Global Scientific JOURNALS

GSJ: Volume 10, Issue 4, April 2022, Online: ISSN 2320-9186

www.globalscientificjournal.com

Sustainable Airport Passenger Terminal Design – A Review of the Architecture of Terminal 3 Jewel Changi Airport, Singapore

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Abstract

This study examines design practices in airport passenger terminal design with the sustainability of the building as a primary consideration. The aims of this research are to draw important conclusions about sustainable airport design from a rigorous review of Jewel Changi Airport T3 using the case study research method. From the key findings it was observed that the terminal interior is designed to connect with the groundside landscape, building performance, and green technology, resulting in an articulated design approach. Horizontal integration by the green continuation from the airport groundside to within the terminal through a succession of transparent surfaces of the building is one of the design components of sustainable thinking in Jewel Changi Airport T3. The terminal's large green walls and various plant communities, on the other hand, incorporate natural performance and systems into the architecture. The futuristic interior concept and design for thorough bio-integration should be further developed with integrative thinking and multidisciplinary approaches to transcend dualistic thinking, as a futuristic concept perceives feedback dynamic through systematic integration of mechanical parts and the human body's natural mechanisms. For an ecologically friendly airport, architects, landscape architects, and technology engineers may push the boundaries of hybrid design and culture. To be implemented in the form of an assessment study of the real situation in the selected case study, leading to the identification of findings, conclusions and recommendations.

Keywords*: sustainability, green technology, building performance, bio-integration, ecologically friendly*

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1. Introduction

A passenger airport terminal is one of the most complicated types of structures. Airports vary in size and architectural style, but all serve visitors by offering a particular level of necessary processes (immigration, customs, security check, etc.) based on high-tech computerized technology, as well as supplementary services such as duty free stores or restaurants. They are operational for the most of the day and night, allowing uninterrupted passage of travelers via halls, hallways, gates, and so on. In compared to other types of buildings, the aforementioned variables result in comparatively significant energy usage. As a result, ethical architectural and engineering concepts are unavoidable in today's highly developed, environmentally conscious civilizations. Recent trends in passenger terminal architecture are explored in this study.

An airport that is a product of advanced technology has ignored natural environs and relied only on architectural methods. Airports are typically used as global trading centres as well as national gates or entrances across the world. Because of its significance as a national entry, the design quality, programming diversity, and functional efficiency are being assessed more closely. In the instance of Singapore's Changi Airport, the interior landscape of Terminal 3 (T3) has received international attention for its integrated approach of architecture and landscape architecture in airport design. The relevance of sustainable design in Changi Airport Terminal 3's architecture is the implication for a shift from binary to integrative thinking.

Sustainable passenger terminals are those in which the principles of sustainability are applied when designing new ones or operating and maintaining existing ones with their internally and externally spaces, with basic considerations of design patterns, as well as aspects of movement and flexibility, within an approach that integrates environmental, social, and financial implications. Environmental elements deal with limiting pollution and decreasing its impact based on global environmental evaluation methods, whereas social aspects accomplish the greatest levels of passenger pleasure in addition to the sustainability of awareness and education, resulting in a high economic return based on offering investment spaces inside them with many privileges that support the national economy, companies, and individuals.

1.1 Area of Study: Emergence of Singapore Changi Airport T3

The third terminal project at Singapore Changi Airport has a significant impact for breaking the binary thinking and integrating nature with the built environment with methodical high performance in airport planning and design. The importance of the project will be carried closely with landscape architects, architects, and interior designers in the early stages of planning and design. Paya Lebar airport, Singapore's old international airport, was designed in 1955 with a capacity of one million passenger movements. Later, rising worldwide air travel demand resulted in major traffic congestion and passenger capacity issues. There was an urgent need for airport expansion since it barely handled four million movements of passengers in the 1970s. The government chose to construct a new international airport at Changi that would be five times larger than Paya Lebar. Land reclamation work became a key issue prior to airport relocation since it needed highly sophisticated engineering technology for leveling, soil stabilization, and runway strengthening (Vincent, 2008). Since 1975, a massive landfill and seafill of about 52,000,000 square meters has been developed, as has a canal to drain water. The first terminal opened in 1981, the second in 1991, and the third in 2008, which helped to connect all three terminals (Probert, 2006) In contrast to the first and second terminals, the third terminal is highly praised for establishing an interdisciplinary and collaborative design approach with a good internal landscape.

2. Literature Review: Sustainability in Airport passenger terminals

Throughout the twentieth century, a certain form of the 'conventional' airport passenger terminal was evolved. Due to the large number of people and large volumes with no daylight, as well as the continuous increase of stringent regulations, massive amounts of ductwork, piping, electric installations, and so on were suspended to structural elements under floor slabs to allow for adequate micro-climatic conditions inside the building. This resulted in overgrown foundations, columns, beams, and slabs, as well as less efficient long-term economic performance of the structure. Airports began to have a significant environmental impact, as well as increased operational expenses. Norman Foster, a British architect and technocrat, devised and first applied a breakthrough notion into the design. His design for Stansted Airport (which opened to passengers in 1991) was a departure from traditional terminal architecture. This concept is presently continually being reproduced and refined by architects all around the world (including Foster himself). The approach includes low-tech solutions and geographical considerations to deliver improved airport functional operation not only in terms of investment expenses, but also in terms of operational savings. At the same time, it suggests ways to reduce energy use and environmental imprint. In terms of design sustainability, the strategy is to develop a lightweight, 'Big shed'1 modular canopy structure that provides sunshine and air holes for less energy-consuming interior conditions while maintaining structural integrity (see Fig. 1). So far, the great majority of desirable solutions are seen to be contained in Foster's model, both in terms of operational functionality and life cycle economic and ecological analyses. Despite the fact that airport terminal buildings vary greatly owing to external factors such as intended capacity, climate conditions, economic concerns, and so on, the principles for the design adopted in Stansted's terminal may be considered as an emerging trend in passenger terminal architecture.

Seeing as building sustainability necessitates a holistic approach to the design process from the outset (conceptual design) to the end of construction, it is far easier to incorporate sustainable solutions into newly built terminals rather than building extensions, where design opportunities are frequently limited by existing conditions. It does not imply that building additions should not comply with current building codes; nonetheless, for the purposes of this article, examples of new designs will be offered as model solutions.

Fig. 1. London-Stansted Airport terminal, designed by Norman Foster. Terminal is roofed by a lightweight canopy structure, allowing natural insulation, daylight penetration and natural ventilation of the building. (Source: http://www.si.wsj.net/)

3. Research Methodology: A Review of the Jewel Changi Airport T3, Singapore

Jewel Changi mixes two environments—an intensive marketplace and a beautiful garden—to establish a new community-centric typology as the heart, and spirit, of Changi Airport, fulfilling its purpose as a connection between the current terminals. Jewel combines a sense of being in nature with cultural and leisure activities, emphasizing the airport's role as an uplifting and dynamic urban hub and mirroring Singapore's status as "the City in the Garden." Under one roof, the 135,700-square-meter hub houses landside airport operations, indoor gardens and leisure attractions, retail offers, restaurants and cafés, and hotel accommodations. Jewel involves both in-transit travelers and the general public, since it is directly linked to Terminal 1 and Terminals 2 and 3 through pedestrian bridges. Gateway gardens on each of the compass axes—north, south, east, and west—orient visitors and provide visible links between Jewel's interior program features and the other airport terminals.

Fig 2: An aerial view of Jewel at Changi Airport. (Photo: Courtesy of Jewel Changi Airport Devt).

Layout

Changi's architecture is basic and graceful. Two runways flank three terminals in a horseshoe configuration. The tourist support facilities, such as car parks, roadways, drop-off porches, a hotel, and an MRT station, are located in the center of the horseshoe. The spectacular control tower, which serves as a lighthouse and a landmark for Changi, tops it all off. This horseshoe design maximizes airplane docking space while allowing for optimal passenger movement. The central Airport Boulevard, which splits out to the three terminals, is where passengers arrive. The MRT station is located between Terminals Two and Three, ensuring that travellers do not have a long walk to their destination. Passengers do not need to walk far from their separate terminals to access amenities because all amenities are located in the center and the terminals are warped about in a horseshoe form. Changi is a pleasure to navigate compared to airports like JFK, where terminals are distributed in a massive loop, or CDG, where terminals are sprawled out in two long parallel lengths.

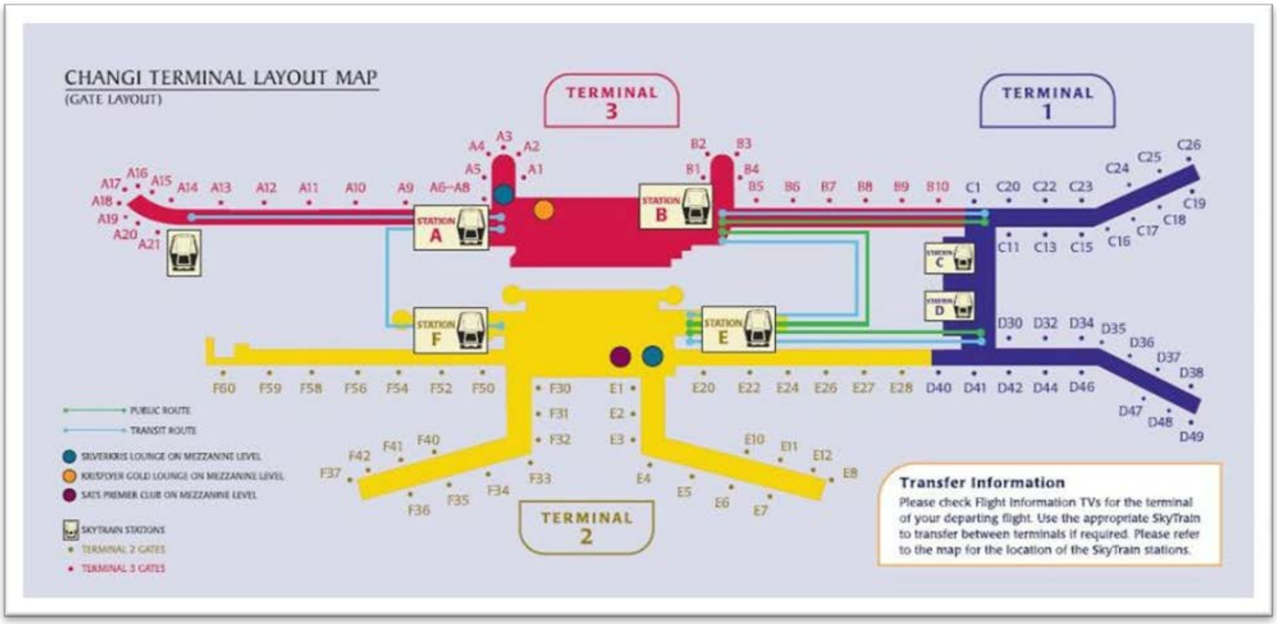

Fig 3: Changi terminal layout map (Photo: Courtesy of Jewel Changi Airport Devt).

Architecture

The Forest Valley, a tiered indoor garden with walking pathways, cascading waterfalls, and tranquil seating spots, lies at the heart of Jewel. The world's highest indoor waterfall—a 'rain vortex'—showers down from an oculus in the domed sky to the Forest Valley garden seven storey’s below, among the more than 200 different varieties of trees and plants. The waterfall, which can flow over 10,000 gallons per minute at its height, contributes in the cooling of the landscape surroundings and gathers substantial rainfall for reuse in and around the structure. A multi-level retail bazaar surrounds the gardens on five floors, with entrance to the garden via a series of vertical canyons. Jewel's roof geometry is based on a semi-inverted toroidal dome. The combined structural and façade system, which spans 200 meters at its widest point and is only supported periodically around the rim of the garden, provides for a near-column-free interior.

Fig 4: The world's largest indoor waterfall will be featured in the lovely forest valley.

An integrated system of glass, static and dynamic shade, and an innovative and efficient displacement ventilation system were necessary to achieve a degree of comfort for the variety of activities as well as to support the huge array of plant life within appropriate sunlight. Jewel has been granted GreenMark Platinum designation in Singapore. The Canopy Park, located on the fifth floor, features 14,000 square meters of attractions that are interwoven into the garden settings. Net constructions hung in the trees, a suspended overhead wires glass-bottom bridge walk, a planted hedge labyrinth, and a mirror maze are among the projects, which were created in partnership with globally renowned artists. A topiary walk, horticultural displays, and a 1,000-person event plaza are also included. The airport has become an attraction in its own right, thanks to Jewel.

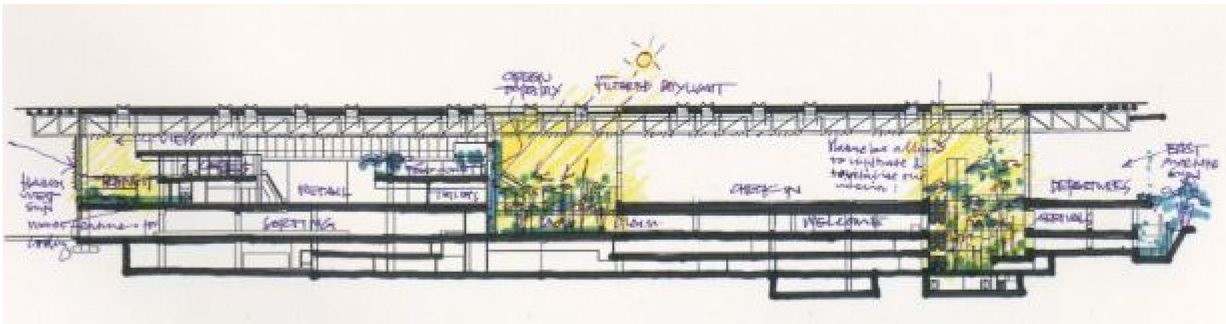

Fig 5. Section of T3 (Vincent, 2008)

The Changi Airport T3 landscape master plan envisioned the interior landscape integrating with the groundside landscape, building performance, and technology. The articulated thought method is affected by the unique design techniques. First, a series of large clear glass ‘skins' of the building continue the green theme from the airport's groundside gardens to the inside of the terminal. Visitors within the terminal will enjoy a more comfortable and natural environment thanks to the visual green connectedness. These places, such as an internal park, have the ability to favorably affect the establishment of a new culture and place perception. Regarding the impact of landscapes on the built environment, Waldheim (2006) stated that the landscape medium has proven uniquely capable of providing a cultural frame for apprehending and intervening in contemporary urbanization sites. Landscape must be understood in relation to its connectedness in order to be perceived and considered as a more appealing medium. For spatial continuity between inner and outside areas, many architects use translucent materials. In other words, the setting denotes a process of erasing or blurring the distinction between them. The green continuation strategy of Changi T3 can be seen as one of the necessary steps in integrating nature and the built environment. Second, Tierra Design, a Singapore-based Landscape Design firm, designed the T3 terminal's green walls – a giant multi-story vertical garden – and other vegetation communities, which integrate natural performance and system into the building (Figure 4).

Fig 6: Workers construct the Jewel's skylight. Photo: Charu Kokate / Safdie Architects

Hanging creepers and a waterfall were incorporated into the five-meter-high "Green Wall" to create a tropical. Inside the structure, they also serve as natural ventilation, filtration, and temperature and humidity controls (ASLA, 2009). Several studies (Dimoudi and Nikolopoulou 2003, Gartland, 2008, Akbari 1997, McPherson 2002) have found support for some environmental and energy benefits to human environments in terms of microclimates. T3's indoor air quality and environmental conditions were improved by testing and selecting acceptable plant species for long-term viability (ASLA, 2009). The selection of environmentally sensitive items incorporated financial concerns in addition to aesthetic features of ecological design. Landscaping is no longer seen as an afterthought to architecture. It was crucial in the completion of the architecture. Vertical gardens and their massive shape are prominently included in architecture components, and are expected to create a precedent as an uncommon instance among airports throughout the world. This has important implications in terms of breaking down binary thinking and integrating not only landscape architecture and architecture, but also natural systems and building performance.

Fig 7: The hedge maze is designed for adults and kids alike. (Photo: Courtesy of Jewel Changi Airport Devt.)

Third, T3's inner landscape is built on a foundation of landscape and technology integration. Thanks to a double-layer cable support system and a novel roof design with 'butterfly-winded' skylights, the notion of a gigantic green wall was able to be successfully erected and managed. The cable support components are easy to attach and detach from the lattice, and they also effectively regulate and maintain the vegetation (Vincent, 2008). The provision of sufficient natural light to the flora for photosynthesis is a significant concern for the vertical garden. The 919 skylights on the roof were installed to allow natural light to enter the edifice. While close closeness to skylights may not pose an issue for high-altitude plants, low-altitude vegetation requires technological aid to obtain sufficient light. More light is provided through perforated metal surrounding catwalks, and artificial light is used to raise lux levels for the plants (Vincent, 2008). The airport's richness and diversity may be increased by combining nature and technology. The internal environment of Changi airport T3 might be described as a cyborg landscape, since Meyer characterized systemic integration as "a mix of machine and biology" or "cyborg" (Meyer, 1997).

4. Sustainable Airport Passenger Terminal Design

The study of Changi Terminal and other researches were used in this study to estimate the fundamental levels of dealing required to accomplish the environmental sustainability of passenger terminals. Previous knowledge has been classified and organized using the LEED Global Classification system "due to its global spread and popularity, as well as the environment of the LEED system's emergence in the United States, which occupies the continent of North America and has a diverse and diverse range of climatic environments." This explains why it was chosen as an "ideal research model," as it has been implemented at numerous airports.

4.1 Location and Transportation

This level is concerned with the nature of passenger terminal site planning and design, as well as the adoption of modes of transportation, whether the design and implementation of a new station or the operation and maintenance of an existing station, and in accordance with each of the following:

- Site development: Laying out the station near car parks, car rental areas, and the services center, as well as centralizing the site between runways to decrease runway and taxiway distances and travel time.
- Protecting sensitive land: Choosing suitable sites within the limitations of biological development, decreasing the environmental effect of the site, and protecting ecologically sensitive land by avoiding large agricultural lands, flood plains, habitat regions, and water areas.
- Adopting alternative mobility (walking, cycling, public transportation, teleworking, informal transportation choices, green automobiles, etc.) and encouraging access to transit quality (multiple transports) such as bus stops, tram stations, and heavy and light railway stations.

4.2 Sustainable sites

This level is represented by the criteria to be used in selecting a sustainable site and lowering the environmental effect of a new plant, as well as the options that can be used in the development and rehabilitation of an existing station's site, as follows:

- Pre-design site assessment: includes a topography survey, hydrological detection, climatic analysis, plant survey, soil survey, human usage detection, and human health impact analysis.
- Site development-protection of habitat: this is reflected by the rehabilitation of damaged areas and the maintenance of spare green spaces.
- Heat island reduction: limiting overdevelopment and treatment of horizontal surfaces by covering parking lots with plant ceilings or solar power production systems, for example.
- Treatment of other surfaces by the use of trees, plants, and power producing buildings to shade them, as well as the use of different solar breakers, light shelves, and screen walls.

4.3 Water conservation in airport terminals

This level is illustrated by the necessity of saving water and finding sustainable techniques to minimize water consumption and rationalize its usage as follows:

- Indoor water consumption reduction: through the construction of sensitive installations (automated sensing), continuous maintenance and leak detection, the use of efficient equipment, and the implementation of water-saving watering system for indoor gardens.
- Reducing outdoor water usage through the use of local drought-resistant plants, the installation of a water-saving irrigation system, and so on.
- Water metering: Measuring water use with meters, utilizing recycled water to cool plant towers, storing and collecting rainfall for non-drinking purposes, and so on.

4.4 Conservation of energy and atmosphere in airports

This level is represented by the use of processors in the terminal that reduce energy consumption, which can be used when designing a new terminal or when operating and maintaining an existing terminal, as well as interior design, in addition to the operational efficiency of various devices and structures and the importance of efficient environmental management and the adoption of renewable energies, as described below:

- Minimal energy performance: by improving energy performance by adopting thermal insulation of the terminal, distributing and reflecting light, and using energy-saving structures in terms of the use of LED lamps, adopting works sensors through CO2 monitoring, the use of effective and efficient devices and installations, the use of lighting control systems, and determining the correct sizes of equipment.
- Advanced energy metering: installing meters to help management and finding further energy-saving potential, as well as an energy usage plan and future demands.
- Efficient management: the use of an orderly sequence in building operations, the use of building work schedules, the use of equipment operating schedules, whether air

conditioning equipment or lighting levels, taking into account the minimum requirements for cooling, adjusting changes to schedules, whether for different seasons, days of the week, or times of day, the use of mechanical and electrical equipment description

- Renewable energy generation, such as photovoltaic solar energy, wind energy, hydropower, geothermal energy, biomass energy, and so on.

4.5 Indoor environmental quality

This level was based on the adoption of air quality, lighting, thermal comfort, and sound performance concerns, and it was as follows:

- Indoor air quality: in terms of the installation of air treatment units in the building, the installation of air handling units for air outflow, the design of good ventilation spaces, the thermal division of the areas into multiple cooling, and the prohibition of smoking inside the building except in designated smoking areas, as well as the promotion of indoor air quality strategies through the installation of inlet systems for cleaning dirt and particulate matter, the installation of filters in ventilation systems and implementing a system to create high CO2 alarms, employing automatic signaling devices for minimal opening, and decreasing volatile organic compounds (VOCs) that influence human respiration, among other things.

- Interior lighting is represented by the use of natural lighting through the use of multiple lines of glass vision in different directions, as well as the quality of the external look and visual clarity through a broad view of the aircraft and take-off to relieve friction and positive feeling, and artificial lighting through control lighting to meet user needs and preferences (on / off, mid-level), and providing high quality lighting sources with a lifecycle.

- Thermal comfort management: the use of systems for continuous monitoring and improvement of inhabited spaces (temperature, radiation, humidity, and airspeed), constant monitoring, periodic testing, and maintenance.
- Green cleaning: represented by the management policy in terms of standard operating procedures for cleaning, maintenance, with management for them and continuous scrutiny, protection of occupants of the building at risk during cleaning, selection of suitable materials and disinfectants for use, safe handling and storage of detergent chemicals, promote the conservation of energy, water and chemicals in cleaning, strategies to improve and promote hand hygiene, as well as products and materials in terms of reducing the environmental impacts of cleaning products, convertible paper and garbage bags, and integrated pest management in terms of providing integrated pest management teams, continuous inspections and surveillance, non-chemical preventive measures for pests

5. Conclusions

This article has focused on energy, water, building materials, and IEQ impacts as essential concerns in the design and management of airports within the wide realm of sustainability. The examples offered in these four categories should hopefully motivate airports throughout the globe to search for synergies, or techniques that bring several sustainability advantages with a single expenditure, rather than only focusing on individual concerns. Changi Airport (Terminal 3) in Singapore is a project that defies the dichotomous thinking that has governed the built environment. They attempted to push the boundaries of design and culture in airport design by working closely with architecture firms, engineers, and interior designers. Some could argue that the landscape is a little too showy for T3's interior. The internal landscaping, on the other hand, represents a major and creative architectural approach to blending nature with the structure and technology. T3's indoor landscape is a holistic combination of architecture and nature. Through a methodical integration of mechanical elements and the human body's inherent functions, the notion experiences a synthetic feedback dynamic. Synthetic feedback techniques between the building, plants, and technology improve building performance. The interior idea and design should be further developed using integrative thinking and interdisciplinary methods on the airport layout in order to attain comprehensive bio-integration.

Recommendations

- Any passenger terminal design or restoration should take into account the environmental, social, and economic issues of long-term passenger terminals.
- As a first step toward the construction of a sustainable passenger terminal, developing management and organizational plans and strategies based on sustainability principles, outlining goals, methods, and time frames, as well as operational procedural stages.
- The importance of designing, operating, and maintaining passenger terminals in accordance with legal requirements and design dimensions for sustainable passenger terminals, as well as developing operational and administrative practices and adopting various modern technological developments such as intelligent systems, technologies, building materials, alternative energy sources, and so on, in order to promote sustainable development and raise awareness and educate people about it.
- The duty to assess existing authorized designs for operation and maintenance, as well as new construction at local airports, and change them to meet the criteria of the age connected with the pursuit of sustainable development.

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