existing buildings presents an opportunity to reduce dependence on municipal water infrastructure while contributing to broader goals of environmental resilience and sustainability.

While further research is needed to evaluate long-term performance, maintenance requirements, water quality, and urban-scale implementation, this project demonstrates that the atmosphere itself can become a source of water. As cities continue to face increasing environmental pressures, building-integrated resource harvesting systems offer a promising pathway toward more adaptive, resilient, and regenerative forms of architecture.

Fig 5.1: Interior redering on building looking at facade system.

BIBLIOGRAPHY:

- Ganguly, Auroop Ratan, and Ruth Linnaea Cahill. "Specialty Grand Challenge: Water and the Built Environment." Frontiers in Built Environment, vol. 10, 2024, article 1494360. Frontiers Media SA,https://www.zotero.org/yandira_thesis/collections/IP7MUMCB/items/RMXJSAIN/reader
- Dinar, Ariel, and Yacov Tsur. "Chapter 1 – The State of Water Resources and the Need for a Comprehensive Perspective." The Economics and Governance of Water Resources, Cambridge University Press, 2021, pp. 1–14. https://www.cambridge.org/core/books/abs/economics-of-water-resources/state-of-water-resources-and-the-need-for-a-comprehensive-perspective/13B3BE3C3CB8888F6056E5A7B4C1EFBB
- Tzanakakis, Vasileios A., Nikolaos V. Paranychianakis, and Andreas N. Angelakis. "Water Supply and Water Scarcity." Water, vol. 12, no. 9, 2020, article 2347. MDPI,
- Elshennawy, Abdullah A., Magdy Y. Abdelaal, Ahmed M. Hamed, and Mohamed M. Awad. "Evaluating Mesh Geometry and Shade Coefficient for Fog Harvesting Collectors." Water Resources Management, 2023, https://link.springer.com/article/10.1007/s11269-023-03644-4
- Pawar, Nikhil R., Suman S. Jain, and Smitha R. God. "Experimental Study of Fog Water Harvesting by Stainless Steel Mesh." International Journal of Scientific & Technology Research, vol. 6, no. 6, June 2017,
- Fernandez, Daniel M., et al. "Fog Water Collection Effectiveness: Mesh Intercomparisons." Atmospheric Research, vol. 151, 2015, pp. 131–144.
- Fessehaye, Mussie, et al. "Fog-Water Collection for Community Use." Renewable and Sustainable Energy Reviews, vol. 29, 2014, pp. 52–62. Elsevier,
- Drelich, Jaroslaw, Emil Chibowski, Dennis Desheng Meng, and Konrad Terpilowski. "Hydrophilic and Superhydrophilic Surfaces and Materials." Soft Matter, vol. 7, no. 21, 2011, pp. 9804–9828. Royal Society of Chemistry,
- Holmes, Robert, Juan de Dios Rivera, and Emilio de la Jara. "Large Fog Collectors: New Strategies for Collection Efficiency and Structural Response to Wind Pressure." Atmospheric Research, vol. 151, 2015, pp. 236–249. Elsevier
- Carvajal, Danilo, Luis Silva-Llanca, Dante Larraguibel, and Bastián González. "On the Aerodynamic Fog Collection Efficiency of Fog Water Collectors via Three-Dimensional Numerical Simulations." Atmospheric Research, vol. 245, 2020, article 105123. Elsevier https://doi.org/10.1016/j.atmosres.2020.105123
- Azeem, Musaddaq, et al. "Optimal Design of Multi-Layer Fog Collectors." Physics of Fluids, vol. 32, no. 8, 2020, article 083305. AIP Publishing, https://doi.org/10.1063/5.0011678.
- Schunk, Christian, et al. "Testing Water Yield, Efficiency of Different Meshes and Water Quality with a Novel Fog Collector for High Wind Speeds." Aerosol and Air Quality Research, vol. 18, 2018, pp. 240–253. https://doi.org/10.4209/aaqr.2016.12.0528.
- Schemenauer, Robert S., and Paul I. Joe. "The Collection Efficiency of a Massive Fog Collector." Atmospheric Research, vol. 24, no. 1–4, 1989, pp. 53–69. Elsevier, https://doi.org/10.1016/0169-8095(89)90036-7.
- Uvarani, Aka, and Aruna Kumar Behura. "Fog Harvesting Efficiency Analysis of Biomimicking Surfaces: A Review." Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 2024, pp. 1–23. SAGE Publications, https://doi.org/10.1177/09544089241230162.
- Caldas, Luis, et al. "Water Harvesting from Fog Using Building Envelopes: Part I." Water and Environment Journal, vol. 32, no. 4, 2018, pp. 570–581. Wiley, https://doi.org/10.1111/wej.12335.
- Gogoi, Bidyut Jyoti. "Water Scarcity: A Major Concern for Citizens." *International Journal of Civil Engineering and Technology*, vol. 10, no. 6, June 2019, pp. 43–53. IAEME Publication.
- "What Is La Garúa and Where Is It Found?" Biology Insights, 5 Jan. 2026, https://biologyinsights.com/what-is-la-garua-and-where-is-it-found/.

- Abbott, Hannah, and Celia Garcia. *Lima, Peru: A Case Study of Lima's Urban Water System*. ArcGIS StoryMaps, 30 July 2024, https://storymaps.arcgis.com/stories/a00e36c2327a4a4397592cc357bc22d5.
- "The Weather and Climate in Lima." LimaEasy, updated 17 July 2023, https://www.limaeasy.com/lima-guide/lima-information/the-weather-and-climate-in-lima-peru
- Ioris, Antonio A. R. "Scarcity, Neoliberalism and the 'Water Business' in Lima, Peru." *Human Geography*, vol. 5, no. 2, 2012, pp. 28–42. SAGE Publications, https://doi.org/10.1177/194277861200500207.
- Ioris, Antonio A. R. "The Geography of Multiple Scarcities: Urban Development and Water Problems in Lima, Peru." *Geoforum*, vol. 43, no. 3, May 2012, pp. 612–622. Elsevier, https://doi.org/10.1016/j.geoforum.2011.12.005.
- Lius, Vesa Olavi. *ALLFROMAIR® Addendum No. 5 (v3): Fog Integration*. Technical Disclosure Commons, 21 Apr. 2026, https://www.tdcommons.org/dpubs_series/9885.
- Castro, C., Merzthal, G., Veenhuizen, R. (2010). Integrated Urban Water Management in Lima, Peru: Building capacity for treatment and reuse of wastewater for green spaces and urban agriculture - A review of the SWITCH Lima project. IRC. https://es.ircwash.org/sites/default/files/lima_building_capacity_for_treatme-castro_et_al.pdf
- Weiss, N., Caillaux, Sánchez, C., V. & C., Solís, R., Alcázar, F., Durand, M., Cascón, E., Zevallos, J. (2015). Urban Water Supply in Peru. A perspective from the Academies of Sciences. (pp.474-503). Edition: 1. The Inter-American Network of Academies of Sciences (IANAS). https://ianas.org/wp-content/uploads/2020/08/uwc17.pdf
- Gobierno del Perú (GOB.pe).
- Aslan, D., Selçuk, S. A., & Mutlu Avinç, G. (2022). A biomimetic approach to water harvesting strategies: An architectural point of view. International Journal of Built Environment and Sustainability
-
- Caldas, L., Andaloro, A., Calafiore, G., Munechika, K., & Cabrini, S. (2018). Water harvesting from fog using building envelopes: Part I. Water and Environment Journal
-
- Hadba, L., Bitonto, M., Oliveira, M., Mendonça, P., Zanelli, A., & Silva, L. (2024). A nature-inspired green–blue solution: Incorporating a fog harvesting technique into urban green wall design. Sustainability
- Li, C., Ni, Z., & Li, Y. (2023). An application of bio-inspired superwetting surfaces: Water collection. In New Advances in Powder Technology. Intech