Financial Feasibility and Infrastructure Planning for Vertiport Operators

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Abstract

This capstone project developed a comprehensive business plan for implementing vertiports to support electric vertical takeoff and landing (eVTOL) operations in Brazil. The rapid advancement of urban air mobility technologies requires infrastructure accommodating these innovative transportation methods. The study examined the operational costs and mandatory fees needed to establish financially viable vertiports, meticulously considering Brazil's regulatory, economic, and geographic landscape. This research thoroughly examined the financial feasibility and logistical requirements of eVTOL infrastructure to bridge the existing gaps in understanding. Key research questions include: What are the primary cost drivers for vertiport implementation? What are the regulatory and operational challenges that require immediate attention? How can vertiports be integrated into existing urban transport systems? The study utilized a mixed-methods approach, combining quantitative analysis of cost structures with qualitative insights from industry experts. This research contributes to the conceptual framework of urban air mobility by providing actionable insights for policymakers, investors, and urban planners. Ultimately, the project aimed to support the sustainable and efficient development of eVTOL operations in Brazil.

Keywords: eVTOL, vertiports, urban air mobility, aviation, infrastructure

Introduction

The transportation sector is rapidly transforming through Urban Air Mobility (UAM), driven by electric vertical take-off and landing (eVTOL) aircraft. Concerning this rapid change, this capstone focuses on the vertiport business in Brazil and provides a comprehensive business plan that considers operating costs, regulatory framework, and commercial viability. The study looks at specific regulations in Brazil related to economic activities and geography to assess the potential for expanding eVTOL operations supported by vertiports. Despite the growing interest in UAM, further research is critical to business planning for vertiport development in Brazil.

By examining cost factors, regulatory barriers, and integration plans while considering the Brazilian scenario, this study aimed to fill these gaps. In addition, it presents a business plan for a vertiport operator based mainly on examining issues related to the charging of electric vehicles and the possibilities for business expansion. The results of this business plan include the financial needs for the vertiports, fee estimates, and a possible profitability rate, among others. The analysis encompasses factors such as delineating the geographic demand for eVTOL passenger services, assessing the necessary infrastructure, and evaluating the electrical power supply requirements.

This proposed business plan used qualitative data and quantitative insights to devise viable strategies for integrating eVTOL aircraft within urban areas in Brazil. Through quantitative analysis, we prioritized operational efficiency and cost and addressed stakeholder views and regulatory hurdles through qualitative research. The research compiled information so that vertiports are economically viable and socially acceptable for implementing eVTOLs, which enables advances in urban transport.

Problem Statement

The rapid advancement of Advanced Air Mobility (AAM) technologies is transforming the transportation sector globally. With its unique regulatory, economic, and geographic landscape, Brazil presents opportunities and challenges for implementing vertiports to support eVTOL operations (Andrade et al., 2022). Despite the growing interest and potential benefits of electric aircraft in urban environments, more research regarding vertiport development's business planning and feasibility was needed (Cox, 2023).

Project Goals

The primary goal of this study was to create a detailed business plan that meticulously examined the financial feasibility and logistical requirements necessary for establishing vertiports in Brazil. It included a comprehensive investigation into operational costs, mandatory fees, and regulatory requirements, ensuring that vertiports are commercially viable and operationally sustainable. A significant component of this project is the identification and analysis of primary cost drivers for vertiport implementation, providing actionable insights for policymakers, investors, and urban planners. Additionally, the study addressed regulatory and operational challenges that require immediate attention and devises strategies to integrate vertiports seamlessly into existing urban transport systems. This research comprehensively examined Brazil's regulatory framework and economic landscape to identify barriers and opportunities that inform the development of a robust eVTOL business plan. The research results support the sustainable and efficient growth of eVTOL operations in Brazil.

Project Scope

The scope of this capstone project was to ensure a focused exploration of eVTOL for Brazil. We assessed the financial feasibility and infrastructure planning necessary to implement vertiports in Brazil. We provide a comprehensive business plan that addresses the specific needs and challenges of establishing eVTOL operations in country.

Within the Boundaries of the Study

The focus of the study was on financial feasibility and operational costs of vertiports in Brazil. Include is a detailed examination of the cost structures involved in vertiport development, encompassing construction, maintenance, and operational expenses. The a cost analysis provides a thorough financial breakdown and feasibility assessment, essential for determining the economic viability of vertiports in Brazil.

A critical component of this study was examining Brazil's regulatory and economic landscape. The examination involved analyzing the specific regulatory framework governing urban air mobility and identifying potential barriers and opportunities for vertiport development. The investigation showed actionable insights that can assist policymakers, investors, and urban planners in making informed decisions regarding the implementation of vertiports by understanding regulatory requirements.

Additionally, the project developed integration plans for eVTOL operations within existing urban transport systems. It includes evaluating the geographic demand for eVTOL passenger services and assessing the necessary infrastructure, such as electrical power supply requirements. By devising viable strategies for integrating eVTOL aircraft into urban areas, the study seeks to ensure that vertiports are economically and socially acceptable.

Stakeholders, like industry experts, were engaged in the research and offered qualitative insights through interviews and consultations. The qualitative research complemented the quantitative analysis, providing a balanced perspective considering operational efficiency and regulatory compliance. The study comprehensively addressed stakeholder views and regulatory hurdles to investigate broader implications and challenges of vertiport implementation.

Outside the Boundaries of the Study

The study did not delve into areas outside its primary scope, such as the detailed technical design of eVTOL aircraft, which is beyond its purview. While we considered the operational requirements of eVTOLs, we did not engage in the technical intricacies of aircraft design and development. Similarly, we only conducted global regulatory comparisons within the context of Brazil, focusing instead on Brazil's specific regulatory framework governing urban air mobility, with references to international best practices and standards.

Our capstone project delivered a focused, detailed, and impactful analysis of Brazil's financial feasibility and infrastructure planning required for vertiport implementation. While environmental sustainability is essential, the study does not include long-term environmental impact assessments beyond the initial feasibility and operational phases. Instead, it concentrated on the financial and logistical aspects to ensure the vertiport's initial implementation was feasible and efficient. The findings contribute significantly to the sustainable and efficient development of eVTOL operations, supporting the broader goals of urban mobility transformation and environmental sustainability.

Definition of Terms

This section clarifies specific terms used throughout the project. Determining these terms ensures a common understanding, crucial for accurately interpreting the research and its findings.

Advanced Air Mobility (AAM) is a concept that encompasses new and innovative air transportation systems, including eVTOLs, designed to integrate safely and efficiently with existing airspace systems, transforming urban, suburban, and regional mobility.

Air Traffic Management (ATM) is the coordination and management of aircraft movement in airspace and at airports, ensuring safe and efficient operations. ATMs must evolve to accommodate increased traffic from eVTOL operations in urban environments.

Aviation Security (AVSEC): Combination of measures and human and material resources intended to safeguard civil aviation against acts of unlawful interference.

Cost of Available Seat Kilometer (CASK): It is an indicator to measure the unit cost expressed in cash value to operate each seat for every kilometer. The lower the CASK value would mean that it's easier to earn revenue.

Department of Airspace Control (DECEA): A Brazilian government agency responsible for managing and controlling air traffic in Brazilian airspace, including integrating new aviation technologies such as eVTOLs.

Electric vertical take-off and landing (eVTOL): Aircraft that can take off and land vertically using electric power, representing a key element in the future of urban air mobility with the potential to reduce urban traffic congestion and environmental impact.

European Union Aviation Safety Agency (EASA): European agency responsible for civil aviation, which includes the certification, regulation, and monitoring of aircraft, including eVTOL, and their operations in Europe.

Federal Aviation Administration (FAA): The US government agency responsible for regulating all aspects of civil aviation, including the certification and oversight of eVTOL aircraft and vertiport operations.

Helipads and heliports: Existing infrastructure used for helicopter operations, which can be adapted for using eVTOLs.

National Civil Aviation Agency (ANAC): The regulatory body in Brazil responsible for overseeing civil aviation activities, including the certification and operation of eVTOL aircraft and vertiports.

Regional Air Mobility (RAM): A segment of Advanced Air Mobility focused on using electric or hybrid-electric aircraft for regional transportation, typically over distances more significant than those covered by Urban Air Mobility (UAM).

Type Certification: An approval issued by aviation authorities such as the ANAC, FAA, or EASA, certifying that a specific model of an aircraft meets the necessary safety and regulatory requirements.

Unmanned aircraft system (UAS): An aircraft without a human pilot on board, controlled remotely or autonomously, commonly called a drone.

Urban Air Mobility (UAM): A subset of Advanced Air Mobility, UAM focuses on using eVTOLs and other small aircraft for short-haul air transportation in urban areas. It intends to relieve traffic congestion and offer faster travel options in densely populated cities.

Vertiport: A dedicated facility for taking off, landing, and recharging eVTOL aircraft. Vertiports can be integrated into existing or newly built urban environments to support the growing urban air mobility ecosystem.

Literature Review

A technological revolution is underway with advanced, dense, and safer battery technology (Singh, 2024). A new aircraft type is under development based on this new battery technology (O'Brien et al., 2024). The eVTOL aircraft promises to establish a brand-new market: scalable urban air mobility in cities worldwide. However, it is essential to remember that batteries were invented over two hundred years ago. Alessandro Volta used simple components, such as strips of copper, cardboard, zinc, and separators made from damp leather. With these, he developed the first battery in history (Wilcox, 2023). Since their original design, batteries had significant advancements over the past few decades, evolving into highly sophisticated technology. No longer just essential components in smartphones and laptops, batteries have become indispensable to modern life.

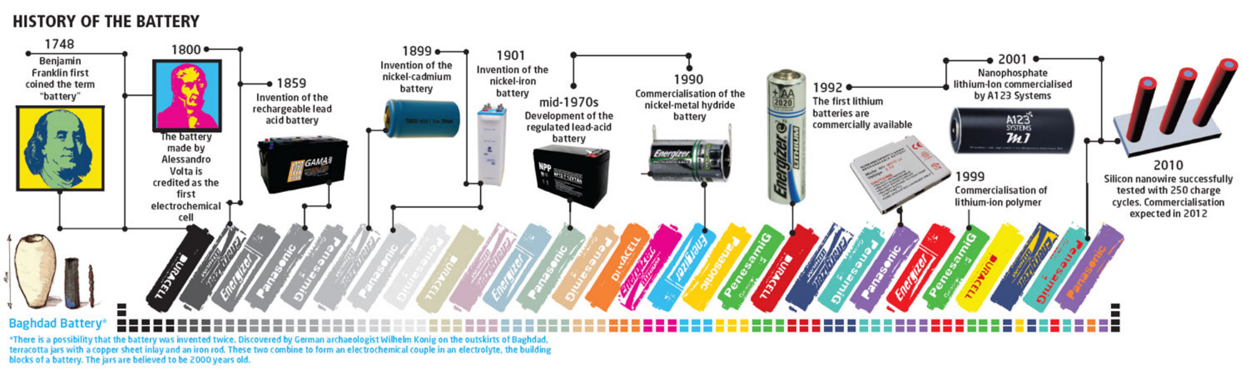
However, the development of a commercially viable lithium-ion battery is relatively recent. In 1979, researchers John B. Goodenough and Koichi Mizushima developed the first rechargeable lithium cell (Mahmud et al., 2022). According to Vieira et al. (2019), this innovation was crucial to the success of the lithium-ion battery. Its rechargeability became a fundamental requirement for battery-powered electric mobility. Research and development in battery technology have been driven by alarming global warming indicators and the decarbonization agreements made by various countries (Khan, 2024). In this context, numerous startups emerged in the last decade to provide products that do not rely on oil and have zero CO2 emissions (United Nations, 2024). Ramos and Ruiz-Gálvez (2024) reported that this shift significantly accelerated the development of batteries. The energy transition in the industry, mainly in the automotive sector, played a significant role in this acceleration.

Batteries are crucial in the millions of electric vehicles (EVs) sold annually. In the last decade, the average battery costs have decreased by 90%, driven by advancements in battery chemistry and manufacturing processes (International Energy Agency, 2024). Khan (2024) observed that lithium-ion batteries are the cornerstone of modern economies. They have revolutionized electronic devices and electric mobility and are increasingly being integrated into power systems.

Rashid (2024) reported that the advancement of battery technology has fueled significant investments. Specific energy densities exceeding 100 kWh have driven this progress. These advancements have propelled investments in a sector once considered science fiction: electric vertical takeoff and landing aircraft (eVTOLs). Utilizing battery packs like those in electric vehicles but with higher specific densities and specialized configurations to support the energy demands during takeoff and landing, several electric aircraft startups have emerged (Holden & Goel, 2016). Leading companies in this space include Joby, Lilium, Vertical Aerospace, Eve Air Mobility, Archer, and Beta Technologies.

Figure 1

History Of Batteries: A Timeline (Bobby, 2014).



The aircraft under development are designed for various missions, such as cargo and passenger transport. Operational costs are expected to be around five times lower than those of helicopters. Additionally, these eVTOLs promise enhanced operational safety due to motor redundancy. However, the viability of this emerging industry depends on comprehensive ecosystem development. This involves manufacturers, airlines, aviation authorities, air traffic control, and vertiport operators.

Helicopters have long been a critical element of vertical flight technology. However, they need to meet the evolving demands of future urban and regional air mobility (McKinsey &

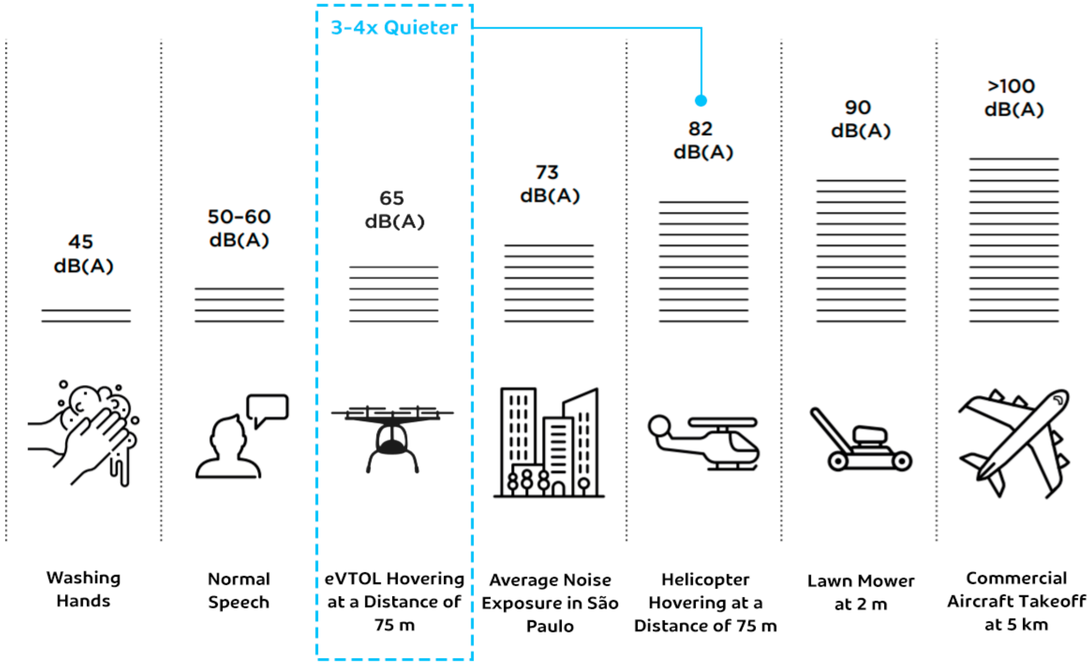
Company, 2022). These limitations include high noise levels, substantial operating costs, and reduced flexibility. As a result, helicopters are less suitable for widespread urban use compared to eVTOL aircraft, which are better placed to meet the challenges of urban and regional air mobility.

The eVTOLs are significantly quieter than helicopters, a crucial factor in urban areas where noise pollution is a significant concern. As Ale-Ahmad and Mahmassani (2022) mention, eVTOLs are four times quieter than helicopters, making them much more compatible with dense, noise-sensitive city environments. This substantial noise reduction enhances the quality of life for urban residents. It also opens more opportunities for integrating air mobility into city infrastructure without causing significant disruptions.

Moreover, the economic advantages of eVTOLs over helicopters are significant. Helicopters are notoriously expensive to operate in terms of fuel consumption and maintenance. eVTOLs, benefiting from electric propulsion systems, drastically reduce operational costs by being ten times cheaper, as mentioned by Ale-Ahmad and Mahmassani (2022). This makes eVTOLs a viable option for regular urban use, where cost-efficiency is critical for operators and passengers. The lower operational costs also translate into more affordable fares for passengers, which could significantly broaden the market for UAM services.

Figure 2

Noise Emissions Comparison (Viola & Dyment, 2022).



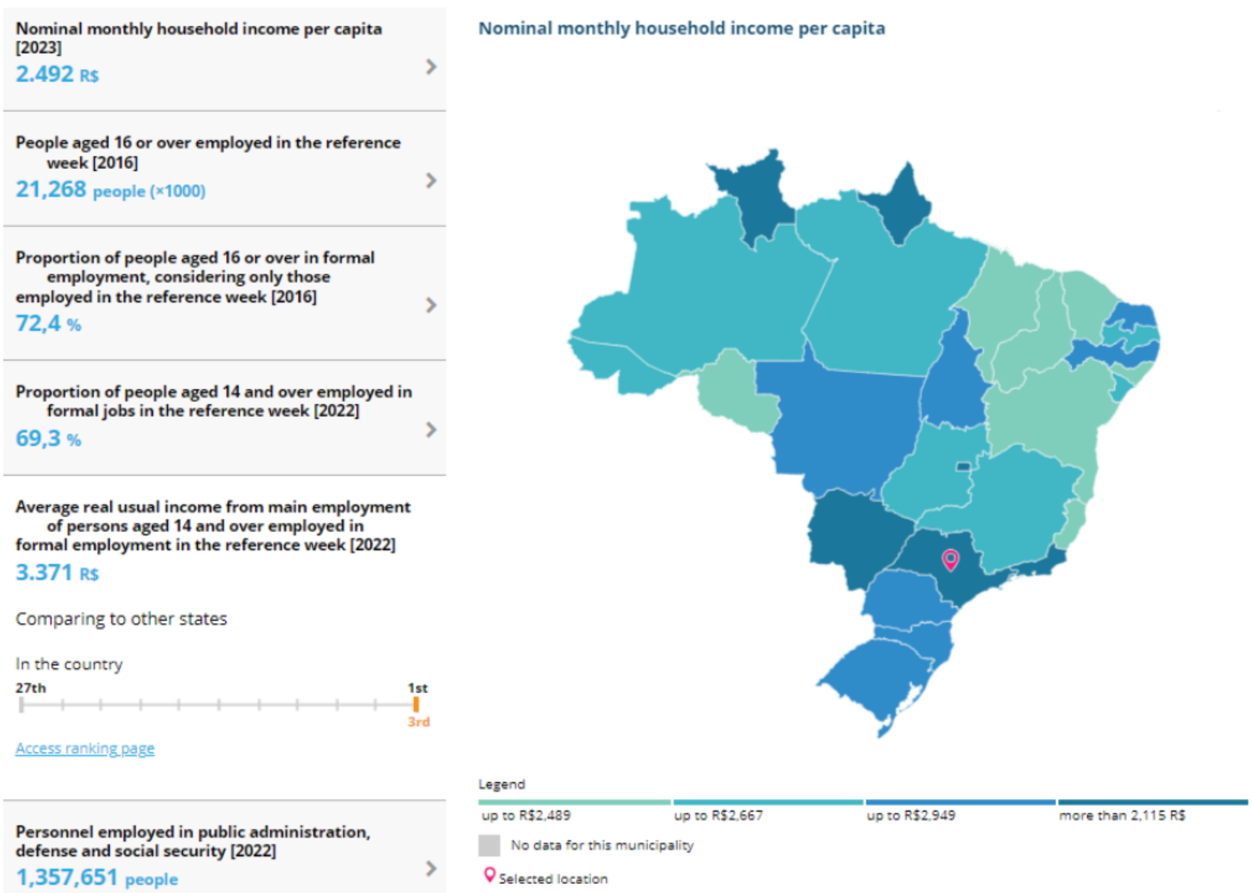
In addition, eVTOLs bring significant advancements in safety and technological innovation, such as lower noise emissions as shown in Figure 2. The development of eVTOLs is sustained by rigorous safety standards to ensure urban reliability. Extensive research and development efforts ensure that eVTOLs are efficient and safe for widespread use (Aerospace America, 2020). This focus on safety is the industry trend in gaining public trust and regulatory approval. Another advantage of eVTOLs is their built-in propulsor redundancy. Unlike helicopters, which rely on a single rotor system, eVTOLs utilize multiple distributed electric propulsion.

The environmental impact of eVTOLs is significantly lower than that of helicopters. eVTOLs use electric propulsion, which eliminates emissions during flight, aligning with global efforts to reduce carbon footprints in urban areas. This environmental advantage is increasingly important as cities worldwide seek to adopt greener technologies and reduce their reliance on fossil fuels.

São Paulo's dense urban landscape and heavy traffic congestion create a pressing need for innovative transportation solutions. As the largest economy in Latin America, São Paulo has the highest global congestion of helicopter operations (Brähler & Flörke, 2011). In this context, eVTOLs can alleviate traffic congestion by providing a more efficient and direct mode of travel, particularly for shorter distances within the city. Their ability to take off and land vertically eliminates the need for traditional runways. This allows them to operate from designated vertiports on rooftops, parking lots, or other suitable urban spaces.

Figure 3

Economical São Paulo State Overview (IBGE, 2023).



The city's commitment to sustainability aligns well with the environmental benefits of eVTOL technology (GEF, 2019). Electric propulsion systems reduce emissions of greenhouse gasses and air pollutants, contributing to cleaner air and a healthier environment. Additionally, eVTOLs can operate on renewable energy sources, further enhancing their sustainability credentials. The eVTOL embracement can demonstrate leadership in sustainable urban development. It can also position itself as a global model for green transportation by significantly reducing travel times and improving accessibility. This, in turn, reduces the number of private vehicles.

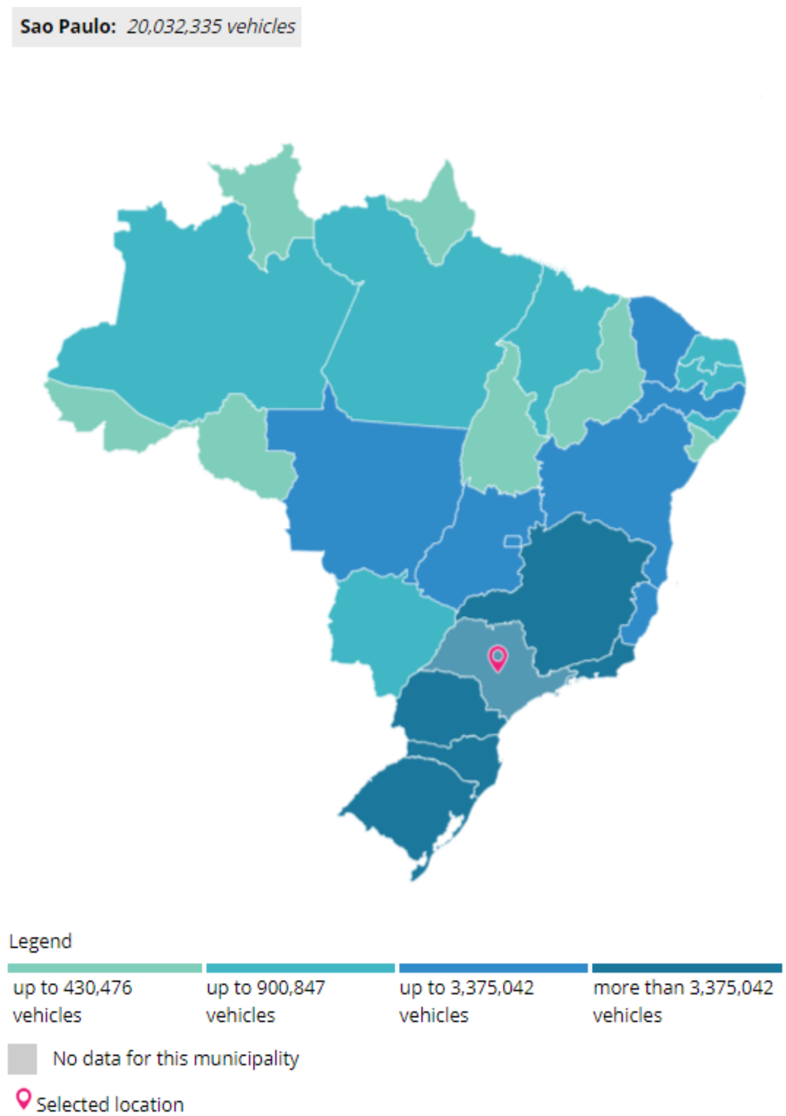
Furthermore, São Paulo's strong economic base and entrepreneurial ecosystem provide a favorable eVTOL development and deployment. The city's thriving technology sector and supportive regulatory framework can attract investment and foster innovation in this emerging field. Collaborations between industry, academia, and government can accelerate the development of eVTOL infrastructure, operational procedures, and safety standards.

One major challenge in implementing Urban Air Mobility (UAM) as a practical transportation option is ensuring the financial sustainability of all supply chains. This challenge encompasses several aspects, beginning with the construction of Vertiports and extending to the supply of electrical energy for aircraft charging. Our research, which included consulting the ERAU academic library, is vital for assessing financial feasibility. It focused on introducing Vertiports in São Paulo and developing strategies for long-term sustainability.

During our research, we found only three articles discussing the feasibility of vertiports to eVTOL operations in São Paulo City. These articles mainly focus on vertiports that facilitate routes from airports to city destinations, using existing rooftop landing spots in São Paulo and adaptable sites like multi-level car park structures (Ribeiro et al., 2023; O’Reilly et al., 2024; Lopes & Silva, 2023).

Figure 4

Number of vehicles by Brazilian State (IBGE, 2023).



As the vertiport network expands, it holds the potential to link various point-to-point locations, thereby creating an extensive city-wide transportation network. While these documents do not explicitly offer detailed financial information or specific projections for vertiports, they indicate that vertiport development is pivotal for supporting eVTOL operations. This development is crucial for improving urban mobility in São Paulo City. This potential is a cause for optimism about the future of urban mobility in São Paulo (Ribeiro et al., 2023; O'Reilly et al., 2024; Lopes & Silva, 2023).

Hence, the literature review highlighted the potential of eVTOL aircraft to revolutionize urban transportation. By establishing a sustainable network of vertiports, Brazil can position itself as a global leader in innovative and eco-friendly mobility solutions. Advancements in battery technology have made eVTOLs a viable option. They offer significant advantages over traditional helicopters regarding noise reduction, operational costs, safety, and environmental impact. São Paulo can enhance its urban mobility, reduce congestion, and improve air quality. By embracing this emerging technology, the city can contribute to a more sustainable future.

Methodology

In this research, a comprehensive literature review was conducted to examine advancements in electric aircraft technologies. The focus was on critical manufacturers, challenges within the ecosystem, and the potential for air networks. The review also highlighted how São Paulo, Brazil, stands out as a leading location for global eVTOL potential. The lack of specific infrastructure in São Paulo underscores the need for a technical study. Additionally, a financial feasibility analysis is crucial for a company operating vertiports.

The method for developing this study involved a matrix and fluid approach. The method ensured that the objective of demonstrating the viability of vertiport operators was achieved. Results showed a clear return on investment.

The research followed a carefully designed flow, which includes the following steps. First, we analyzed battery technology's maturity and eVTOL aircraft's sustainability. This step was crucial for understanding the current state of electric aircraft and their potential impact on future urban air mobility.

Next, various eVTOL aircraft models were mapped and compared to statistically study the average operational costs. The goal was to obtain a generic CASK (cost per seat kilometer) that could serve as a benchmark for future operations. Statistical data about São Paulo was collected, including population, income levels, real estate costs, and other relevant factors. This data was essential for defining assumptions and identifying potential locations for vertiports. The locations were where future eVTOL airlines could establish financially viable air networks.

More than ten key points of interest were selected for viability analysis as potential sites for constructing future vertiports. This selection was based on strategic considerations related to urban planning and air traffic potential. Additionally, financial modeling was performed for the investments and operational costs associated with a vertiport. This modeling included considerations for infrastructure, personnel, technology, electricity, auxiliary revenues, and other related expenses.

Finally, models were developed to determine the landing and takeoff fees paid by airlines, as well as the boarding fees paid by passengers. Profitability models were also created to assess the operations of vertiports, the return on investment, and the necessary initial capital. Mathematical and statistical tools were employed to ensure the thoroughness of this research process. These included technical analyses, linear regressions, and Net Present Value (NPV) assessments. These tools were integral to validating the study's findings and ensuring the robustness of the financial projections.

Data Sources, Collection, and Analysis

Overview

This section outlines the data sources, collection methods, and analysis techniques used in the vertiport’s development and implementation design for eVTOLs (electric vertical take-off and landing vehicles). Data sources include geographic, demographic, economic, and regional infrastructure information. Data collection combined qualitative and quantitative approaches, such as geospatial analyses and consultations on regional standards. The analysis concentrated on the economic performance, population density, and connection to existing transportation methods. The planning of air routes and the vertiport network accounted for the accessibility and traffic absorption capacity of eVTOLs, aiming to optimize vertiport locations and infrastructure. This approach intends to expedite the implementation of an efficient and sustainable urban air mobility system.

Data Source

The primary data sources for this project were geospatial and demographic information obtained from government institutes such as the Brazilian Institute of Geography and Statistics (IBGE, 2021). Secondary sources included regional economic data, urban planning, and transportation infrastructure studies, available in public reports and development agency databases (Atlas Brasil, 2022). Regional and urban standards were consulted to ensure compliance with local regulations (ANAC, n.d.). The data supported the air route planning and vertiport network development. Lastly, industry benchmarks and best practices in urban mobility were reviewed to ensure that the project aligned with current trends and standards in air mobility and infrastructure.

Data Collection

Data collection involved both qualitative and quantitative methods. Geospatial tools were used to map potential vertiport locations, while demographic and economic data from governmental databases assessed regional viability. Surveys and interviews with local authorities provided insights into regulatory requirements and infrastructure integration. Economic data helped evaluate the potential demand for eVTOL services. Air traffic data and route planning metrics were analyzed by the internal team, whose expertise optimized vertiport layouts for airspace compliance and operational efficiency. This approach ensured a safe, accessible, and well-integrated transportation network.

Instrumentation and Data Testing

The data was tested using various instruments and methodologies to ensure accuracy and reliability. Geospatial analysis was conducted using the Great Circle Mapper (GCMapper, n.d.), which provided precise mapping and site selection capabilities. Economic forecasting models were employed to evaluate potential demand and profitability. An iteration process happened to optimize route planning and ensure regulatory compliance. These tools helped validate data accuracy and test the feasibility of proposed vertiport locations and routes, ensuring that results were reliable and actionable.

Data Analysis

Overview of eVTOL Aircraft under Development

The urban air mobility sector is still developing, with no commercial electric aircraft in operation. Several manufacturers are racing to research, develop, and certify prototypes and compliant aircraft. Collecting data from major manufacturers and their vehicles is crucial for modeling. Key factors include seat capacity, network, and vertiport infrastructure requirements. Creating a matrix with key data from leading eVTOLs helps define aircraft characteristics. This matrix also supports modeling operational costs for future electric aircraft. The five manufacturers selected were based on their suitability for regular commercial operations involving passengers, and their scores on the Advanced Air Mobility Reality Index (ARI) developed by SMG Consulting, as presented in Table 1.

Table 1

Advanced Air Mobility Reality Index (SMG Consulting, 2024).

Manufacturer	ARI	Vehicle Type	Vehicle	Country	Analysis
Volocopter	8.6	Multicopter / Lift + Cruise	VoloCity	Germany	Not selected. One passenger seat and a range of < 20 km.
Ehang	8.5	Multicopter/Lift + Cruise	EH216	China	Not selected. Remotely piloted for two passengers.
Beta Technologies	8	Conventional / Lift + Cruise	Alia-250	USA	Selected.
Joby Aviation	7.9	Vectored Thrust	-	USA	Not selected. Proprietary operation concept.
Archer	7.9	Vectored Thrust	Midnight	USA	Selected.
AutoFlight	7.6	Lift + Cruise	Prosperity I	China	Not selected due to a lack of technical information.
Aerofugia	7.4	Vectored Thrust	AE200	China	Not selected due to a lack of technical information.
Wisk	7.4	Vectored Thrust	Generation 6	USA	Not selected. Target certification after 2030.
Airbus	7.4	Lift + Cruise	CityAirbus NextGen	France	Not selected due to a lack of technical information.
Eve Air Mobility	7.2	Lift + Cruise	Eve	Brazil	Selected.
Vertical Aerospace	7.1	Vectored Thrust	VX4	UK	Selected.
Lilium	7	Vectored Thrust	Jet	Germany	Selected.

Subsequent sections present the five selected eVTOLs in greater detail, including information on the manufacturer, range, speeds, and passenger capacity.

Vertical Aerospace, VX4

Vertical Aerospace, founded in 2016, is based in Bristol, UK. Their VX4 aircraft is an eVTOL with tilt-rotor thrust technology. The company has announced 1,400 pre-orders, including options, globally. In Brazil, pre-orders, including options, amount to 250 units. Figure

5 presents the second prototype of the VX4 undergoing testing in Kemble, UK, during August 2024. During these tests, the eVTOL performed tethered flights with a pilot on board.

Figure 5

VX4 eVTOL prototype aircraft (Vertical Aerospace, 2024).

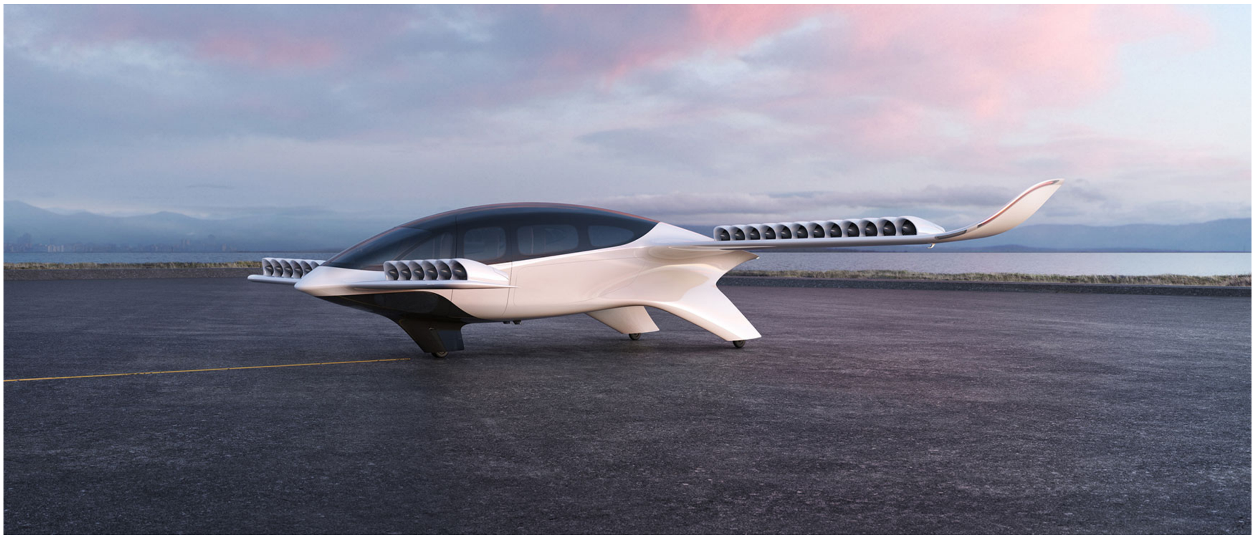
The VX4 can carry 4 passengers and 1 pilot. It has a top speed of 202 mph, cruising at 150 mph. The aircraft has a range of 160 km under normal operating conditions. The CAA and EASA are the primary certification authorities. The targeted entry into service (EIS) is scheduled for late 2026 (Vertical Aerospace, 2024).

Lilium Air Mobility, Lilium Jet

Lilium, founded in 2015, is based in Munich, Germany. The Lilium Jet is an eVTOL with ducted vectored thrust technology. Lilium has announced 2,900 pre-orders, including 220 from Brazil. The premium version of the aircraft accommodates 6 passengers and 1 pilot. Figure 6 displays a rendering of the Lilium Jet, which features a unique propulsion system consisting of 30 battery-electric motors utilizing a ducted propeller design.

Figure 6

Lilium Jet eVTOL rendered aircraft (Lilium Air Mobility, 2024).



It has a maximum speed of 250 km/h and a range of 175 km. Lilium targets a competitive CASK of $2 per kilometer per passenger with 100% of load factor. The EASA is the primary certification authority for the Lilium Jet. The targeted entry into service (EIS) is scheduled for 2026 (Lilium Air Mobility, 2024).

Eve Air Mobility, EVE-100:

Eve Air Mobility, incubated in 2017 and became independent in 2020, is based in Florida, US. The EVE-100 is an eVTOL with a lift-plus cruise propulsion system. The company has announced 1,825 pre-orders, including 285 from Brazil. Figure 7 illustrates a rendering of the EVE-100, which integrates nine motors arranged in a lift + cruise design configuration. This system operates without requiring any components to change position during flight .

Figure 7

EVE-100 eVTOL rendered aircraft (Eve Air Mobility, 2024).

The EVE-100 aircraft accommodates 4 passengers and 1 pilot in its configuration. It has a cruise speed of 200 km/h and a range of 100 km. It has a wingspan of 15.2 meters, a length of 10.3 meters, and a height of 1.74 meters. The ANAC and FAA are the primary certification authorities. The targeted entry into service (EIS) is scheduled for 2026 (Eve Air Mobility, 2024).

Beta Technologies, ALIA A250 VTOL:

Beta Technologies, founded in 2017, is based in Vermont, USA. The ALIA A250 is an eVTOL with a lift-plus cruise propulsion system. It has a wingspan of 15.2 meters and can carry up to 5 passengers. A single pilot pilots the aircraft and is IFR capable.

According to The Alia platform demonstrates a 1.7-fold increase in VTOL miles per dollar when compared to the fixed operating costs of the helicopter Bell 407. In terms of environmental performance, the Alia platform offers 488% greater carbon efficiency compared to the Bell 407's emissions. Similarly, the Alia platform delivers 1.8 times more miles per dollar in comparison to the fixed operating costs of the Cessna 208, while providing a 300% improvement in carbon efficiency over the Cessna 208's emissions. Figure 8 shows the ALIA 250 eVTOL hovering at low altitude during a test campaign conducted in Vermont, USA.

Figure 8

Alia 250 VTOL during a hover flight (Beta Technologies, 2024).

In the earlier version, it has a maximum cruise speed of 250 km/h and a range of up to 200 km. The FAA is the primary certification authority. The targeted entry into service (EIS) is scheduled for 2026 (Beta Technologies, 2024).

Archer Aviation, Midnight:

Archer Aviation, founded in 2018, is based in California, USA. Their Midnight eVTOL has a range of 160 km and a top speed of 240 km/h. It can carry a payload of 450 kg, including 1 pilot and 4 passengers. Figure 9 depicts the Midnight eVTOL during one of its test flights in California, USA, in 2024. In 2024, Archer Aviation successfully completed 402 test flights, including transition flights and the advancement of landing profiles. The aircraft is equipped with 12 electric motors, six of which are configured in a tilt-rotor arrangement.

Figure 9

Archer Midnight eVTOL aircraft during a flight test (Archer Aviation, 2024).

The company has an order book of 1,141 aircraft. The FAA is the primary certification authority. The targeted entry into service (EIS) is scheduled for 2025 (Archer Aviation, 2024).

Lessons from eVTOL Aircraft under Development

The developing eVTOLs share many similar general characteristics. The exception is the propeller composition. Variations exist between Multicopter/Lift + Cruise, Vectored Thrust, and Conventional/Lift + Cruise designs. The number of engines influences the range but does not significantly impact operational costs. In general, the eVTOL has approximately eight electric motors. It accommodates one pilot and four passengers. Its range is about 150 km, with a cruising speed of around 244 km/h. The average rapid battery recharge time is 15 minutes. The average CASK is approximately $3 during the entry into service by late 2026. Manufacturers generally aim to limit aircraft to a maximum weight of 3,750 kg. This restriction is due to regulatory requirements from aviation authorities and certification processes. Additionally, the average maximum diameter of an eVTOL is 15 meters.

Overview of Vertiport Infrastructure and Structural Typologies

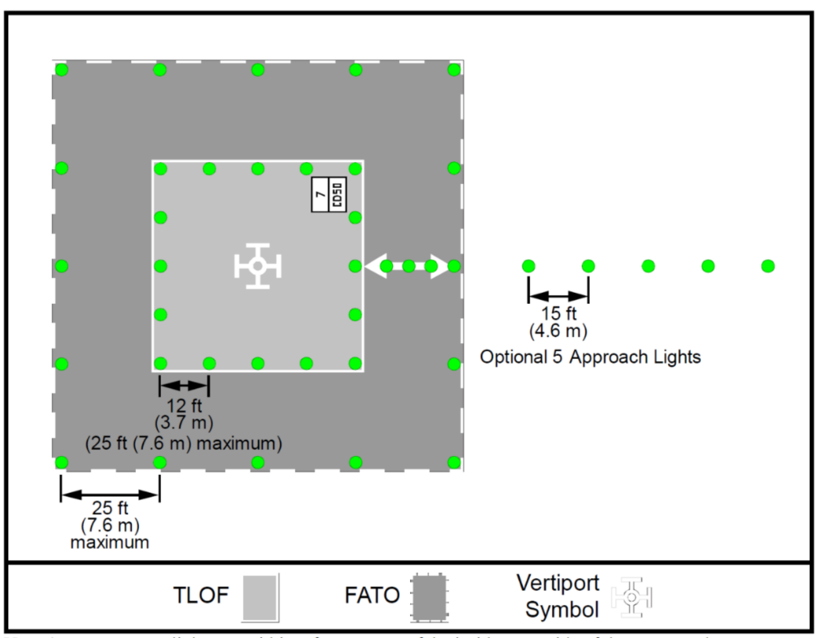
Vertiports represent a critical component in the evolving field of advanced air mobility, serving as the operational bases for eVTOL, which will be the urban air taxis, drones, and eVTOL operations. Developing vertiports is essential to accommodate the anticipated increase in air traffic within urban environments and regional air networks. To emphasize the importance of this development before the eVTOL operation, we will discuss two main topics: the structural elements and typologies of vertiports. That will help us to understand their regulation, functionality, and integration within the broader transportation ecosystem.

Fundamental Structural Components of Vertiports

The core infrastructure of a vertiport encompasses several essential elements. It is highly regulated, starting with the landing and take-off pads, where the most fundamental components are designed to support the eVTOL aircraft's specific physical and operational characteristics.

Figure 10

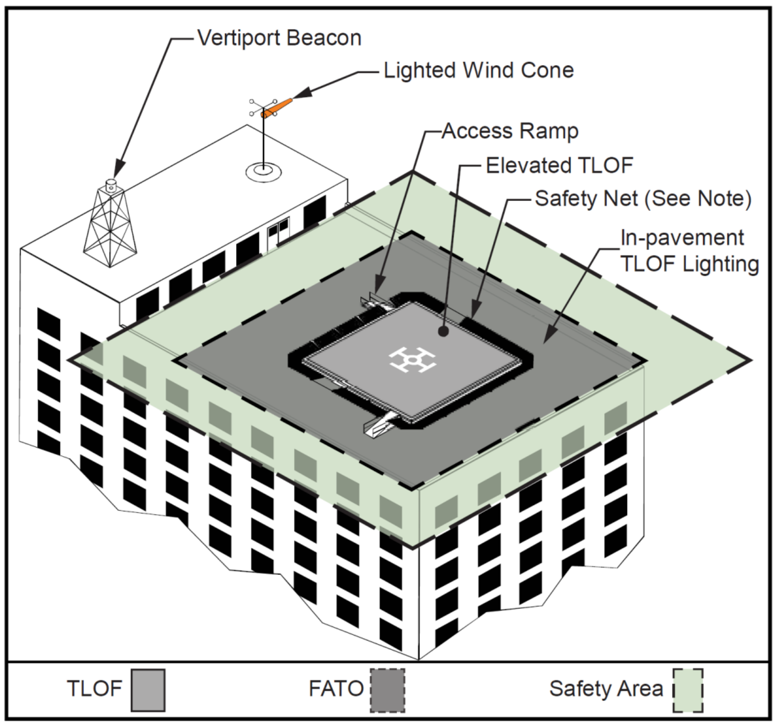
Vertiport Required Area (FAA, 2022).



Their size, weight-bearing capacity, and thrust management systems are critical to ensuring safe landing and take-off for diverse eVTOL configurations. The representations below, Figure 10 and Figure 11 were removed from the FAA manual to simplify the example. (FAA, 2022). However, we find a similar regulation in Annex 14 (ICAO, 2022) and regarding Brazilian aviation on the RBAC 155 (ANAC, 2024).

Figure 11

Vertiport Required Area (FAA, 2022).



Unlike current heliport structures, vertiports must incorporate facilities to accommodate passengers when discussing passenger services to support airline operations or on-demand services. Depending on the location and scale of operations, these facilities can range from minimalistic shelters to full-fledged terminal buildings, akin to small airports. As most eVTOL aircraft are expected to operate on electric power, vertiports typically include infrastructure for charging or swapping batteries, which is essential to the efficient operation of electric air mobility networks. While the presence of charging bases at a vertiport may not always be mandatory, it is crucial for the network supporting eVTOL operations to include such infrastructure to provide necessary maintenance and technical repairs, ensuring operational safety.

Figure 12

eVTOL Charging Station (Flying Vehicle Charging Stations Set to Scale in U.S., n.d.).

Based on the complexity of managing air traffic in urban airspace, many vertiports will be necessary to house dedicated air traffic control systems or integrate them into broader regional air traffic management networks.

Typologies of Vertiport Structures

Vertiports can be categorized based on their spatial configuration, location, and the nature of the operations they support, with primary types including Rooftop, Ground-based, and Multi-modal Vertiports. Rooftop Vertiports are built atop high-rise buildings, optimizing urban space in dense metropolitan environments, and facilitating intra-city transportation by connecting key urban nodes and reducing surface-level congestion. This type of vertiport is commonly found in private buildings and is currently used to receive private helicopters. However, there are no regulations for using private vertiports for public transport, and even if such regulations were to exist, current structures would need to be adapted to accommodate eVTOLs.

Figure 13

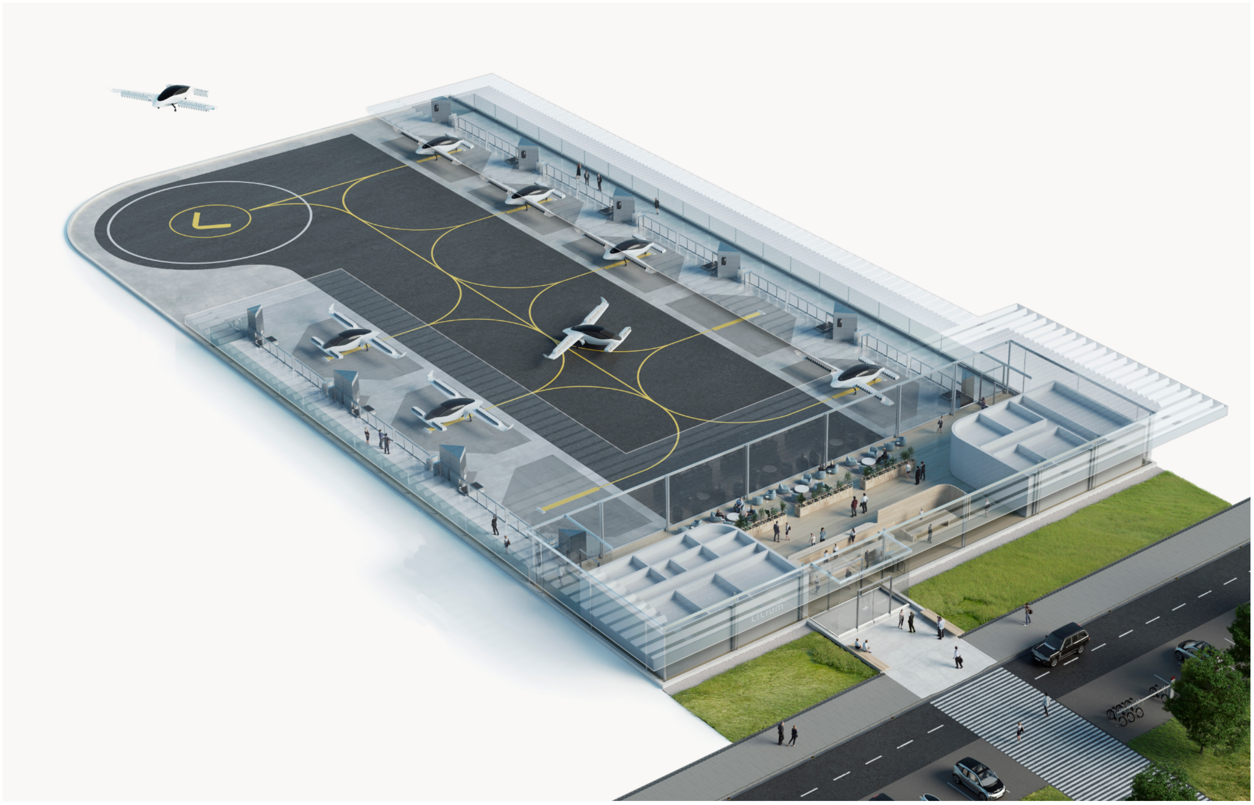
Rooftop Helipad (Potential Future Vertistop).

The other one is the Ground-based Vertiports, typically located at ground level in areas such as parking lots or on the outskirts of urban centers. These vertiports can accommodate more extensive operations and may serve as regional air mobility hubs.

The example shown in Figure 14, made by Lilium (eVTOL manufacturer), projects a ground based Vertiport with a take-off area, parking stations, and passenger terminal.

Figure 14

Ground-based Vertiport (Designing a Scalable Vertiport - Lilium, n.d.)



The last one is the Multi-modal Vertiports, which serve a dual function by integrating with other forms of public transportation, such as buses, trains, or subways. Multi-modal vertiports may also function as logistics hubs, supporting passenger and cargo transport services.

Locations and Network

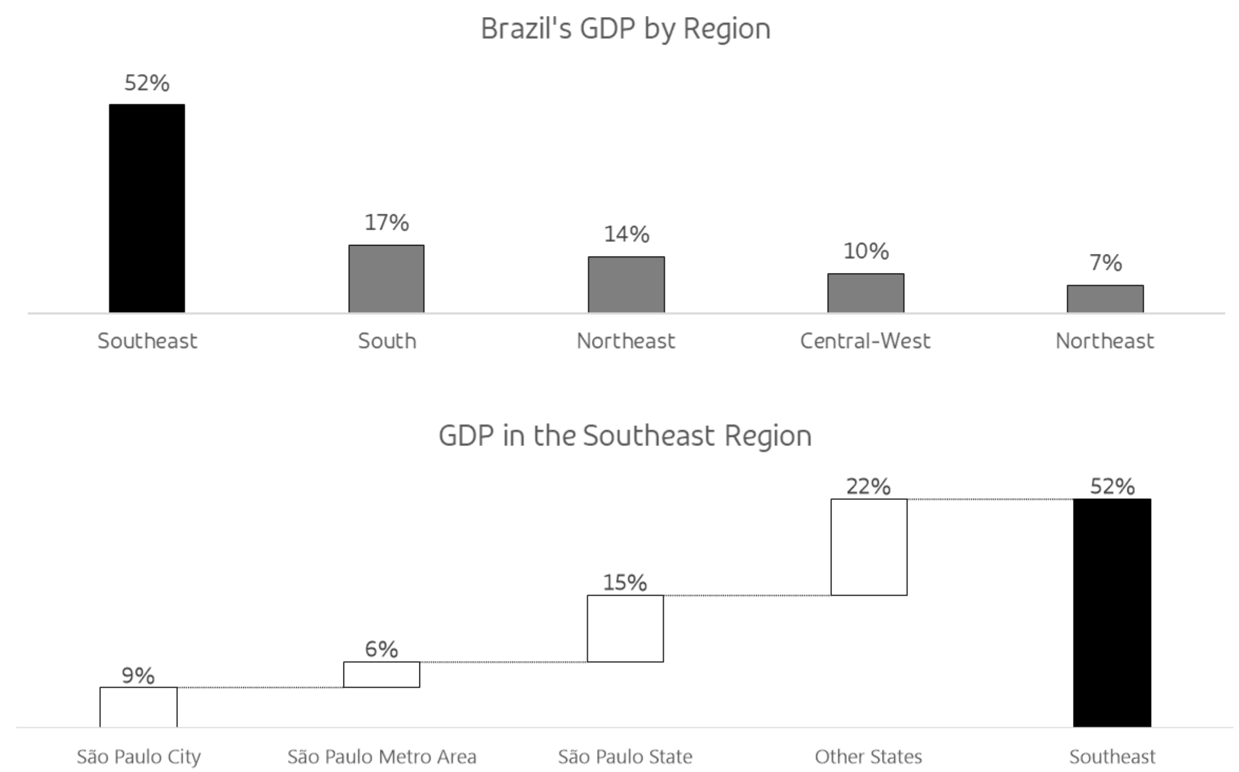
Data analysis involved interpreting data from diverse sources, including geospatial, demographic, economic, and regulatory information, to assess the feasibility and efficiency of the project. Advanced analytical methods were used to identify patterns, optimize aerial and vertiport route planning, and comply with air traffic and urban planning regulations. The analysis supported strategic decision-making, providing a strong foundation for developing and deploying urban air mobility infrastructure.

Based on its high economic significance, the São Paulo region was chosen as the starting point for implementing the vertiport. This decision is supported by an analysis of the Gross

Domestic Product (GDP) provided by IBGE (2021), which reported Brazil's GDP of R$ 1.649 trillion in 2021, highlighting the region's robust economic activity. São Paulo was selected due to its robust economic activity, high volume of business and tourism, well-established transportation infrastructure and growing demand for urban mobility solutions, as shown by the representativeness of its GDP for the Brazilian economy in Figure 15.

Figure 15

Brazil's GDP by Region and Representativity (IBGE, 2021).



Note. The detail of the Southeast region highlights the significance of São Paulo's GDP within the Brazilian economy. Adapted from *"Produto Interno Bruto dos Municípios [GDP by City]",* by the Brazilian Institute of Geography and Statistics (IBGE), 2021.

This decision aimed to enhance the initial implementation of the vertiports by leveraging the region's economic potential and connectivity, ensuring better operational forecasts and integration with the existing transport system.

The choice of neighborhoods for implementing vertiportals in São Paulo was based on GDP (IBGE, 2021) and the Human Development Index (HDI) from Atlas Brasil (2022), which reflects the quality of life and well-being of the population in different regions. The HDI considers factors such as education, health, and income, making it possible to identify areas with the greatest potential for positive impact on urban mobility and access to services.

Neighborhoods with high HDI, such as Congonhas, Berrini, Faria Lima, and Pinheiros, were prioritized due to their strong infrastructure, accessibility, and demand for innovative mobility solutions. This approach ensures that vertiports are strategically located to maximize the social and economic benefits of the new infrastructure. The results are presented in Table 2.

Table 2

Chosen São Paulo City Location and HDI.

Station	Location	Region	HDI
CGH	**Congonhas**	Vila Nova Conceição/Moema/Jardim Luzitânia/Parque Ibirapuera	0.944
		Campo Belo	0.932
		Jardim Aeroporto	0.927
		Jabaquara	0.864
		Vila Santa Catarina	0.835
SITO	**Berrini**	Berrini/Vila Funchal	0.944
		Brooklin	0.934
		Morumbi	0.927

Station	Location	Region	HDI
SIJF	**Faria Lima**	Vila Olímpia	0.956
		Vila Nova Conceição/Moema/Jardim Luzitânia/Parque Ibirapuera	0.944
		Jardim Europa	0.949
		Jardim Paulistano	0.965
RTE	**Campo de Marte**	Santana	0.828
		Bom Retiro/Vila Guilherme	0.722
		Tatuapé	0.862
SIRZ	**Pinheiros**	Pinheiros	0.949
		Alto de Pinheiros	0.936
		Pinheiros	0.921
		Butantã	0.861
		Sumaré	0.943
		Vila Madalena	0.944
SDMT	**Avenida Paulista**	Consolação	0.887
		Bela Vista	0.832
		Paraíso	0.806
		Bexiga	0.794
		Pacaembú/Higienópolis	0.961
		Vila Mariana	0.952

Expanding to the metropolitan region and key cities, Guarulhos, Alphaville, Jundiaí, Campinas, Americana, Santos, São Sebastião, São Roque, and Sorocaba were selected for vertiports implementation based on GDP, reflecting the economic potential of each region. These cities were chosen for their economic relevance, infrastructure, and proximity to strategic urban centers. The GDP analysis ensured that the selected locations could handle the demand for air mobility solutions, supporting the expansion of the vertiport network. This approach aims to enhance connectivity between high-activity economic areas and major transport hubs, fostering an integrated urban mobility system. The results are presented in Table 3.

We have considered three implementation plans (pessimistic, realistic, and optimistic) for assembling the vertiports network. Each plan represents a distinct level of expectation for the project's success, focusing on economic forecasting and profitability. The pessimistic scenario envisions a proposed implementation with low uptake of urban air mobility and infrastructure limitations, potentially resulting in lower profitability and a greater need for initial investments.

Table 3

Chosen São Paulo Metropolitan Locations.

Station	Location	Region	GDP (BRL) per Capita
GRU	**Guarulhos**	Guarulhos	55,084
		Mairiporã	22,076
SDBC	**Alphaville**	Barueri	207,461
		Osasco	122,766
		Santana de Parnaíba	79,580
SDJD	**Jundiaí**	Jundiaí	135,081
		Louveira	385,774
		Cajamar	287,385
VCP	**Campinas**	Campinas	59,634
		Hortolândia	77,358
		Matão	63,716
		Valinhos	59,843
		Vinhedo	154,055
SDAI	**Americana**	Americana	62,271
		Paulínia	457,518
		Limeira	51,678

		Piracicaba	84,226

Station	Location	Region	GDP (BRL) per Capita
SSZ	**Santos**	Santos	55,508
		Guarujá	32,292
		Cubatão	165,608
		São Vicente	16,507
SJPQ	**São Sebastião**	São Sebastião	174,696
		Ilhabela	385,606
		Caraguatatuba	36,202
JHF	**São Roque**	São Roque	37,075
		Alumínio	210,671
		Mairinque	56,474
		Ibiúna	29,609
SOD	**Sorocaba**	Sorocaba	64,047
		Votorantim	31,488
		Araçoiaba da Serra	34,075

The realistic scenario considers gradual adoption, with progressive solution freedom and infrastructure development, leading to sustainable growth and moderate profitability over time. The optimistic scenario projects high demand from the beginning, with an accelerated expansion of the vertiport network and higher profitability as the infrastructure adapts to growing traffic.

The scenarios in Figures 16, 17, and 18 were created to evaluate the economic risks and potential project profitability, allowing strategic adjustments according to market performance.

Figure 16

Pessimistic Implementation Plan Scenario.

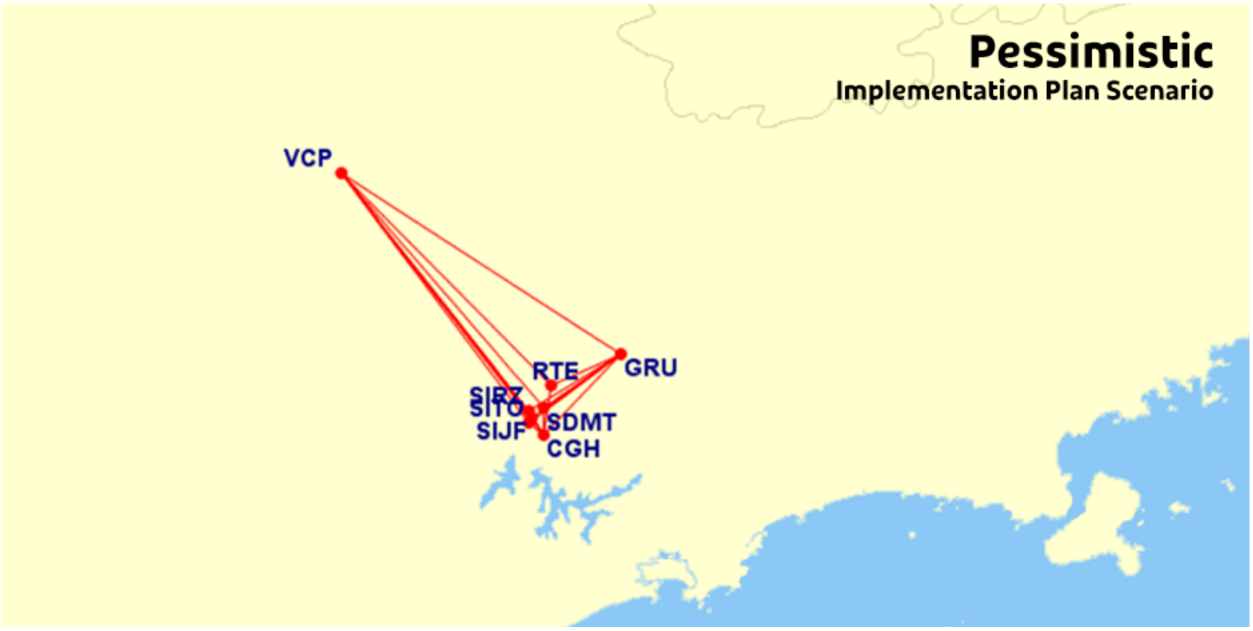


Figure 17

Realistic Implementation Plan Scenario.

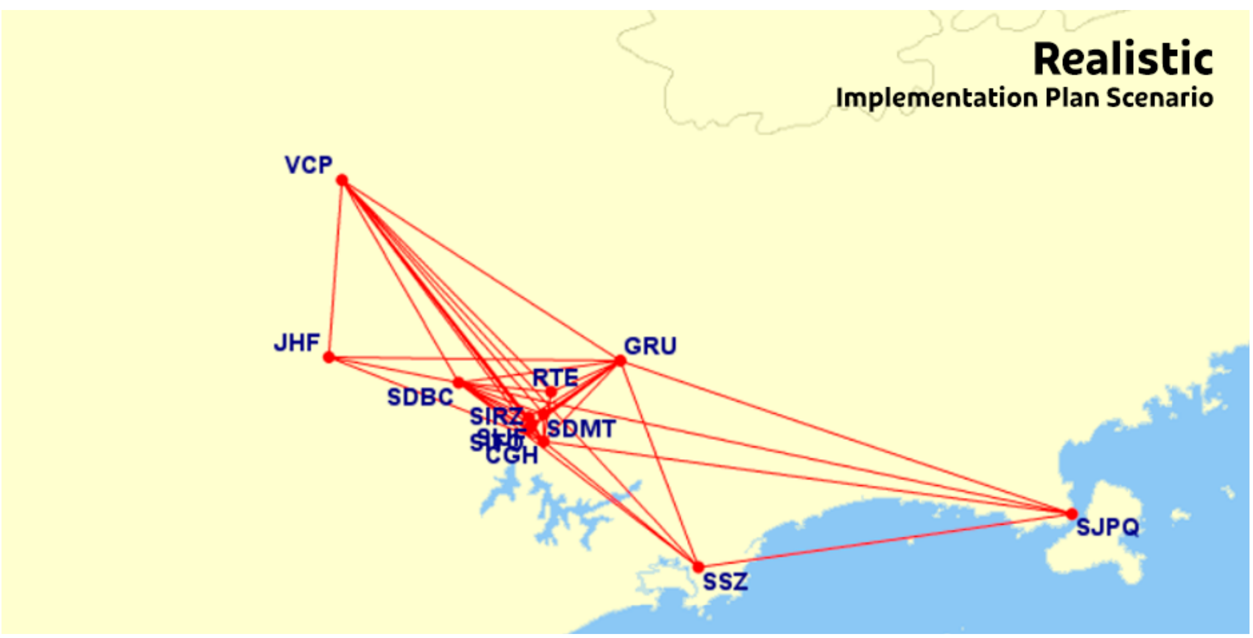
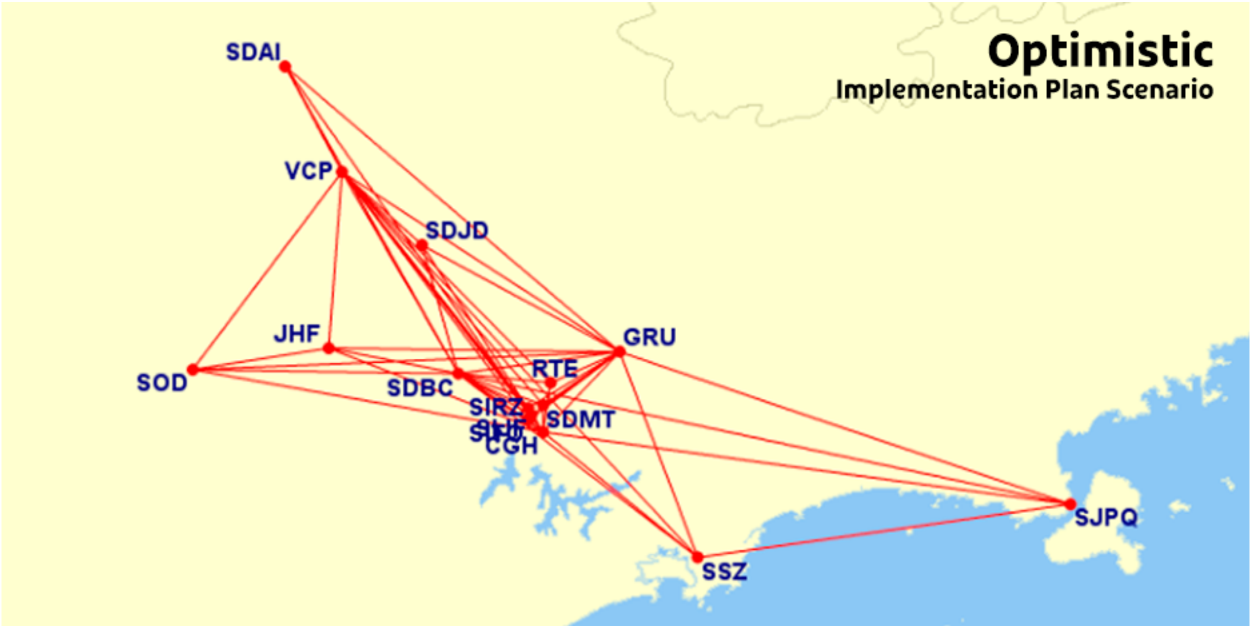


Figure 18

Optimistic Implementation Plan Scenario.



The vertiport project relied heavily on data analysis to make informed decisions about site selection, route planning, and infrastructure optimization. By examining geospatial, demographic, economic, and regulatory data, we pinpoint regions with the most potential impact on air mobility. We ensured regulatory compliance and integration with the urban transportation network through advanced analytical methods, setting the stage for a well-informed and strategic implementation of vertiports. This approach maximized the social and economic benefits of the project while allowing us to adapt to market changes and unforeseen events.

Vertiport Site Pricing

In assessing the cost of the site for the development of vertiports in the São Paulo area, a structured approach was adopted to estimate the price per square meter of suitable site based on the locations chosen for the network analysis. This section outlines the methods used for data gathering and the subsequent analysis applied to derive accurate cost estimates.

Vertiport Pricing Data Gathering

1. **Real Estate Listings from Online Platforms**

   The first source of data was a selection of reputable Brazilian real estate websites that list sites for sale in various regions surrounding São Paulo. The websites utilized included VivaReal, ZapImoveis, and Imovelweb, all providing extensive listings across the São Paulo area and surrounding cities. These platforms were chosen based on their relevance, market presence, and comprehensive data on-site listings.

The focus was on gathering information for plots ranging from 500 to 1500 square meters, as this size range is suitable for vertiport construction, allowing for both the facility's infrastructure and operational needs.

For each available property, the data points were recorded for location, site size (square meters), and listed sale price. Using this data, we calculated the price per square meter for each plot by dividing the total sale price by the site size. This yielded a preliminary estimate of site value across different regions. To minimize potential outliers or skewed data, we aggregated multiple listings within each city to calculate an average price per square meter.

2. **Municipal Real Estate Transaction Database (ITBI)**

   To supplement the information from the real estate websites, we leveraged the publicly accessible database of real estate transactions (ITBI) provided by the São Paulo municipal government. This data provided finalized sale prices for transactions, offering a reliable benchmark for our cost estimates.

Vertiport Pricing Data Analysis

Once the data was gathered from sources, some analytical steps were employed to extract meaningful insights. First, the price per square meter was calculated for each property by dividing the total sale price by the land area. This provided a standardized metric for comparison across different regions. Next, the data was reviewed for outliers, with listings or transactions that showed prices significantly higher or lower than the average flagged for further investigation. If deemed necessary, these outliers were removed from the dataset to ensure the accuracy of the analysis.

Table 4

Average Price Per m²

City/Region	Average Price per m² (R$)
Santos	2,492.75
Campinas	1,308.84
Jundiaí	1,175.54
Americana	800.33
Sorocaba	729.89
São Sebastião	594.99
São Roque	290.37
Congonhas	4,424.97
Berrini	4,518.76
Faria Lima	13,643.07
Pinheiros	14,056.91
Avenida Paulista	8,141.68
Campo de Marte	3,427.55
Guarulhos	2,314.36
Alphaville	2,340.76
Average	**4,017.38**

After cleaning the data, the results were grouped by city or region, allowing for the calculation of an average price per square meter for each location. A comparison was then conducted between the asking prices listed on real estate websites and the actual sale prices recorded in the municipal transaction data, ensuring consistency and accounting for discrepancies. Finally, a robust estimate of the price per square meter for land in each region was established by synthesizing the information from both the listings and transaction records. Table 4 shows the average price estimates per square meter.

Rental Price Estimation Approach

In addition to analyzing site purchase prices, understanding the costs of renting or leasing a site is crucial for a comprehensive financial assessment. Using the methodology outlined in "The Appraisal of Real Estate" (*The Appraisal of Real Estate, 2020*), rental prices were estimated as a percentage of the market value. For this analysis, we consulted data from the *Global Property Guide* and *Imovelweb*, which reported a gross rental yield of 5.57% for São Paulo in the second semester of 2024. Table 5 presents the calculated rental prices based on this methodology.

Table 5

Estimated Annual Rental Price

City/Region	Annual Rental Price per m² (R$)
Santos	138.80
Campinas	72.85
Jundiaí	65.45
Americana	44.57
Sorocaba	40.67
São Sebastião	33.14
São Roque	16.18
Congonhas	246.57

City/Region	Annual Rental Price per m² (R$)
Berrini	251.85
Faria Lima	759.05
Pinheiros	783.96
Avenida Paulista	453.49
Campo de Marte	190.86
Guarulhos	128.93

Adding the land cost per square meter, we will use the average construction cost in São Paulo. In September 2024, the average was R$1,867.85. The construction cost per square meter is influenced by various factors such as the property's location, labor, materials, the Selic rate, and INCC. This information was obtained through the Brazilian Institute of Geography and Statistics (IBGE, 2024), which provides data on the average construction costs in Brazil through the National System of Research and Indexes of Civil Construction (Sinapi).

Charging Station Costs

A key element of vertiport infrastructure is the charging stations needed to power eVTOLs between flights. However, since eVTOL technology is new and proprietary, detailed cost information for charging infrastructure is still being determined. This lack of transparency makes assessing costs for high-powered eVTOL charging stations difficult.

To address this, we can use a scaling approach, applying cost data from established Level 3 DC fast chargers (DCFC) for electric vehicles (EVs). We can estimate the financial investment needed for aviation-grade, high-power eVTOL charging systems by leveraging these known costs and industry-standard scaling rules. This method provides a reasonable starting point for planning eVTOL infrastructure.

According to McKinsey & Company, a DCFC from 150 to 350kW DCFC charging unit can cost anywhere from $45,000 to over $100,000, and installation costs can range from $40,000 to over $150,000. (Fröde et al., 2023)

Based on that we'll use the six-tenths rule for cost scaling, which is widely accepted in the industry:

$$C_2 = C_1 \times (S_2/S_1)^{n}$$

Where:

C_2 = Cost of new equipment (1MW charger)

C_1 = Cost of reference equipment (350kW charger)

S_2 = Capacity of new equipment (1000kW)

S_1 = Capacity of reference equipment (350kW)

n = scaling exponent (0.6 for hardware, 0.4 for installation)

Using the high-end estimate for a 350kW charger and considering the costs of $140,000, and the installation cost at $65,984 (The International Council on Clean Transportation, 2019) as our baseline we come to the following costs for 1MW charger.

Table 6

Estimated 1MW charging station cost.

Description	Cost to Implement, in USD
Hardware Cost (1MW Charger)	$271,460
Installation Cost	$100,824
Total Cost	**$372,284**

Given the high costs associated with eVTOL charging stations, leasing can be a practical option for vertiport operators. This approach allows businesses to access necessary equipment without the burden of significant upfront investments. One effective method for estimating leasing costs is the capital recovery factor (CRF) (LeRoy & Fowler, 1982). The CRF converts the total cost of the equipment into manageable payments based on interest and the equipment's lifespan. Using a 7% interest rate and a 15-year lifespan, the monthly lease payment would be $3,406.23.

Human Capital Costs

The operation of a vertiport requires a diverse and skilled workforce to ensure efficient, safe, and customer-oriented services. Human capital needs span various crucial operational areas, each contributing to the seamless functioning of the facility.

The staffing requirements are tailored to accommodate different operational scenarios, such as single or multiple work shifts, to meet varying demands and operational hours.

Critical operational areas include:

1. Ticket Sales/Check-In: Staff responsible for processing passenger tickets and managing the check-in process.
2. Boarding/Deboarding: Personnel assisting passengers during boarding and deboarding procedures, crucial for efficient operations.
3. Maintenance (AUX): Technical staff overseeing vertiport facilities, equipment maintenance, and upkeep.
4. AVSEC (Aviation Security): Team dedicated to ensuring security protocols are followed, including passenger and luggage screening.
5. Security: Additional security personnel are critical if the vertiport is outside an airport.

6. Cleaning: Staff responsible for maintaining cleanliness and hygiene standards throughout the facility.

Each of these areas requires specific skills and training, contributing to vertiport operations' overall functionality and safety. All human capital needed incurs costs related to their tasks, summarized in the following tables.

Table 7

Human capital required for 1 Work Shift (12 hours)

Area	Staff	Staff with Rotation	R$ Month
Ticket Sales/Check In	1	2	R$ 5,600.00
Boarding/Deboarding	1	2	R$ 6,450.00
Maintenance	1	2	R$ 5,600.00
AVSEC	2	4	R$ 10,656.00
Security	1	2	R$ 5,382.00
Cleaning	1	2	R$ 6,087.00
Total	**7**	**14**	**R$ 39,721.00**

Table 8

Human capital required for 2 Work Shifts (18 hours).

Area	Staff	Staff with Rotation	R$ Month
Ticket Sales/Check In	2	4	R$ 11,200.00
Boarding/Deboarding	2	4	R$ 12,900.00
Maintenance	2	4	R$ 11,200.00
AVSEC	4	8	R$ 21,312.00
Security	2	4	R$ 10,656.00
Cleaning	2	4	R$ 12,174.00
Total	**14**	**28**	**R$ 79,442.00**

Project Outcomes

Implementing vertiports to support eVTOL operations in Brazil will significantly enhance urban mobility, reduce traffic congestion, and promote sustainable transportation alternatives. This project will yield a comprehensive understanding of the financial feasibility, infrastructure requirements, and regulatory challenges involved in establishing vertiports. It will also provide actionable strategies to integrate eVTOLs into existing transport systems, ensuring operational viability and commercial sustainability in the Brazilian market. These results will form the foundation for future investments and urban planning efforts, solidifying Brazil's leadership in urban air mobility.

Results

This section analyzes the fundamental aspects required to establish a vertiport network for eVTOL operations in São Paulo, focusing on demand forecasting, network planning, and cost estimates. To assess the potential for eVTOL adoption, a top-down methodology was applied to forecast annual passenger volumes across different demographic user groups, covering airport travelers and domestic and international tourists.

In addition, the fundamentals of network planning are examined, and operational requirements and load factors are evaluated in various scenarios. Each scenario considers a unique set of operational assumptions, which provides insight into how different configurations of vertiports, eVTOL units, and installation locations can affect the efficiency and adaptability of the network under varying demand conditions.

Finally, cost estimates outline the financial parameters essential for sustainable vertiport operations. This includes initial investments, construction expenses, and operating costs in various site configurations and geographical locations. This section aims to provide a basic understanding of the investment requirements for vertiport implementation, supporting a robust eVTOL infrastructure in São Paulo's urban setting.

Demand Forecasting

A top-down methodology has been used to estimate the potential annual number of eVTOL passengers during the first years of operation in São Paulo. Data from Table 6 and the following considerations were used:

- 2% of Class A passengers and 0.5% of Class B would fly once a year.
- Guarulhos Airport (GRU) handles over 4,000 first-class or business-class seats arriving at or departing from the airport daily, which is a proxy made from ANAC (n.d.) data.
    - With a load factor of 50%, 5% of passengers would utilize eVTOL for airport shuttles.
    - Furthermore, for other international tourists, it is anticipated that 3% will opt for eVTOL transportation.
- 0.5% of domestic tourists would use eVTOLs for at least one flight during their stay in São Paulo.
- The GOL Effect on the annual growth of demand in the Brazilian aviation market between 2001 and 2014 after GOL commenced operations.
- A sensitivity variation of -10% for the pessimistic scenario and +10% for the optimistic.

The forecast for 2027–2035, as shown in Figure 19, relied on these estimates, with the "GOL Effect" embodying the realistic scenario attributable to the anticipated impact of the new business model on the aviation industry. The ultimate projected year was utilized in the network planning.

The “GOL Effect” refers to the exponential increase in Brazil's air travel demand. Since beginning operations, GOL has stimulated demand for air travel in Brazil. Passengers began comparing airfare with bus tickets, finding them affordable. GOL’s business model triggered a cascade effect within Brazil’s aviation industry. The phenomenon became widely known as the “GOL Effect” (Mundo das Marcas, 2006).

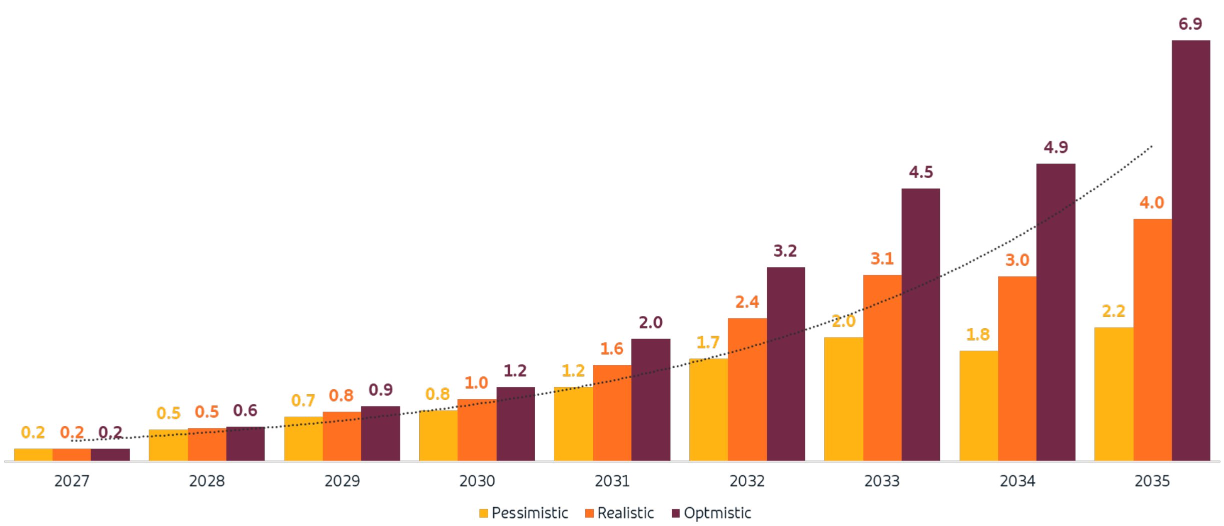
Table 6

Breakdown of Brazilian Social Classes (IBGE,2021).

<table>
<tr><th>Social Class</th><th>Characteristics</th><th>% of Population</th></tr>
<tr><td>Class A</td><td>More than 15 minimum wages</td><td>2.8%</td></tr>
<tr><td>Class B</td><td>5 to 15 minimum wages</td><td>13.2%</td></tr>
<tr><td>Class C</td><td>3 to 5 minimum wages</td><td>33.3%</td></tr>
<tr><td>Class D</td><td>1 to 3 minimum wages</td><td rowspan="2">50.7%</td></tr>
<tr><td>Class E</td><td>Up to 1 minimum wage</td></tr>
</table>

Figure 19

Estimation of eVTOL Passenger Demand in São Paulo with Sensitivity Scenarios Adjusting ±10% Variations (in Millions of Potential Passengers).



Network Planning

The planned eVTOL network operations are based on 2035. The projections consider several operational premises and constraints, and three demand scenarios—pessimistic, realistic, and optimistic—are outlined to account for uncertainties in market conditions and technological development.

Operational Constraints

The Flight Time was based on an average airspeed of 244 km/h for each eVTOL and the GCMapper (n.d.) calculations for the given routes on each scenario. Furthermore, the Block Time is defined as the rounded-up flight time plus 10 minutes for operational adjustments. A minimum turnaround time of 15 minutes is assumed, based on fewer than five passengers per operation.

Each departure carries an average of 4.2 passengers, with maximum operational capacity projected for Mondays and Fridays, the peak business days, with a reduced capacity forecasted for other days.

Planned Operations per Scenario

The pessimistic scenario considers 72 eVTOLs and 8 locations to form the vertiport network. The average load factor will be 47.6%, reflecting lower market demand and operational capacity.

Besides, the realistic scenario consists of 144 operating eVTOLs, the expansion to 12 locations, reflecting moderate demand growth. The average load factor of 62.6% indicates improved utilization of available capacity.

Finally, the optimistic scenario has 196 eVTOLs expected to operate in 15 locations with greater infrastructure development in response to high demand. The average load factor will reach 77.6%, reflecting optimal capacity usage and robust market adoption.

Table 5 summarizes the results for each scenario. Furthermore, considering the maximum peak-day and quarter-hour operations shown in Tables 6 and 7, the number of vertiport stations for each location was obtained and Table 8 summarizes the results.

Table 6

Estimated Seats by Day, Week, and Year, with the Average Passenger Load Factors.

Seats	Pessimistic	Realistic	Optimistic
Monday	13,574	26,813	36,086
Tuesday	12,896	15,685	21,652
Wednesday	12,217	12,334	18,043
Thursday	12,896	15,685	21,652
Friday	13,574	26,813	36,086
Saturday	11,402	11,530	16,058
Sunday	12,217	13,406	21,652
Total per Week	88,777	122,266	171,230
Year	4,629,064	6,375,318	8,928,420
Passengers (2035)	2,202,745	3,992,042	6,928,740
Load Factor (LF)	47.6%	62.6%	77.6%
Operating eVTOL	**72**	**144**	**196**

Table 6 shows that the local ecosystem is expected to have between 72 and 196 operational eVTOLs in São Paulo by 2035. This represents approximately one-quarter of the total orders and options announced for all of Brazil.

Table 7

The Peak-Day Total Operations by Vertiport for each Scenario.

Vertiport	Scenario		
	Pessimistic	**Realistic**	**Optimistic**
CGH	704	1,000	1,216
GRU	712	1,004	1,236
RTE	280	384	384
SDMT	282	386	386
SIJF	282	386	386
SIRZ	282	386	386
SITO	282	386	386
VCP	408	632	928
SDBC	0	1,008	1,280
SSZ	0	348	348
JHF	0	352	440
SJPQ	0	112	112
SDAI	0	0	264
SDJD	0	0	448
SOD	0	0	392
Total	**3,232**	**6,384**	**8,592**

Table 8

The Peak-Day Total Operations per Quarter-Hour by Vertiport for each Scenario.

Vertiport	Scenario		
	Pessimistic	**Realistic**	**Optimistic**
CGH	22	29	38
GRU	14	22	32
RTE	6	8	8

Vertiport	Scenario		
	Pessimistic	Realistic	Optimistic
SDMT	8	10	10
SIJF	8	10	10
SIRZ	8	10	10
SITO	8	10	10
VCP	14	20	29
SDBC	0	22	33
SSZ	0	9	9
JHF	0	8	12
SJPQ	0	7	7
SDAI	0	0	16
SDJD	0	0	16
SOD	0	0	20
Total	**88**	**165**	**260**

Table 9

The Number of Stands by Vertiport for each Scenario.

Vertiport	Scenario		
	Pessimistic	Realistic	Optimistic
CGH	8	10	13
GRU	5	8	11
RTE	2	3	3
SDMT	3	4	4
SIJF	3	4	4
SIRZ	3	4	4
SITO	3	4	4
VCP	5	7	10
SDBC	0	8	11

Vertiport	Scenario		
	Pessimistic	Realistic	Optimistic
SSZ	0	3	3
JHF	0	3	4
SJPQ	0	3	3
SDAI	0	0	6
SDJD	0	0	6
SOD	0	0	7
Total	**32**	**61**	**93**

Cost Estimations

To ensure a financially sustainable operation for the eVTOL network, defining the costs of implementing and operating the Vertiport network that would serve these aircraft was necessary. To do this, we performed a financial analysis that a vertiport operator would need to consider for its operation, including the cash flow of the operation, as well as the initial investment costs of building and installing the charging stations.

We used the values raised in the data analysis, considering the local currency (Real R$) and using the exchange rate of R$ 5.50 for each dollar. In addition, we considered the following metrics:

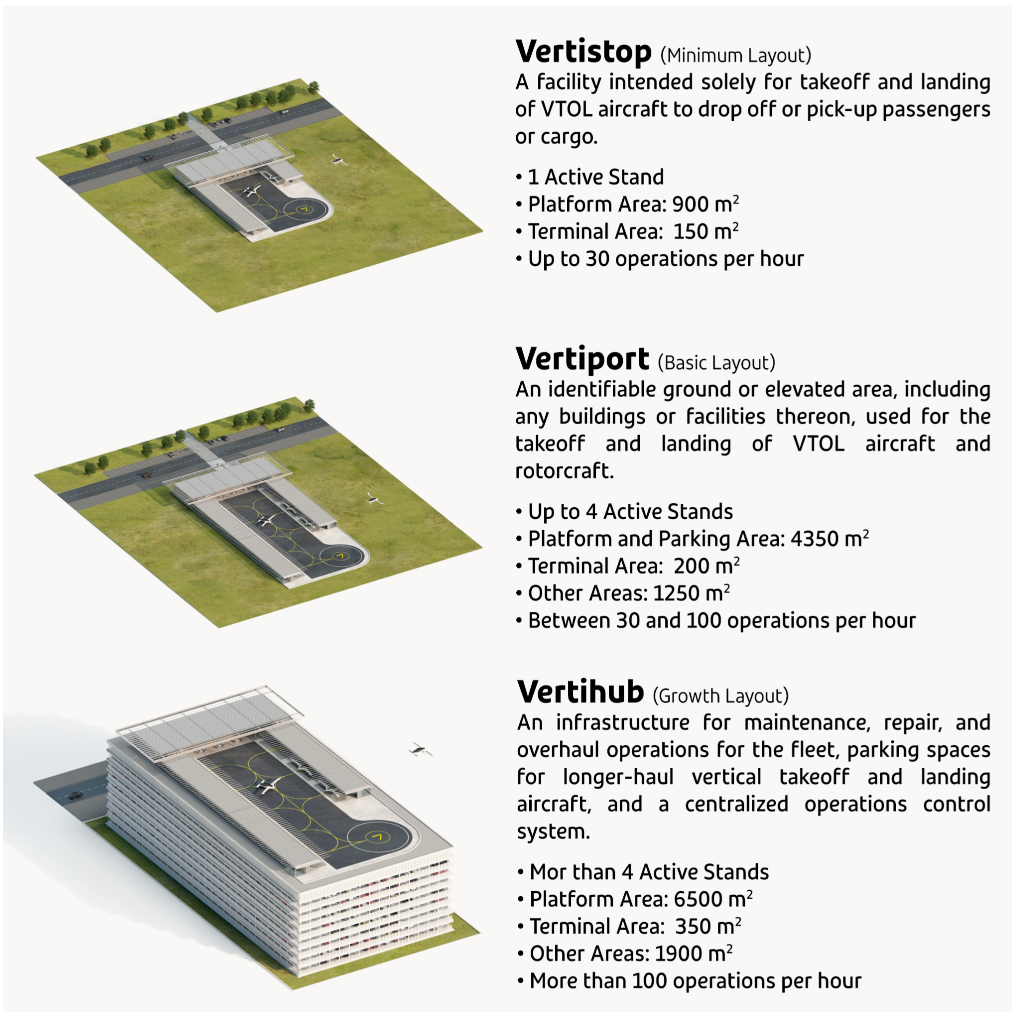
- Vertiport Size;
- Construction Cost;
- Inflation Rate;
- Labor Cost;
- 1 MW charger;
- Landing Frequency;

- Landing/takeoff fee;

Based on the size of the Vertiport, we established three possible scenarios that would meet our proposed flight network for the city of São Paulo, Figure 20 provides a high-level description for the types of facilities that may accommodate arrival and departure operations.

Figure 20

Vertiport Layouts for Minimum, Basic, and Growth Sizes.



Note. Concept of vertiport types by size developed by the authors. Adapted from "*Initial Development and Integration of a Vertiport Automation System for Advanced Air Mobility*

Operations" by Tiwari, A. I., Ramirez, C. V., Homola, J., & NASA Langley Research Center (2021), and "*Designing a Scalable Vertiport"* by Lilium Air Mobility (2020).

According to Tiwari et al. (2021), a vertistop (minimum layout) is a facility intended solely for takeoff and landing of eVTOLs to drop off or pick-up passengers and cargo. A vertiport (basic layout) is an identifiable area, including any buildings or facilities thereon, used for the takeoff and landings of eVTOLs. A vertihub (growth layout) has an infrastructure for maintenance, repair, and overhaul operations for the fleet, parking spaces for longer-haul eVTOL aircraft, and a centralized operations control system.

The number of operations considered was based on the demand and network ramp-ups from 2027 until 2035. A typical operation week for the realistic scenario resulted in Table 10 monthly operations by vertiport and year. Finally, the average number of operations for the 2027-2035 period of three vertiports was considered to check the financial feasibility and the landing fees.

Table 10

The Monthly Number of Operations by Year and its Average - Realistic Scenario.

Monthly Operations	2027	2028	2029	2030	2031	2032	2033	2034	2035	Avg.
CGH	147	389	582	725	1,122	1,667	2,174	2,156	2,831	**1,310**
GRU	148	391	584	728	1,126	1,674	2,183	2,165	2,842	**1,316**
RTE	57	149	223	279	431	640	835	828	1,087	**503**
SDMT	57	150	225	280	433	644	839	832	1,093	**506**
SIJF	57	150	225	280	433	644	839	832	1,093	**506**
SIRZ	57	150	225	280	433	644	839	832	1,093	**506**
SITO	57	150	225	280	433	644	839	832	1,093	**506**
VCP	93	246	368	458	709	1,054	1,374	1,363	1,789	**828**
SDBC	148	392	587	731	1,131	1,681	2,191	2,173	2,853	**1,321**

Monthly Operations	2027	2028	2029	2030	2031	2032	2033	2034	2035	Avg.
SSZ	51	135	203	252	390	580	757	750	985	**456**
JHF	52	137	205	255	395	587	765	759	996	**461**
SJPQ	16	44	65	81	126	187	243	241	317	**147**
SDAI	0	0	0	0	0	0	0	0	0	**0**
SDJD	0	0	0	0	0	0	0	0	0	**0**
SOD	0	0	0	0	0	0	0	0	0	**0**
Total	**940**	**2,483**	**3,717**	**4,629**	**7,162**	**10,646**	**13,878**	**13,763**	**18,072**	**8,366**

The first scenario, being the smallest of all, we consider the operation that will take place on vertistop platforms. We will only have a stop-and-go operation, with a minimum infrastructure to receive the eVTOL and the customers who will board and disembark from the aircraft. We use the expected average operation to calculate this scenario according to the network analysis that was previously performed above.

In this scenario calculation, we used the Campo de Marte location, with IATA code RTE, as a reference for this operation. Due to the rental cost and the flow of business aircraft, operations would have one of the highest implementation costs. To calculate the RTE location operation, we used the following parameters:

- Vertiport Size of 1,050 m²;
- Location rent costs of R$ 66,416.88;
- Construction Cost of R$ 1,867.85 per m²;
- 4.50% as the inflation rate, considering the IBGE forecast;
- Sixty months to the payback;
- Labor Cost of R$ 79,442 per month;

- Landing Frequency 506 per month (average of 10-year projection);

Based on this data, we made the financial projection using the Net Present Value (NPV), which is a comprehensive tool that considers all aspects of an investment, including inflows, outflows, risk, and the period to define the amount that the Vertiport operator must charge for landing and take-off to recover its investment in 5 years.

For this specific case, the RTE location, we find the value of R$362.97 (or, in Dollars, $65.99) has the minimum landing/takeoff fee to recover his investment in 5 years.

In the second scenario, we used the location VCP, full name Viracopos Airport in Campinas City, using the basic ground structure to operate eVTOLs. We will need at least two charge stations to recharge the eVTOL and support that operation. To execute the VCP calculation, we used the following parameters:

- Vertiport Size of 4,850 m²;
- Location rent costs of R$ 29,443.54;
- Construction Cost of R$ 1,867.85 per m²;
- 4.50% as the inflation rate, considering the IBGE forecast;
- Sixty months to the payback;
- Labor Cost of R$ 158,884 per month;
- Landing Frequency 828 per month (average of 10-year projection);
- Two 1-MW Charger stations with an investment cost of R$ 4,095,124;

To recover the investment in this location, the operator must charge the amount of R$ 524.29, or 95.33 dollars.

In the last scenario, our central hub to support our São Paulo operation and has the highest expected volume of operations, we focus on Congonhas Airport, CGH, where we will have an expected flow of 1310 monthly operations. Hence, in that case, we used the following parameters to do the calculation:

- Vertiport Size of 9,750 m²;
- Location rent costs of R$ 200,338.13;
- Construction Cost of R$ 1,867.85 per m²;
- 4.50% as the inflation rate, considering the IBGE forecast;
- Sixty months to the payback;
- Labor Cost of R$ 317,768 per month;
- Landing Frequency 828 per month (average of 10-year projection);
- Four 1-MW Charger stations with an investment cost of R$ 8,190,248;

In Congonhas, due to the high investment in charging stations and the need to recoup the investment in 5 years, the operator must charge R$774.08, or 104.74 dollars. This value can be reduced by adding a fee to the eVTOL that uses the charging system.

Return on Investment (ROI)

The assessment of the overall economic viability of the vertiport operator for the different scenarios is based on the proposed network, the number of landing and take-off cycles for eVTOL operations and the operational and implementation costs of vertistops, vertiports and vertihubs.

The return on investment (ROI) is set as a premise for five years; therefore, following the entry into service (EIS) in 2027, it is expected that the ROI will be achieved by 2032. From 2033 to 2035, the operation will be based solely on operational expenditures (opex) to maximize profit.

According to the analysis of cost estimates, the vertiport operator needs to invest in capital expenditures (capex) and operational expenditures (opex) to construct and operate the different vertiports. Table 11 summarizes the average implementation costs for each design of vertiport.

Table 11

Average Costs of Implementation and Operation over a 5-Year Term for Different Designs.

Design	Total Capex (R$)	Monthly Opex (R$)	5-Year Total (R$)
Vertistop	1,961,242.50	145,858.88	**10,712,775.00**
Vertiport	13,154,196.50	188,327.54	**24,453,849.00**
Vertihub	26,401,785.50	518,106.13	**57,488,153.00**

The average capex values for each vertiport layout type take into account the construction of the vertiport and, if necessary, the installation of the required electric charging infrastructure. The monthly opex includes costs related to land rental, building maintenance, and personnel. A vertistop requires approximately R$ 10.7 million over five years for implementation and operation, while a vertiport requires R$ 24.5 million, and a vertihub more than R$ 57 million.

Based on the Peak-Day Total Operations per Hour by Vertiport for each scenario, the classification of the required vertiport structure type for each location was determined. Table 12 shows the proposed design type for each location across the different sensitivity scenarios.

The vertiport design classification for each scenario was based on the assumption that a vertistop can support up to 30 eVTOL operations per hour, a vertiport can handle between 30 and 100 operations per hour, and a vertihub can accommodate more than 100 operations per hour. The number of operations was determined by the potential number of active stands available at each location. The operational scale-up of eVTOLs is necessary for the mass use of transportation and for its financial viability from the air operator's point of view.

It is important to note that these financial estimates and design classifications are based on current projections and assumptions. As the eVTOL industry evolves, technological advancements, regulatory changes, and improvements in operational efficiencies may significantly impact both capex and opex values, as well as the overall capacity of vertiports. Continuous reassessment of these factors will be crucial for adapting the infrastructure to meet future demands and ensuring the long-term viability of the vertiport network.

Table 12

Vertiport Design Classification for Each Scenario.

Vertiport	Scenario		
	Pessimistic	**Realistic**	**Optimistic**
CGH	Vertiport	Vertihub	Vertihub
GRU	Vertiport	Vertiport	Vertihub
RTE	Vertistop	Vertiport	Vertiport
SDMT	Vertiport	Vertiport	Vertiport
SIJF	Vertiport	Vertiport	Vertiport
SIRZ	Vertiport	Vertiport	Vertiport
SITO	Vertiport	Vertiport	Vertiport
VCP	Vertiport	Vertiport	Vertihub
SDBC	Vertistop	Vertiport	Vertihub
SSZ	Vertistop	Vertiport	Vertiport
JHF	Vertistop	Vertiport	Vertiport

Vertiport	Scenario		
	Pessimistic	**Realistic**	**Optimistic**
SJPQ	Vertistop	Vertistop	Vertistop
SDAI	Vertistop	Vertistop	Vertiport
SDJD	Vertistop	Vertistop	Vertiport
SOD	Vertistop	Vertistop	Vertiport

Note. The proposed network has been optimized to enhance the efficiency of origins and destinations maximizing the number of daily operations, ensuring that the vertistops indicated in the table do not have operations.

The landing fee charged for each cycle (one landing and one takeoff) varies according to the vertiport layout, as outlined in the implementation costs. In this study, a vertistop charges R$ 362.97, a vertiport R$ 524.29, and a vertihub R$ 774.08. These average values already account for the inflation rate and other additional factors. Table 13 consolidates the average fees applied for each of the scenarios studied.

Table 13

Average Landing Fees Based on Design Quantity for Each Scenario from 2027 to 2035.

Layout	Landing Fee (R$)	Design Quantity, Scenario		
		Pessimistic	**Realistic**	**Optimistic**
Vertistop	362.97	8	4	1
Vertiport	524.29	7	10	10
Vertihub	774.08	0	1	4
Average Landing Fee		**R$ 438.25**	**R$ 497.92**	**R$ 580.15**

It is noted that the optimistic scenario predicts a higher demand for eVTOL flights. According to the proposed network, an additional set of routes has been added, resulting in a greater capital investment. In contrast, the pessimistic scenario features a more streamlined set of operational bases, leading to a reduced need for investment.

Based on the calculation of capex and opex costs, along with revenues solely from landing fees—excluding media, retail leasing, parking, and other sources—the three scenarios present interesting results for the vertiport operator.

- **Pessimistic Scenario**: The initial implementation investment is R$ 97.4 million, with average annual operational costs of R$ 29.8 million and average annual revenue of R$ 45.7 million. The result from 2027 to 2035 is a gross profit of R$ 45.9 million, resulting in a return on investment (ROI) of 12.5%.
- **Realistic Scenario**: The initial implementation investment is R$ 166.6 million, with average annual operational costs of R$ 35.8 million and average annual revenue of R$ 56.3 million. The result from 2027 to 2035 is a gross profit of R$ 17.6 million, resulting in a return on investment (ROI) of 3.6%.
- **Optimistic Scenario**: The initial implementation investment is R$ 240.3 million, with average annual operational costs of R$ 49.2 million and average annual revenue of R$ 78.3 million. The result from 2027 to 2035 is a profit of R$ 21.5 million, resulting in a return on investment (ROI) of 3.1%.

It is important to note that the scenario has been termed "pessimistic" from the perspective of passenger demand for commercial and regular eVTOL flights. Consequently, the initial capital investment (capex) is significantly lower than in the other scenarios, given the reduced number of origins and destinations. Additionally, while this scenario shows a positive result for the vertiport operator, it is deficit for the eVTOL operators due to a load factor below 50% and the break-even point. Therefore, the pessimistic scenario may be deemed unsustainable for the regional urban air mobility sector. Conversely, both the realistic and optimistic scenarios yield an average ROI of just over 3%, with the eVTOL operators achieving better load factor levels.

The landing fees in this study ranged from R$ 438.25 (US$ 79.68) to R$ 580.15 (US$ 105.48), which, for a cost per available seat kilometer (CASK) between US$ 3 (Entry Into Service) and US$ 2 (Maturity 2035), would represent approximately 16.2% and 24.3%, respectively. This indicates that the implementation of vertiports needs to be phased to reduce the allocated capital costs and to lower the landing and takeoff fees. Future vertiport operators must seek auxiliary revenues to alleviate the pressure on landing fees, aiming to promote a sustainable ecosystem for all stakeholders.

Limitations

The research we conducted does have some limitations that may affect the implementation of vertiports to support eVTOL operations in Brazil. The limitations highlight the complexity of establishing a new infrastructure for urban air mobility in a densely populated and regulated environment. First, regulatory and compliance constraints present significant challenges. Brazil's regulatory framework for urban air mobility is still evolving, which may lead to unexpected requirements or delays. The ongoing adjustment of national and local policies for vertiport operations could impact the project timeline, implementation costs, and operational feasibility. Compliance with these changing regulations will require continuous adjustments, potentially influencing project outcomes and financial projections.

Another critical limitation lies in the financial feasibility assumptions underpinning this study. Financial projections are inherently based on estimations of demand, cost of land, and operational expenses, subject to market volatility. For instance, unexpected fluctuations in real estate prices, inflation, or shifts in economic conditions could affect the project's overall feasibility. These financial variables add an element of risk that may impact the commercial viability and scalability of vertiport infrastructure in São Paulo and other critical Brazilian cities.

The technological dependencies associated with eVTOL operations also limit the study's projections. The effective implementation of vertiports depends on advancing eVTOL vehicle and battery technologies, particularly regarding charging capabilities and safety standards. Any delays in these technological advancements or obstacles in implementing the necessary charging infrastructure could constrain vertiport functionality and reduce the project's projected operational capacity. As a result, the successful deployment of vertiports is contingent upon the readiness of eVTOL technology and its supporting systems.

Additionally, we did not conduct a comprehensive environmental impact assessment, focusing on operational and financial feasibility. Urban air mobility introduces new noise pollution, energy use, and air quality considerations in densely populated areas. Long-term ecological impacts of eVTOL operations within São Paulo's urban landscape remain unexplored, suggesting a need for future studies to assess this transportation model's sustainability comprehensively. These insights are crucial for public acceptance and regulatory compliance in the long run.

Lastly, operational limitations must be acknowledged. São Paulo's high air traffic congestion and dense urban layout could limit the efficiency of vertiport operations, especially during peak travel hours. Additionally, weather conditions such as heavy rain or wind may hinder eVTOL flights, impacting reliability. These factors could reduce vertiport accessibility and disrupt the frequency and timeliness of eVTOL services, challenging the seamless integration of this new transport system into existing urban mobility networks.These limitations highlight the complexity of introducing vertiports in Brazil and emphasize the importance of ongoing adaptation and research to address regulatory, technological, financial, environmental, and operational challenges.

Conclusions and Recommendations

This section presents the key findings from our research, providing robust conclusions and actionable recommendations for implementing vertiports to support eVTOL operations in Brazil. Our study addressed critical business questions about the feasibility, costs, and regulatory challenges of vertiport development, reinforcing the significance of these findings for industry stakeholders and policymakers. The recommendations propose practical strategies for advancing, focusing on regulatory alignment, financial feasibility, and technological readiness. Additionally, we suggest future research areas to enhance the long-term success of vertiports and eVTOL operations. Detailed explanations for each section follow below.

Conclusions

This research addressed crucial gaps in understanding the financial feasibility, regulatory challenges, and infrastructure needs of implementing vertiports in Brazil to support eVTOL operations. The findings emphasized the substantial business potential for vertiports, highlighting key cost drivers and regulatory hurdles that can significantly impact the success of these facilities. The study provides research questions about vertiports' operational and financial viability, offering invaluable insights to investors, urban planners, and government agencies. By bridging these gaps, this research substantially contributes to the evolving body of knowledge on urban air mobility and presents actionable strategies for the aviation industry.

The significance of these findings is directly linked to the escalating demand for sustainable urban mobility solutions. As cities like São Paulo grapple with mounting congestion and environmental issues, vertiports present a promising solution to alleviate urban transportation challenges. Practitioners in the transportation and aviation industries must heed these findings to construct a compelling business case for expanding vertiport networks, ensuring profitability and regulatory compliance.

Recommendations

The successful implementation of vertiports in Brazil hinges on the following key recommendations:

1. **Regulatory Alignment:** Collaboration with Brazilian aviation authorities, such as ANAC, is essential to align vertiport operations with current and future regulations. Operators must ensure compliance while maintaining flexibility in infrastructure design to accommodate future adjustments as urban air mobility regulations evolve.
2. **Financial Feasibility:** Vertiport operators should actively explore public-private partnerships to reduce the initial investment burden. Leveraging government incentives focused on sustainable urban mobility is crucial to ensuring long-term profitability. The financial models presented in this study should guide investment strategies.
3. **Technological Readiness:** Operators must invest in flexible and scalable vertiport infrastructure that can accommodate the rapid advancements in eVTOL technology, particularly in charging stations and maintenance facilities. This will ensure long-term operational viability and competitiveness in the urban air mobility market.

4. **Future Research:** Further research is necessary to explore the environmental impact of eVTOL operations, particularly regarding noise pollution, energy consumption, and public acceptance. Studies should also focus on integrating vertiports with existing urban transportation systems to create a seamless, multimodal transportation network.

These recommendations offer a practical pathway for realizing the potential of vertiports in Brazil, ensuring their commercial viability while contributing to broader urban mobility and environmental goals.

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