

Evolution of Airport Terminals: Current Situation, Trends and Sustainability

Francisco Berenguel-Felices*, Roberto Alonso González-Lezcano, Juan Manuel Ros García

Department of Architecture and Design, Escuela Politécnica Superior, Universidad San Pablo-CEU, CEU Universities, Montepríncipe Campus, 28668 Boadilla del Monte, Madrid, Spain

*Corresponding author: francisco.berenguefelices@usp.ceu.es

<https://doi.org/10.5755/j01.sace.38.2.40885>

The human desire to fly has accompanied us throughout history, leaving evidence from the most ancient cultures. Leonardo da Vinci left us documents with designs for different devices that gave credence to the dream of flight. However, five hundred years passed before, on December 17, 1903, the Wright brothers successfully piloted an airplane. In just over a century, the evolution of this means of transportation, along with technological advances, has completely transformed the way humanity interacts, giving rise to the phenomenon of globalization. A prominent place in this panorama is occupied by airports, which technically are transportation hubs; symbolically, gateways to countries; and, buildings where one waits for connections between flights to any destination in the world. These unique venues have become icons of architecture and engineering. They seek to demonstrate their excellence to travelers, seeking rest and recreation amidst the rapid transit above the clouds. The research analyzes the evolution of these unique buildings, which have adapted their development and offerings to that of aircraft, their range, size, and speed. The causes and responses are highlighted. The changes introduced in the commitment to sustainability up to the current situation are also studied. Finally, trends in airport terminal design are summarized.

Keywords: airport capacity; airport efficiency; design review; historical evolution; passenger terminals.

On December 17, 1903, the Wright brothers managed to fly an airplane in a controlled manner, in the fourth and last flight, with Wilbur Wright as pilot, the distance traveled was 260 m and the time used was 59 seconds. Since then, the evolution has been very fast, radically changing the way of living on Earth, giving way to globalization, concerning the movement of people and the transfer of knowledge across international borders. July 25, 2019, recorded the day with the most air traffic in history with 230,000 flights, with peaks of more than 30,000 planes flying simultaneously. A snapshot of this day is depicted in Fig.1.

The rapid development led from pioneer flights to military aviation in the First World War, which ended; air traffic developed in a disorderly way in sport or military aerodromes. The first airport (Fig. 2) was the U.S. Army's College Park Airport, in Maryland near Washington, commissioned in 1909, still in operation. In the early years, in these aerostations, passengers, companions and visitors were mixed until the first ones boarded the aircraft. Once boundaries were established between those who flew and those who did not, the terminals were divided into airside and landside, in a safe and controlled manner (Bibián Díaz, 2014).

Sustainability in airport terminal buildings was a marginal issue until the 1960s. From the 1970s onwards, a minimal environmental focus, noise and basic ventilation began. In the 1990s passive measures were introduced (solar orientation, skylights, more thermally efficient materials)

JSACE 2/38

Evolution of
Airport Terminals:
Current Situation,
Trends and
Sustainability

Received
2025/04/03
Accepted after
revision
2025/09/12

Abstract

Introduction



Journal of Sustainable
Architecture and Civil Engineering
Vol. 2 / No. 38 / 2025
pp. 37-52
DOI 10.5755/j01.sace.38.2.40885

Fig. 1

July 25, 2019, busiest
air traffic day in history
(Source: flightradar24,
2019)



Fig. 2

The first airport (Source:
College Park Aviation
Museum)



and sustainability certifications appeared. With the turn of the century, bioclimatic design and active strategies (geothermal energy, green roofs, water reuse, solar panels) and optimized structural design (efficient modulation, lightweight roofs, recycled materials) are included from the design stage. London Heathrow's T5 (2008) integrated energy-saving strategies from the design stage; Singapore Changi's T3 and Madrid Barajas' T4+T4S stand out for their use of natural lighting, modular roofs, efficient ventilation and connection with the environment. Since then, it has continued to evolve significantly in recent years. Today, it has become central to the design, operation and public image of airports. This evolution responds to global environmental pressures, social demands and policies of energy efficiency, emissions reduction and climate responsibility. Authors such as Pitt et al (2009), Boer et al (2009), Nunes & Bennett (2010), Yim et al (2013) studied this field.

The object of the research is to study the evolution of terminal buildings by analyzing their typology, development and application, contemplating the advantages and disadvantages of each one. In this article, a bibliographic review of authors who have proposed different typologies of airport terminal buildings will be carried out. Its application to the terminals object of this study and its evolution caused by different causes. The current situation and typologies are going to be analyzed through three significant terminals put into service between 2018 and 2020. Finally, the trends that can be envisaged will be discussed.

Methodology

Given the different typologies that have occurred over time and the different classifications that have been provided by various authors, to establish a chronology and analyze the causes of the changes, we will proceed as follows:

1. Scientific bibliographic research will be carried out based on the evolution of air transport and the most significant airports in each era, and of the typology of airport terminal buildings. The changes in the sector and their consequences in the different design solutions of the terminal area will be analyzed to adapt to the successive changes. The different typologies will be related and explained.
2. Significant terminals throughout the history of air transport will be analyzed, as well as those of the latest new airports that are relevant for their function as international hubs or for their strategic location, with functionality criteria. Their typologies will be evaluated, pointing out their advantages and disadvantages, and will be associated with the characteristic typologies defined by the authors investigated.

3. The trends that can be glimpsed in the latest terminal buildings put into service and those under development will be pointed out.
4. Conclusions will be drawn, and recommendations will be made based on the analyses carried out.

Referential authors on airport design are Edwards (2004), Bradley (2010), Horonjeff et al (2010), Ashford et al (2011), Shuchi et al (2018). In addition, of course, to the widely applicable manuals of agencies and organizations such as International Air Transport Association (IATA), International Airport Council (ACI), International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA) and National Academies (USA), Eurocontrol and AENA.

Bibián Díaz (2014) publishes 4 examples of airport terminals from the 1930s, the cases considered are:

- Madrid Barajas, which analyzes the need to change the military base in Getafe to the new location in Barajas, the evolution of the competition, during turbulent years, the construction of the facilities in 1931, until the new terminal opened in 1953 and demolition of the previous building.
- Paris-Le Bourget, an airfield that existed since 1914 as a military base, after the armistice inaugurated the first scheduled flights between Paris and London, designated in 1919 first national airport, in 1924 opened a civilian area consisting of pavilions and hangars, until the opening of the first Tempelhof in 1929, Le Bourget was the busiest airport in Europe. In 1935, with the prospect of the Universal Exhibition of 1937, the remodeling of the country's first airport could not be postponed, and George Labro was entrusted with the job, in view of all the difficulties of the site at that time. Despite the efforts of all parties, its completion took place after the inauguration of the Exposition and ground communications were not adapted either. Nevertheless, the building attracted a great deal of attention and was included as a model project in the Royal Institute of British Architects (RIBA) exhibition of 1937. After World War II, Le Bourget quickly became obsolete, and traffic was gradually transferred to Orly.
- In 1935 Ireland, Canada, the United States and Great Britain signed an agreement on the provision of ground facilities for transatlantic flights. Routes across the North Atlantic had to pass through Ireland, the most westerly point north of Europe. New ground facilities were demanded, Collinstown, a former RAF military base in Dublin was designated as a new civilian airport and had to bring forward its operations. The new passenger terminal became essential. The design was commissioned to architect Desmond Fitzgerald, his ambitious project went ahead, opening in 1940, and after the World War ended, it was reopened and became the icon of the new Ireland.
- The last example involves a radical leap in scale. Tempelhof, the massive Berlin airport, built as the largest building of its time, is undoubtedly the ability of its promoters to anticipate the size and complexity that airports would reach in the following decades, thanks to that vision Tempelhof remained operational until 2008 without major modifications being probably the only airport of its importance that has long survived obsolescence.

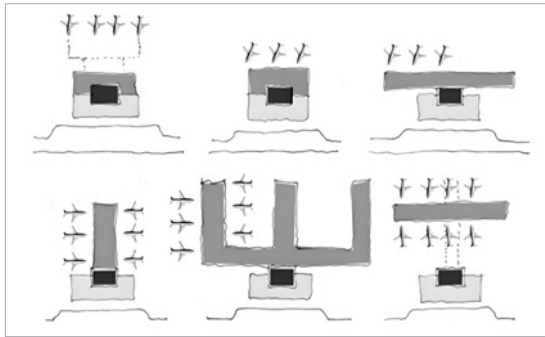
Araujo (2019) exposes that the architecture of each time following a rigorous process seeks the optimal solution, according to the typology of the project, among which he analyzes are the airport terminals. Following Louis H. Sullivan (1896) he wrote "form ever follows function". Araujo summarizes, also in a very clear way, the evolution of these buildings in their relationship with airplanes, as shown in Fig.3.

At first, airplanes cannot approach the terminal (1960s) and boarding and disembarkation is done remotely by shuttles (sketch above left); then, the evolution of airplanes allows them to reach the building; later, the increase in flights and traffic requires lengthening the dock; the next step

State of the art

Fig. 3

20th century terminal
typology (Source: Araujo,
2019)



is to place it perpendicular to the building to provide boarding gates on both sides of the dock; the dock continues to increase with a comb layout; to finish by arranging satellites linked by automatic trains.

Different authors, such as Horonjeff, McKelvey, Sproule and Young (2010) or Ashford, Mumayiz and Wright (2011), propose different typologies: linear (Los Angeles Airport), in jetty (Madrid Barajas

Airport T4 and T4S), in satellite (Heathrow Airport T5), in spine and comb (Munich Airport), in ring (Kansas City Airport), mixed flow (Frankfurt Airport, combination of jetty and satellite).

Ruiz Patón (2021) classifies the typologies of terminals built in the 21st century by assimilating their shape to letters, specifically C (which could well be a U), H and X. He interprets C as an evolution of the linear terminal, summarizing its design in an elongated main body at the ends of which piers are added (Seoul Incheon Airport T1, 2001; Tokyo Haneda Airport T2, 2004; Singapore Changi Airport, T3, 2008; Seoul Incheon Airport T2, 2018). It considers that the H derives from the previous one, it consists of a main body that acts as a junction of two (or four, depending on how they are arranged) perpendicular dykes, whose facades are in contact with the air side (Guangzhou Baiyun Airport T1, 2018). The X *"would be an evolution of the previous ones, a new type proper to the 21st century, involving a change in terminal design, a radial system with the advantages of the other types of centralization of facilities, together with symmetry in the interior order and airside serviced piers on both sides"* (Daxing Beijing Airport, 2019).

From the villa to the terminal building

The airport terminal building has evolved in parallel to aviation and the number of passengers. From the improvised hangar to the 1931 chalet at Madrid Barajas (Fig. 4) to wait for the few planes and passengers (González-Betes et al, 2003).

Fig. 4

Madrid Airport, Barajas
1931 (Source: AENA)

**Fig. 5**

Le Bourget Paris, 1937
(Source: Staff/AFP)



A significant change was the construction of the Paris Le Bourget terminal building (Fig. 5), waited for years, it was developed for the 1937 Universal Exposition, George Labro designed a 233 m. rectilinear building in which he used the marine metaphor of airport (Terrier, 2019).

The 1940 Dublin Airport (Fig. 6) made the terminal a circumference section in plan with the convex face on the air side (O'Brien, 2016).

Berlin Tempelhof (Fig. 7), built between 1936 and 1941, was a qualitative leap, it is the enormous scale and the surprising shape of the terminal, conceived by the German architect Ernst Sagebiel between 1934 and 1936 (based on Albert Speer's master plan), that is most striking about this colossal building.

The audacity of the metal arch with more than 50 meters in cantilever that resolves the terminal roof, and the clarity of the functional

**Fig. 6**

Dublin, 1940 (Source: Dublin Airport Authority)

Fig. 7

Tempelhof Berlin (Source: ENAIRE Foundation)

diagram are still what places the Berlin airport as an example of masterful engineering resolution (Fig. 8). Tempelhof is the precursor and predecessor model of today's super-terminals designed by Foster, Piano or Rogers. British architect Hugh Geoffrey Pearman said of Tempelhof: It was designed to last until the year 2000. Surprisingly, it has remained operational until 2008. Norman Foster described it as "the mother of all airports".

**Fig. 8**

Tempelhof airside, terminal roof (Source: ENAIRE Foundation)

After World War II, there was a rapid growth in the size of airplanes and passenger traffic. Araujo (2019) tells, that in the decade of the 60s of the last century, the use of jets increased the capacity of airplanes and they could no longer approach as to the terminal, transferring passengers by buses or shuttles, adopting then the terminal building its current form, with the section organized in two floors, departures in the upper one and arrivals in the lower one, which in turn, correspond to two levels in the access of road traffic in the so-called landside, where a large parking lot was located. The pioneer building was the Dulles terminal in Washington (Fig. 9) built between 1958 and 1962, designed by Eero Saarinen (Serraino, 2017).

However, the single terminal solution became obsolete in a short time giving way to a set of independent terminal buildings (distributed by airlines), known as satellites that are connected by corridors to the main building. Typology of Araujo's first sketch (2019).

Eero Saarinen himself designed the Trans World Airlines (TWA) terminal at New York's JFK airport (Fig.10) that was built between 1956 and 1962. The terminal ceased operations in 2001 following TWA's bankruptcy. This icon was placed on the U.S. National Register of Historic Places in 1994. It was restored and converted into the TWA Hotel (2019) which retains Saarinen's original design and combines it with an aviation museum, restaurants and a skating rink in winter. Typology of the sixth sketch (third from the second row on the right) by Araujo (2019).

The short life of the single terminal

**Fig. 9**

Dulles Washington, 1962 (Source: Deane Madsen)

Fig. 10

Trans World Airlines (TWA) Terminal, 1962 (Source: Donald Pittenger)

Mega airports with shopping malls

Fig. 11

Kansas City Missouri, 1972 (Source: Missouri Preservation)



Fig. 12

Tampa Airport (Florida, U.S.A.), 1971 (Source: Tampa Intl Airport)



Horonjeff (1969, 1976) lays the foundations for the planning and design of large airports and their corresponding terminal buildings at the end of the 20th century. Araujo (2019) tells that during the 1970s, there were two oil crises (1973 and 1979) and air terrorism appeared. This situation imposed security over efficiency. In addition, the Jumbo jet (Boeing 747) was built, which meant a considerable increase in the number of passengers, so airlines decided to look for flight connection points (hub), resulting in high waiting times in terminal buildings. Operators saw the need to entertain passengers as an opportunity to create commercial areas and obtain added profitability from the space occupied. This situation gave rise to mega-airports in which the aim was to reach boarding by car, as in the case of Kansas City (Missouri), 1972 (Fig. 11). This terminal would have a ring configuration, as seen in the State of the Art.

This idea makes them functional, as in the Tampa airport in Florida, despite not being one of the airports with the highest passenger traffic, it opted for a central building and satellites that are built as it grows, linked by automated trains, the first of which began operating in 1971 (Fig.12); the whole complex, main terminal and parking, (located between runways) linked in short distances horizontally and vertically in the terminal, by elevators and escalators, with optimal times for travel. Also in 1971, Southwest Airlines, the first low-cost airline, began flying, radically changing the existing concept of flying.

Turn of the century

De Neufville (1995) describes how airports will be in the 21st century, emphasizing the location of the terminal in the middle of the airfield, between runways, connected to the landside terminal by means of automatic trains. De Neufville himself, together with other authors, such as Rojas Guzmán (1998), Belin (2002) and Odoni (2003), describe different aspects of the design to gain efficiency in operations and greater profitability in airport exploitation. De Neufville (2006), analyzes the consequences of commercial liberalization and the appearance and great growth of low-cost companies and traffic; furthermore (2007), describes the exclusive low-cost terminal

Fig. 13

London Stansted Airport, Terminal Building, 1991 (Source: Macalloy)



buildings (London Stansted, Norman Foster 1991, (Fig. 13) and analyzes the efforts that conventional terminals must make to adapt to low-cost airlines, emphasizing flexibility and efficiency.

Baker (2014) also analyzes the model. The low-cost phenomenon, the automated trains, the automated baggage handling system, moving walkways, check-in machines, VIP lounges, hotels, and other services offered

have transformed terminals into what they are today. Older airports have opted to grow by adding terminals, while newer ones have opted for a mega-airport structure. The review of significant terminals begins, in addition to the prototype of an exclusive low-cost terminal seen above, with Kansai Osaka Airport, whose basic design was carried out by Paul Andreu and the Aéroports de Paris (ADP) engineering firm in 1987. Renzo Piano (Piano, 2005 and Jodidio, 2011) was selected to develop the architecture of terminal T1 (Fig. 14), with a length of 1.7 km and an unusual curvature in its longitudinal profile to maintain visual contact with the aircraft that always record air traffic. It was put into service in 1994.

Following the authors' classifications contemplated in the State of the Art, its typology would be a dock; Araujo (2019) reflects this



Fig. 14

Kansai Osaka Airport T1
(Source: Vinci Airports)



Fig. 15

Chek Lap Kok Airport
Hong Kong, 1998 (Source:
Foster + Partners)

evolution in the third sketch (top right row of Fig.3). Advantages include the centralization of the central body and the fact that most of the dock's length is available for direct boarding gates; disadvantages include the length of the routes to the furthest gates.

Foster+Partners designed Hong Kong Airport on Chek Lap Kok Island in 1998 (Leslie Jones Architecture, 2017), which was then considered the best in the world (Fig. 15). Its typology, in accordance with the authors cited in the State of the Art, was spine-shaped and branched, a variant of that of the Munich terminal. Araujo (2019) captures this evolution in the fourth sketch (first from the left in the second row) in Fig. 3. In this case, a branching of two open docks develops at the far end of the terminal towards the apron. The advantage of this arrangement is to maximize the length of contact with the apron (on both sides of the docks), accommodating numerous boarding gates with direct contact; the problem is the travel times to the gates furthest from the central core of the terminal.

Hesse Martín (2006), Fernel Fernández (2006), Lamela and de Vargas (2005), Lamela Martínez (2006) and Estudio Lamela and Richard Rogers Partnership (2007) explain from different aspects the expansion of Madrid-Barajas Airport, inaugurated in 2006, and above all, the design, functionality and construction parameters of the new terminal area, which includes T4 (Fig. 16) and the T4S satellite. More recently, Sismanidou and Tarradellas (2017) studied flexible planning in airport capacity expansions, applying lessons learned in the aforementioned new terminal area. Its typology is similar to T1 at Kansai Osaka, although in the case of T4, it has a satellite between runways with a similar configuration, cited in the State of the Art, called a pier; Araujo (2019) collects this evolution in the third sketch (top right row of Fig. 3). The advantages and disadvantages have been mentioned for Kansai Osaka. In the case of Madrid, the satellite building is 2.5 km from Terminal 4 (which is the landside access), connected by an automatic train (Automatic People Mover) in a 4-minute tunnel. Using the T4S satellite improves aircraft movement by connecting to runways; however, it lengthens travel times, since although the transfer is fast, it requires access to station level and waiting for trains.

Fig. 16

Madrid Barajas Airport
T4+T4S, 2006 (Source:
AENA)



Fig. 17

London Heathrow Airport
T5, 2008 (Source: RSHP)



Fig. 18

Beijing Capital Airport T3,
2008 (Source: Foster +
Partners)



Fig. 19

Dubai Airport T3, 2008
(CC BY-SA)



Fig. 20

London Heathrow Airport
T2 and T2B, 2014
(Source: Derek Winsor)



En In 2008, Heathrow T5 (McKechnie et al., 2008) by Richard Rogers (Powell, 2006) (Fig. 17), Beijing Capital T3 by Foster+Partners (Fig. 18) and Dubai T3 (Fig. 19) by Paul Andreu (Jodidio, 2004) were opened. Heathrow T2 by Luis Vidal and T2B by Grimshaw in 2014 both (Fig. 20).

The typologies of Heathrow's T5 and T2 terminals are similar: central core and satellites. T5 is cited in the State of the Art; its functionality is good, like that of American terminal buildings. Araujo represents this typology as the latest step in evolution (sixth sketch, third from the right in the second row). Regarding advantages and disadvantages, this has been mentioned previously.

Foster's T3 at Beijing Capital has a clear spine typology, in line with the references considered, and always with variations. Fig. 17 shows the connection of the spine with the central terminal through large-radius curves that increase the contact length with the platform and, therefore, the number of boarding gates. The advantages and disadvantages are like the previously seen cases with this typology; in this case, this wide curvature also helps to reduce distances traveled. Dubai Terminal 3 has a satellite typology in the middle of the apron, offering its entire length on both sides as the positioning of boarding gates, as its main advantage; its disadvantages are its distance from the airport's central core and the dispersion of services, commercial areas, and facilities.

It can be deduced from the allocation of typologies described by different authors that the design of these terminal buildings included in the analysis dates to the 20th century. Some (Kansai Osaka and Chek Lap Kok Hong Kong) were conceived and built at that time, but the generation of terminal buildings put

into service since 2006 radically changed the design parameters followed until then, significantly expanding the surface areas. Their functionality significantly improves on that of their previous airports; however, these expansions are heavily influenced by all the previously existing facilities, which prevents them from achieving the values they would have achieved by their own design. It will be the entirely new airports brought into service in recent years that will aspire to achieve this excellence.

Singapore Changi deserves a mention. In 2019, it opened the Jewel Changi Airport space (Fig. 21) designed by Moshe Safdie. It looks like a large glass bubble, built on the former parking lot of Terminal 1, connected to the latter and connected by moving walkways



Fig. 21

Singapore Changi Airport
(Source: NACO)



Fig. 22

Amsterdam Schiphol,
planned 2027
(Source: Kaan Architecten
& Estudio Lamela)

to Terminals 2 and 3, and buses to Terminal 4. It is a meeting point with a large grove, a 40-meter waterfall, theme parks, cinemas, and some 300 shops. It focuses on "the experience."

Ruiz Patón (2021) associates the T3 typology with a C, as we have seen, or an H, considering the whole, but with a transfer between long-haul terminals (via conveyor belts or buses).

Furthermore, major airport expansions are underway, such as the construction of Terminal A at Schiphol (Fig. 22), scheduled for 2027 and designed by KAAN Architecten and Estudio Lamela (2020).

Hartsfield-Jackson Atlanta Airport deserves special mention. Opened in 1926, the first finger-board was installed in 1959, and since 1998, it has become the busiest airport in the world. This is still the case, except for 2020 due to the COVID pandemic. Two terminals, the international



**The busiest
airport in the
world**

Fig. 23

Hartsfield-Jackson
Airport (Source: Atlanta
Department of Aviation)

one opened in 2012, and five parallel satellites located between them, all in the middle of the airfield, which has five parallel runways; all these elements are part of a perfect mechanism for processing flights, passengers, and cargo, with adequate infrastructure and very high standards of functionality and quality. This is the explanation in airport terms (Fig. 23). Its typology, terminals with satellites, all parallel and connected elements.

To the aeronautical explanation, we must add the strategic location factors, since more than 80% of the US population is less than two hours away by flight from Atlanta, and Delta Airlines, one of the largest companies in the sector, has its main base of operations at this airport.

New airports facing new challenges

The three major new airports opened between 2019 and 2020 are: Istanbul (April 2019), Beijing Daxing (September 2019) and Berlin Brandenburg (October 2020). The first two projects, before the pandemic, planned to reach 200 Mpax/year by 2028 in Istanbul and 130 Mpax/year by 2030 in Daxing, Beijing. The functionality of the terminal building designed by Zaha Hadid (Jodidio, 2024) at Beijing Daxing Airport (Fig. 24) is noteworthy. Upon its opening, it became the largest airport terminal building in the world at 698,000 m².

Zaha Hadid Architects collaborated with ADPI (Aéroports de Paris Engineering) to develop the project. Despite its large size, project manager Cristiano Ceccato states: "The terminal layout minimizes walking distances between check-in and the boarding gate, as well as the distances between gates for passenger transfers, to a maximum of eight minutes on foot." Furthermore, domestic and international travelers are grouped on different levels. Ceccato continues his description: "With the domestic and international areas distributed vertically—rather than horizontally—we allow for a more congestion-free space for passengers." The terminal building, which has four levels, is distributed around a large central courtyard lit from above with natural light, which the design studio refers to as a "centrally oriented spatial dome," from which the five berthing bays (where the 79 boarding gates are located at the time of its commissioning) project, giving the building the appearance of a starfish in plain view. Various spaces such as check-in and the international security desks are organized around the courtyard on different levels. "The terminal's compact radial design allows a maximum number of aircraft to be parked directly in the terminal with minimal distances from the center of the building, providing exceptional passenger comfort and operational flexibility," says Zaha Hadid Architects.

Fig. 24

Beijing Daxing Airport,
2019 (Source: Xinhua/Ju
Huanzong)



The airport is supplied by solar panels and has a centralized heating system with waste heat recovery implemented by a ground-source heat pump. It also has a rainwater collection and management system. There is a sixth arm in the building that allows landside access, access roads with corresponding departure and arrival curbs, and parking. This arm also houses the transportation hub with local and

high-speed rail stations, as well as a hotel and offices. Planning before the pandemic estimated initial traffic of 45 Mpax/year, hoping to reach 72 Mpax/year by 2025, with an airfield with four runways. By 2030, the airfield was expected to reach 130 Mpax/year, having expanded the airfield to seven runways, one for military use.

As reported in the State of the Art, for Ruiz Patón (2021), the X-shaped typology is new, typical of the 21st century, in this way, Daxing Beijing with this arrangement achieves the best proposal; resources, services and routes are optimized; it saves on facilities, makes all spaces functional, without corridors or lobbies. According to Ruiz Patón, Zaha Hadid, who is characterized by avoiding the axes of symmetry in favor of a free flow of the structure, however, here she resorts to radial star symmetry to give maximum surface area to the air side and minimum routes for passengers, following the maxim: form follows function.

The Istanbul Airport terminal building (Fig. 25) covers an area of 1,400,000 m², making it the largest terminal in the world. It was designed to handle up to 90 million passengers annually in its initial phase. The full expansion will reach 200 million passengers per year with two additional terminal buildings. The airfield currently has four runways. Once fully completed, it is planned to have two more runways, for a total of six.

Its design achieves an efficient distribution of space to reduce transit times and maximize passenger comfort. It would have an H-shaped typology (according to Ruiz Patón, 2021), with very open curves at the ends and a central dam perpendicular to the one that connects the previous ones. While this is not the optimal configuration, having a disproportionately large central core (without boarding gates) through which all passengers pass optimizes the commercial area, although the distances to the furthest boarding gates on the dams can be considerable.



Fig. 25

Istanbul Airport, 2019
(CC BY-SA 4.0)



Fig. 26

Berlin Brandenburg
Airport, 2020 (Source:
Mario Hagen/Pixabay)

Berlin Brandenburg Airport is in Schönefeld, 18 km from Berlin. It has a capacity for 27 million passengers per year with a potential expansion of 58 million. It currently consists of three terminals. Terminal 1 (Figure 26), designed by Gerkan, Marg und Partner (GMP), is the main terminal, covering an area of 360,000 m² and with a design capacity of 25 Mpax/year. The airfield has two runways.

Terminal T2 is the smallest terminal and is intended for low-cost flights. Finally, Terminal T5 was the former Berlin-Schönefeld Airport, which closed in 2021; however, it is ready to reopen if necessary. The airfield has two parallel runways.

The new Terminal T1 is an old-fashioned solution, more typical of the last century: the dam attached to the dam's facade in the shape of an inverted C relative to the apron. This layout doesn't even allow for boarding gates on both sides of the dam (the C would do it). It's difficult to understand the choice of this shape, considering that the rigidity of the old terminal didn't exist; the nearest terminal, T2, is small and unrestrictive, nor does T5, which was the terminal of the former Berlin-Schönefeld Airport, which is far from the operating area. If the intention in the future is to move to an H configuration, with a vertical connection between the long, parallel breakwaters, the possibility of laying on both sides of the constructed breakwaters would still be lost; the new ones would provide it. In any case, travel times would not be improved, nor would functionality. Years before the commissioning of the breakwater, Beria and Scholz (2008) made a comparison with Milan Malpensa's failed attempt to become a major international hub and drew lessons to be applied at Berlin Brandenburg Airport.

The following summarizes the trends in recent airport buildings and those currently underway:

1. Design of terminal buildings with multiple connected docks in a large central area. Examples include Doha Hamad Airport in Qatar (2014), Istanbul in Turkey (late 2018, 2019), and Daxing Airport in Beijing (2019).
2. Biometric terminals and "One ID" (without physical borders): Elimination of traditional counters, with fully automated check-in. Use of facial biometrics and document recognition for boarding. Examples include T4 at Singapore Changi (2017, implementation of "One ID" without human interaction), Dubai (2023, biometric passports and automatic gates), and Los Angeles (2024, biometric controls throughout the terminal).

Current situation and trends

3. Smart and hyperconnected terminals: Integration of artificial intelligence, big data, and 5G. Real-time sensors for traffic management and demand prediction. Use of augmented reality and custom applications to guide passengers. Examples include Hong Kong Terminal Midfield (2015, the first terminal to use AI to automate passenger flow and baggage handling), Seoul Incheon Terminal 2 (2018, smart sensors that predict crowding and adjust operations in real time), and London Heathrow Terminal 5 (under development, planned to become a fully digital terminal by 2030).
4. Modular and sustainable terminals: Buildings designed to adapt to traffic changes without major renovations. Reducing environmental impact through the installation of solar panels, water management, and natural ventilation. Examples include Oslo Gardermoen in Norway (2017, the world's first carbon-neutral airport, using recycled materials and renewable energy), and La Guardia Terminal B in New York (2022, modular renovation to facilitate future expansions without disrupting operations), Stuttgart, Germany (2024, low-energy and electrical self-sufficiency project).

Discussion and conclusions

A review has been conducted of the evolution of significant terminal buildings and their causes, from the late 1930s to the present. It has been possible to observe at Le Bourget in Paris, Dublin, and especially Tempelhof in Berlin, how these constructions sought to adapt to the needs of the passengers of the time and the planes that transported them. Tempelhof's dimensions and 60-year prognosis are impressive today, particularly striking is the shelter it offered through its spectacular roof, designed to mitigate inclement weather for travelers while accommodating the planes themselves. Eero Saarinen's designs were innovative and functional in their time, introducing separate levels for departures and arrivals in a single terminal at Dulles and providing an iconic status with the addition of terminals like the TWA terminal at JFK. We have been able to observe the pragmatic minimalism of Norman Foster at London's Stansted, which responded to the needs of low-cost airlines, as well as the innovative response at the end of the 20th century, showing what terminal buildings would later look like at Chek Lap Kok in Hong Kong. A few years earlier, Piano's impressive Terminal 1 at Kansai Osaka foreshadowed what the next generation of terminals would look like. We have also reviewed the break it represented with respect to design parameters in the new terminal buildings that were being added or replaced at older traditional airports that had already undergone major prior renovations, such as Madrid Barajas with Terminal 4 and Terminal 4S by Rogers and Lamela; London Heathrow with Terminal 5 by Rogers and Terminal 2 by Vidal; the respective Terminal 3 of Beijing Capital by Foster and Terminal 3 of Dubai by Paul Andreu; the Jewell Changi Airport space designed by Safdie in Singapore Changi, offering an enclosed meeting point with a grove, waterfall, theme park, cinemas, and hundreds of shops; an offer that competes with Dubai and Schiphol for unique, original, and attractive offers to visit them on purpose.

The most important conclusion drawn from the research presented in this article is that, starting in the 1960s, the evolution of terminal building typologies is directly related to the increase in boarding gates, offering longer contact lengths between docks and platforms to accommodate walkways that allow direct access to aircraft, improving service quality by reducing operating and travel times. This increase in dock length also increases the distances to the gates furthest from the central core, hence the variety of typological proposals and the mix of solutions.

The introduction of key elements has also been highlighted, such as the separation of landside and airside, the installation of the first jetway (Hartsfield-Jackson Atlanta, 1959), the split level of departures and arrivals (Dulles Washington, 1962), the commissioning of the first automatic train between the terminal and the satellite (Tampa Florida, 1971), functional minimalism in exclusive low-cost airports (London Stansted, 1994), and the introduction of a new typology appropriate for the 21st century (Daxing Beijing, 2019). To name a few considered significant.

Regarding complete new facilities, three of the most recently completed ones were chosen: Daxing Beijing, Istanbul, and Berlin Brandenburg. Of these, the one carried out in Germany is particularly striking. The outdated proposal from Berlin Brandenburg, the disproportionate response from Istanbul, and the functional excellence and new typological contribution of Daxing Beijing are striking.

Regarding design trends, the revival of single terminals, due to their functional advantages and concentration of services and facilities, although Daxing has shown the way, this terminal truly has double symmetry, and the possibilities and limits of buildings with radial symmetry will need to be explored. The idea of interconnected terminals remains open; in fact, it is the initial solution proposed by Paul Andreu for the new Al Maktoum Airport in Dubai: a network of terminal buildings connected to each other, forming a mesh. Its operation and functionality will need to be analyzed.

Regarding the application of new technologies, automated systems are already in operation in several terminals at all stages of the journey through the terminal building, including identification, boarding passes, check-in, and baggage claim. Regarding sustainability in terminal buildings, it is developed with a holistic approach, integrating a strategy into the airport as a whole. According to Zhou & Yang (2016), Rodríguez-Díaz (2017), ACI (2019), IATA (2021), the goal is for these large infrastructures to be carbon neutral, have a minimal water footprint, have regenerative landscaping, and have electric mobility. The facilities are equipped with intelligent digital systems to measure and control consumption, CO₂, occupancy, and comfort, and the passenger experience is evaluated. Sustainability in terminals today focuses on: a) Efficient passive and active design. b) Certifications and transparency. c) Use of renewable energy. d) Modular and adaptable design. e) Local, recycled, or low-impact materials. f) Connection to different modes of public transport. g) The passenger experience is included as part of environmental well-being.

The authors wish to thank CEU San Pablo University Foundation for the funds dedicated to the ARIE Research Group, through the project Ref. G20/6-06- MGI24RGL provided by the CEU San Pablo University.

Acknowledgment

References

- Airports Council International (ACI). (2019). Airport Carbon Accreditation Annual Report. Montreal: ACI World.
- Aeropuerto Hartsfield-Jackson Atlanta. (2024). Los diez aeropuertos más concurridos del mundo. Airport Technology https://www-airport--technology-com.translate.google.com/features/the-top-10-busiest-airports-in-the-world/?_x_tr_sl=en&_x_tr_tl=es&_x_tr_hl=es&_x_tr_pto=rq&cf-view
- Araujo, R. (2019). *La Arquitectura como ciencia: principios de proyecto y tipos de edificios*. Barcelona, España: Editorial Reverte: 257-272. ISBN: 978-84-291-3105-5.
- Ashford, N. J., Mumayiz, S., & Wright, P. H. (2011). *Airport engineering: planning, design, and development of 21st century airports*. Hoboken, New Jersey, USA: John Wiley & Sons. <https://doi.org/10.1002/9780470950074>
- Baker, D. M. (2014). Low-cost airlines management model and customer satisfaction. *International Journal of Economics, Commerce and Management*, 2(9). <https://www.citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.679.4958&rep=rep1&type=pdf> <https://doi.org/10.11634/216837861302317>
- Beria, P. & Scholz, A.B. (2008). Strategies for infrastructure development of airports: A comparison between Milan Malpensa and Berlin. Brandenburg International. International. ATRS Conference.
- Bibián Díaz, C. (2014). *Arquitectura De Aeropuertos: Cuatro Ejemplos De Terminales Aeroportuarias De La Década De 1930 = Architecture of Airports. Four Air Terminal Examples of the 30s*. Cuaderno De Notas, 0(15). <http://polired.upm.es/index.php/cuadernode-notas/article/view/2955> <https://doi.org/10.20868/cn.2014.2955>
- Bobadilla, M. (2020). *El aeropuertos de Berlín-Tempelhof: materialización estética del régimen nazi*.

- Bitácora Arquitectura. <https://doi.org/10.22201/fa.14058901p.2018.38.67057>
- Boer, E., Suter, S., & de Haan, P. (2009). Greenhouse gas emissions from aviation. In OECD/ITF (Eds.), *Transport and Environment*. Paris: OECD Publishing.
- Bradley, A.L.W. (2010). *The independent airport planning manual*. Great Abington, Cambridge, U.K.: 1-78. ISBN: 978-0-85709-140-6. <https://doi.org/10.1533/9780857090355>
- Davies, A.; Gann, D. and Douglas, T. (2009). Innovation in Megaprojects: SYSTEMS INTEGRATION AT LONDON HEATHROW TERMINAL 5. *California Management Review* 51 (2): 101-+. <https://doi.org/10.2307/41166482>
- de la Portilla S.S. y Chávez, M. A. (2019). Airports, Cultural Gates: The Case of Innovative Cities of Pekin and Hong-Kong. *Online Journal Mundo Asia Pacifico* 8 (14): 86-90. <https://publicaciones.eafit.edu.co/index.php/map/article/view/6006>
- de Neufville, R. (1995). Designing Airport Passenger Buildings for the 21st-Century. *Proceedings of the Institution of Civil Engineers-Transport* 111 (2): 97-104. <https://doi.org/10.1680/itrn.1995.27577>
- de Neufville, R. (2006). Accommodating Low Cost Airlines at Main Airports. *Transportation Research Board*. https://www.researchgate.net/profile/Richard_De_Neufville/publication/237430003_Accommodating_Low_Cost_Airlines_at_Main_Airports/links/00b49527a79f80724d000000/Accommodating-Low-Cost-Airlines-at-Main-Airports.pdf
- de Neufville, R. (2007). Low-Cost Airports for Low-Cost Airlines: Flexible Design to Manage the Risks. *Transportation Planning and Technology*. <https://doi.org/10.1080/03081060701835688>
- de Neufville, R. and Rojas Guzmán, J. (1998). Benchmarking for Design of Major Airports Worldwide. *Journal of Transportation Engineering-ASCE* 124 (4): 391-395. [https://doi.org/10.1061/\(ASCE\)0733-947X\(1998\)124:4\(391\)](https://doi.org/10.1061/(ASCE)0733-947X(1998)124:4(391))
- de Neufville, R. and Belin, S. C. (2002). Airport Passenger Buildings: Efficiency through Shared use of Facilities. *Journal of Transportation Engineering-ASCE* 128 (3): 201-210. [https://doi.org/10.1061/\(ASCE\)0733-947X\(2002\)128:3\(201\)](https://doi.org/10.1061/(ASCE)0733-947X(2002)128:3(201))
- de Neufville, R. and Odoni, A. (2003) *Airport systems. Planning, design and management*. New York, USA: McGraw-Hill, Incorporated. ISBN: 0071384774.
- Edwards, B. (2004). *The modern airport terminal: New approaches to airport architecture*. Nueva York, Taylor & Francis. ISBN: 978-0415248129. <https://doi.org/10.4324/9780203646878>
- Estudio Lamela y Richard Rogers Partnership. (2007). *Nueva Área Terminal T4 Del Aeropuerto Madrid-Barajas*. TC Cuadernos. Tribuna De La Construcción (76). ISSN: 1136-906X.
- Estudio Lamela. (2020). <https://www.lamela.com/proyectos/nueva-terminal-del-aeropuerto-de-schiphol/>
- Fernel Fernández, J. P. (2006). *Aparcamiento Y Accesos De La Nueva Área Terminal*. Hormigón Y Acero 57 (239). ISSN: 0439-5689. <http://www.hormigonyacero.com/index.php/ache/article/view/131>
- Foster+Partners. (1998). *Hong-Kong International Airport*. <https://www.fosterandpartners.com/es/projects/hong-kong-international-airport>
- Foster+Partners. (2008). *Beijing Capital International Airport*. <https://www.fosterandpartners.com/projects/beijing-capital-international-airport/>
- Gerkan, Marg und Partner (GMP). (2012). <https://www.gmp.de/en/>
- González-Betes, A.; Rodríguez-Carmona, J. y Rubio García, R. (2003). *Los Primeros Vuelos y Aeródromos en las Capitales Españolas*. Barcelona, España: INE-CO/TIFSA ed. Lunwerg Editores.
- Hesse Martín, J. M. (2006). *Planteamiento Aeroportuario De La Nueva Área Terminal*. Hormigón Y Acero 57 (239). ISSN: 0439-5689. <http://www.hormigonyacero.com/index.php/ache/article/view/128>
- Horonjeff, R. (1969). Analysis of Passenger and Baggage Flows in Airport Terminal Buildings. *American Institute of Aeronautics and Astronautics, Journal of Aircraft*, vol. 5, nº 5. <https://doi.org/10.2514/3.59431>
- Horonjeff, R. (1976). *Planificación Y Diseño De Aeroportos*. primera edición española ed. Madrid, España: Librería Técnica Bellisco: 273-317.
- Horonjeff, R., McKelvey, F. X., Sproule, W. J., & Young, S. B. (2010). *Planning and Design of Airports*. New York: McGraw-Hill Education.
- International Air Transport Association (IATA). (2021). *Guidance on Environmental Assessment for Airports*. Montreal: IATA.
- Jodidio, P. (2004). *Paul Andreu Architect*. Basel, Switzerland: Editorial: BIRKHAUSER VERLAG AG: 34-87; 92-97; 104-107; 112-119; 140-157; 174-177. ISBN: 978-3-7643-7010-7

- Jodidio, P. (2011). *Piano-Renzo Piano Building Workshop 1966 to today*. Colonia, Alemania: Editorial Taschen: 206-229. ISBN: 978-3-8365-0323-5
- Jodidio, P. (2024). *Zaha Hadid. Complete Works 1979 - Today*. (e. O. 2005 Taschen GmbH) Colonia, Alemania: Editorial Taschen: 518-523. ISBN: 978-3-8365-7244-6
- Kaan Architecten (2020). <https://kaanarchitecten.com>
- Lamela y de Vargas, C. (2005). *Estudio Lamela Arquitectos*. Madrid, España: Da Vinci: 30-4. ISBN: 84-496-0123-1 España.
- Lamela Martínez, A. (2006). Nueva Área Terminal (NAT) Del Aeropuerto De Madrid-Barajas T-4. *Informes De La Construcción* 58 (501): 5-22. <http://informesdelaconstruccion.revistas.csic.es/index.php/informesdelaconstruccion/article/view/395> <https://doi.org/10.3989/ic.2006.v58.i501.395>
- Leslie Jones Architecture. (2015). <https://www.leslie-jones.co.uk/news/dubai-airports-sets-commercial-course-for-dubai-world-central/>
- Leslie Jones Architecture. (2017). <https://www.leslie-jones.co.uk/projects/hong-kong-international-airport/>
- Luis Vidal+Arquitectos. (2014). <https://luisvidal.com/en/>
- London Stansted International Airport. (1991). *Terminal Building*. <https://macalloy.com/project/stansted-airport-uk/>
- McKechnie, S.; Mitchell, D.; Frankland, W. and Drake, M. (2008). Heathrow Terminal 5: Terminals T5A and T5B. *Proceedings of the Institution of Civil Engineers-Civil Engineering* 161 (5): 45-53. <https://doi.org/10.1680/cien.2007.161.5.45>
- Nunes, F. M., & Bennett, J. (2010). The role of performance measurement systems in promoting sustainability in airports. *Environment and Planning A*, 42(8), 1893-1910. <https://doi.org/10.1068/a42105>
- O'Brien, S. (2016). Fitzgerald, Desmond (1911-1987). *Routledge Encyclopedia of Modernism*. Londres, Reino Unido: Taylor and Francis. <https://www.rem.routledge.com/articles/fitzgerald-desmond-1911-1987>. <https://doi.org/10.4324/9781135000356-REM220-1>
- Odoni, A. and de Neufville, R. (1992). Passenger Terminal Design. *Transportation Research Part A-Policy and Practice* 26A (1), pp. 27-35. [https://doi.org/10.1016/0965-8564\(92\)90042-6](https://doi.org/10.1016/0965-8564(92)90042-6)
- Piano, R. (2005). *Giornale di bordo*. Firenze, Italia: Passigli Editori: 154-167.
- Pitt, M., Tucker, M., Riley, M., & Longden, J. (2009). Towards sustainable construction: promotion and best practices. *Structural Survey*, 27(3), 187-196. <https://doi.org/10.1108/02630800910971396>
- Powell, K. (2006). *Richard Rogers. Architecture of the future*. Basel, Switzerland: Birkhäuser: 464-473. ISBN: 978-3-7643-7049-7
- Rodríguez-Díaz, A. (2017). Sustainable airport design: Integrating environmental concerns in airport terminal projects. *Journal of Air Transport Management*, 62, 34-43. <https://doi.org/10.1016/j.jairtraman.2017.03.006>
- Ruiz Patón, A. (2021). *Grandes terminales aeroportuarias del siglo XXI: Un estudio tipológico*. TFG ETSAM Universidad Politécnica de Madrid. https://oa.upm.es/67612/1/TFG_Jun21_Ruiz_Paton_Alba.pdf
- Safdie, M. (2019). *Jewell Changi Airport*. Singapore Changi. <https://www.safdiearchitects.com/projects>
- Serraino, P. (2017). Saarinen: Eero Saarinen 1910-1961 "Un expresionista estructural". Colonia, Alemania: Editorial Taschen: 60-67; 82-87.
- Shuchi, S.; Drogemuller, R. and Buys, L. (2018). Flexibility in airport terminals: Identification of design factors. *Journal of Airport Management*, Henry Stewart Publications, vol. 12(1): 90-108. <https://doi.org/10.69554/JWOA2744>
- Sismanidou, A. and J. Tarradellas. (2017). Traffic Demand Forecasting and Flexible Planning in Airport Capacity Expansions: Lessons from the Madrid-Barajas New Terminal Area Master Plan. *Case studies on transport policy*, Elsevier, Vol. 5, Issue 2: 188-199. <https://doi.org/10.1016/j.cstp.2016.08.003>
- Terrier, J.E. (2019). *Aéroport de Paris-Le Bourget 1910-2019. Un siècle d'histoire*. Paris, France: Amarena Éditions. ISBN: 978-2-9568579-0-7
- Yim, S. H. L., Stettler, M. E. J., & Barrett, S. R. H. (2013). Air quality and public health impacts of UK airports. Part II: Impacts and policy assessment. *Atmospheric Environment*, 67, 184-192. <https://doi.org/10.1016/j.atmosenv.2012.10.032>
- Zaha Hadid Architects. (2019). *Beijing New Airport Terminal Building*. <http://www.zahahadid.com/architecture/beijing-new-airport-terminal-building/>
- Zhou, X., & Yang, H. (2016). Low-carbon design for airport terminal buildings. *Energy and Buildings*, 133, 91-102. <https://doi.org/10.1016/j.enbuild.2016.09.053>

About the authors

FRANCISCO BERENGUEL-FELICES

Researcher

Department of Architecture and Design, Escuela Politécnica Superior, Universidad San Pablo-CEU, CEU Universities

Main research area

Design review; sustainable architecture; sustainable constructions; civil engineering and architecture

Address

Address Avda Montepíncipe s/n. Montepíncipe Campus, 28668 Boadilla del Monte, Madrid, Spain
E-mail: francisco.berenguefelices@usp.ceu.es

ROBERTO ALONSO GONZÁLEZ-LEZCANO

Full Professor

Department of Architecture and Design, Escuela Politécnica Superior, Universidad San Pablo-CEU, CEU Universities

Main research area

Efficient facilities; sustainable architecture; sustainable constructions; civil engineering and architecture

Address

Avda Montepíncipe s/n. Montepíncipe Campus, 28668 Boadilla del Monte, Madrid, Spain
E-mail: rgonzalezcano@ceu.es

JUAN MANUEL ROS GARCÍA

Full Professor

Department of Architecture and Design, Escuela Politécnica Superior, Universidad San Pablo-CEU, CEU Universities

Main research area

Architectural projects; sustainable architecture; sustainable constructions; civil engineering and architecture

Address

Avda Montepíncipe s/n. Montepíncipe Campus, 28668 Boadilla del Monte, Madrid, Spain
E-mail: jmros.eps@ceu.es