ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

A Study of Space Syntax on the Zhejiang Huanglong Aquatics Centre

Zhen Yi Goh[1], Ahmad Sanusi Hassan[1*], Bhattraradej Witchayangkoon[2], Muhammad Hafeez Abdul Nasir[1], Yasser Arab[3], and Jestin Nordin[1]

[1]School of Housing, Building and Planning, Universiti Sains Malaysia, MALAYSIA.
[2]Department of Civil Engineering, Thammasat School of Engineering, Thammasat University, THAILAND.
[3]Department of Architectural Engineering, Dhofar University, SULTANATE of OMAN.
**Corresponding Author (Tel: +60 4 6532844, Email: sanusi@usm.my).*

Paper ID: 16A2B

Volume 16 Issue 2

Received 09 March 2025
Received in revised form 15 May 2025
Accepted 24 May 2025
Available online 09 June 2025

Keywords:
Spatial configuration; Architectural space; Spatial transitions; Space syntax analysis; Building typology; Spatial Design; Justified graph; Wayfinding; Permeability; Visibility graph analysis (VGA); Spatial layout; Public users' circulation.

Abstract

This study applies space syntax to measure and examine the space configuration of Zhejiang Huanglong Aquatics Centre, China. The research objective investigates the users' movement inside the building affected by the spatial layout. Based on the understanding that spatial layouts impact human interactions and activities, this research aims to thoroughly evaluate the permeability of the architectural space within the Zhejiang HuangLong Aquatics Centre. The specific case study being examined is the Zhejiang HuangLong Aquatics Centre. The methodology of this research study is a quantitative survey and analysis illustrated with the justified graph and visibility graph analysis (VGA). This method will employ quantitative answers in the evaluation of the level of permeability and wayfinding, with cross-analysis to VGA integration and connectivity in mapping performance of the spatial configuration. The research reveals a maximum depth level of 17 through space syntax analysis, characterised by semi-public and semi-private nodes in the building spatial layout design. The design is attributed to the sports facility's intention to accommodate visitors, athletes, and staff. The Zhejiang Huanglong Aquatics Centre exhibits high permeability and wayfinding, especially for a sports facility building. The design features easy circulation for public users' movement, while its users' navigation for private users is moderately challenging.

Discipline: Architecture

Cite This Article:

Goh, Z.Y., Hassan, A. S., Witchayangkoon, B., Hafeez, M. A., and Nordin, J. (2025). A Study of Space Syntax on the Zhejiang Huanglong Aquatics Centre. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 16*(2), 16A2B, 1-21. http://TUENGR.COM/V16/16A2B.pdf DOI: 10.14456/ITJEMAST.2025.9

1 Introduction

This study examines the spatial configuration of the aquatic centre, characterised as a sports facility building typology. Sport building typology provides spaces to carry out recreational sports. It is essential for the community, as a recreational sport may become a lifestyle, balancing physical and spiritual needs and improving physical, mental, and social well-being (Hanani, 2017). Space syntax comprises a range of methods used to examine the spatial arrangements of different areas on both the building and urban levels. (Khaled et al.,2019) The arrangement of spaces within buildings significantly influences their usage by individuals (Khaw et al., 2023; Hassan, 2004) - a method for depicting and examining the relationships among different spaces within buildings. The basic goal of space syntax is to investigate the spatial transition of human movement from one location to another (Hafeez et al., 2023). The fundamental assumption underlying Space Syntax is that individuals typically opt for the most straightforward route to their destination, characterised by minimal changes in direction. The complexity of the space syntax system increases with more directional changes, rendering the spatial arrangement design less effective or efficient (Sadalla & Magel, 1980).

The chosen case study, the Zhejiang HuangLong Aquatics Centre, is an aquatic sports facility that achieved the Third Prize in the 2014 Second (BIM) Design Competition of the Hubei Survey and Design Association. This building played a crucial role in the events of the swimming and diving venue during the 2022 Asian Games. It boasts a standard competition pool measuring 50m×25m, a training pool of 50m×21m, and a diving pool spanning 21m×25m. Situated within the Huanglong Sports Centre, it is a key component of the region's significant sports complex (ArchDaily, 2019).

This research aims to thoroughly evaluate the permeability of the architectural space within the Zhejiang HuangLong Aquatics Centre to establish a correlation between its spatial layout and functional characteristics. The objective is to identify a blueprint for building layouts to inform future designs within the sports facility building category. The study conducts an in-depth analysis of the Zhejiang HuangLong Aquatics Centre in Hangzhou, China.

2 Literature Review

Space syntax is a technique that analyses the relationship between spaces of urban areas and buildings. It evaluates the integration and connectivity of spaces within a building and represents it in a formalised graph-based version of spatial layout configuration in the architectural analysis (Li et al., 2015). The study of space syntax is rigorously directed by reason. Instead of discerning identity by observation, space syntax helps the intuitive design process by adding justification (Hillier & Hanson, 1984). Space syntax analyses are based on deep permeability and wayfinding level analysis. Permeability allows or limits the movement of people or vehicles in a direction or within the spaces inside a building. For instance, the level of permeability contains public, semi-public, semi-private, and private spaces. Wayfinding is a design process that leads people through the physical environment and deepens their experience and understanding of the space.

Consequently, that building's circulation and ease of wayfinding can be proven through space syntax analysis (Knoll, 2015; Natapov et al., 2015). The fundamental objective of space syntax is to examine how people move spatially between different locations. (Hafeez et al., 2023). Space Syntax views spaces as voids—such as rooms, squares, streets, and fields—between structures like walls, fences, and other barriers that affect human movement or visual perception. (Abdul Nasir et al, 2023).

3 Case Study: The Huanglong Sports Centre in Hangzhou, China

The Huanglong Sports Centre, located in the northern part of West Lake, the central district of Hangzhou, is an alternative venue for the 2022 Asian Games. It covers around 49,000 square meters and accommodates 3,000 spectators. The centre includes a standard competition pool measuring 50m x 25m, a training pool measuring 50m x 21m, and a diving pool measuring 21m x 25m (ArchDaily, 2019).

For this case study, the architect mentioned constraints on construction space, and adhering to the typical approach would violate local codes, limiting occupancy to below 45%. A straightforward solution using the design from the architect's experience involves stacking spaces vertically. However, this arrangement poses challenges in providing better circulation from the surrounding buildings, especially for users to access the building on foot. After a thorough evaluation, the architect focuses more on vehicular access by having all-sided accessibility with three main entrances for vehicular access. The space configuration provides good building accessibility for vehicular access but not pedestrian access (ArchDaily, 2019).

3.1 Building Typology

A sports facility in this building accommodates and facilitates various activities for leisure and sports. These buildings are equipped with amenities and spaces tailored for sports and recreational pursuits, fostering physical activity, social engagement, and overall well-being among participants. The facilities include gyms, sports complexes, and fitness centres. A sports facility, or a sports facility, refers to an enclosed or open area designated for sports activities or competitions. They can include a wide range of venues such as sports pavilions, stadiums, gymnasiums, health spas, boxing arenas, swimming pools, roller and ice rinks, and other similar places where people engage in physical exercise, participate in athletic competitions, or witness sporting events. (Mallen et. al., 2010)

3.2 Building Style

The case study has an architectural style of parametricism, characterised by its distinctive curved forms and extensive use of glass and steel. Parametricism, rooted in advanced digital technologies, allows for the creation of dynamic and non-linear architectural designs. The curved forms depart from traditional rectilinear structures, emphasising fluidity and visual intrigue. The prevalent use of glass and steel aligns with parametric principles, promoting transparency, lightness, and technological sophistication. Parametricism in architecture is a style that utilises parametric design and advanced computational systems to create complex and innovative forms. It has been described as a dominant, single style for avant-garde practice and is particularly suited to large-scale urbanism. The traditional need for coding to create parametric design has become obsolete with the advent of powerful visual programming languages, making parametricism a valuable skill for architects. This approach requires additional knowledge of structural integrity, material tolerance, fabrication optimisation, and sustainability. Parametricism's preoccupation with expressive surface structures enables architecture to draw on historical knowledge, such as the complex curved structures of Gothic cathedrals and modern masters. (Riekstins, 2018)

4 Method

This research is an analytical investigation that utilises quantitative analysis, employing graphs to assess the permeability and quality of spatial networking, particularly in terms of wayfinding. The initial step in this study involves selecting a building case study, with the Zhejiang HuangLong Aquatics Centre chosen as the focus, particularly exploring its role as a sports facility. Information gathering from journals and online articles forms the foundation, including creating original floor plan drawings using AutoCAD. This study, which examines the spatial networking system, utilises the justified graph, which illustrates both the level of permeability and the wayfinding characteristics of the spaces under investigation. The justified graph, as defined by Hillier and Hanson (1984) and Tarabieh et al. (2019), provides insights into the layout plan's permeability level and the building's internal configuration. Subsequent steps entail identifying and labelling spaces within the building to create justified graphs. The study delves into the background and project details using qualitative techniques such as online research, articles, journals, and books. Additionally, quantitative analysis, including visibility graph analysis (VGA), is employed to examine permeability levels and wayfinding, utilising justified graphics to analyse spatial networking dynamics. Conducting a practical wayfinding analysis entails establishing the hierarchical order of each space through the movement levelling system (Yusoff et al., 2019).

4.1 Likert Scale

This study uses the Likert Scale to assess permeability and wayfinding analysis. It categorises spaces into five discernible levels of privacy: public, semi-public, semi-private, private, and highly private (Yusoff et al., 2019).

Table 1: Likert Scale of Measurement for Space Syntax Analysis

Likert Scale Rating	Permeability Level	Wayfinding Level
4-6	Public	Very Easy / Straightforward
7-9	Semi-Public	Easy / Straightforward
10-12	Semi-Private	Average
13-15	Private	Difficult
16-17	Extremely Private	Very Difficult

Annotation using numerical order on spaces within the building layout indicates users' movement sequence. These numerical labels are categorised into five ranges on the Likert Scale, reflecting the level of permeability and wayfinding, as detailed in Table 1. A higher depth level on the Likert Scale signifies greater privacy of the space and increased difficulty in wayfinding for users.

The permeability and wayfinding analysis comprises primary, secondary, and tertiary levels. The space with the highest percentage in hierarchy weightage is designated as the primary level, offering the most straightforward access to users.

4.2 Justified Graph

As depicted in Figure 1, the justified graph arranges spaces numerically to signify their depth within a building. As Lee (2020) explained, the higher the number assigned to the designated space, the further it is from reach.

Table 2: Categorisation of Alphanumeric and Colour Based on Building Function

Function	Alphanumeric	Colour
Building Access	E (E1,E2,E3,etc.)	Pink
Public Spaces for Visitors	(1,2,3, etc.)	Blue
Corridor	C (C1,C2,C3, etc.)	Dark Yellow
Corridor for Services	CS (CS1,CS2,CS3, etc.)	Dark Yellow
Lift	L (L1,L2,L3, etc.)	Light Orange
Fire Lift	FL (FL1,FL2,FL3, etc.)	Light Orange
Lift Lobby	LL (LL1,LL2,LL3, etc.)	Brown
Staircase	S (S1,S2,S3, etc.)	Red
Fire Staircase	FS (FS1,FS2,FS3, etc.)	Red
Administration	SC (SC1,SC2,SC3, etc.)	Yellow
Amenities Room	R (R1,R2,R3, etc.)	Green
Services	SR (SR1,SR2,SR3, etc.)	Grey

Each numerical value enclosed within the circle corresponds to a specific area marked on the building's floor plans. The horizontal axis serves as a visual representation of the depth level. The unique lines connecting the circles indicate the presence of connections between the interconnected spaces.

Subsequently, the labelled layouts are transcribed to create the data tabulation using the justified graph technique. This process entails analysing permeability and wayfinding, which relies on the graph to track the movement of spaces within the sports facility.

The floor plan analysis will be executed comprehensively to showcase the depth of the permeability study for the building, with each node distinctly identified. All nodes will receive designated names, their accessibility and depth will be assessed, and they will be distinguished using a variety of colours. The numbering system will denote whether the wayfinding and permeability are favourable or unfavourable. Elaborate data extracted from the justified graph will be structured into a table to offer a detailed overview of the permeability and wayfinding levels. This table will unveil and facilitate an understanding of the hierarchy and narrative of the building.

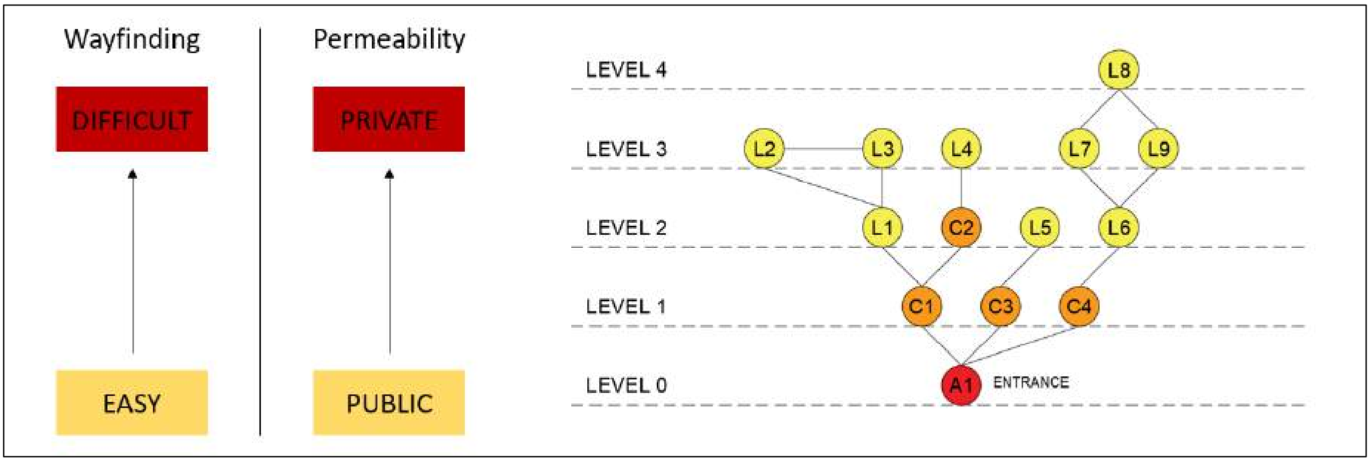


Figure 1: Example of Justified Graph.

Colour codes are utilised in the floor plan layouts to signify the function of each space, ranging from public to the most private areas. As the order of spaces ascends, the depth of the spaces increases, indicating the level of privacy and the complexity of wayfinding. The analysis of permeability and wayfinding examines spatial networking (Ooi et al., 2022). Justified graphs are employed to identify the permeability and wayfinding/access depth levels. The annotated floor plan layouts are transposed to generate data tabulations using the justified graph technique, encompassing permeability and wayfinding assessments based on the graph to visualise the flow of spaces in the sports facility (Elizondo, 2021).

The justified diagram consists of black lines to show the linkage of each node (Nasab et al., 2019). Data from the justified graph is tabulated in detail to show the level of permeability and wayfinding. The numerical labels on the justified graph are categorised into the five ranges of the Likert Scale, indicating the level of permeability and wayfinding, as shown in Table 1.

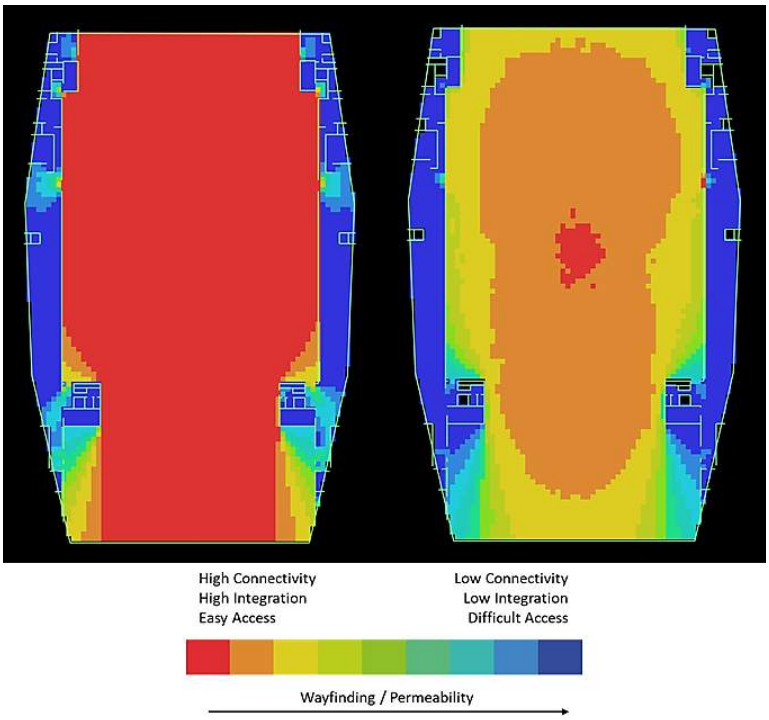


Figure 2: Example of VGA Connectivity Graph, VGA Integration Graph, and measurable scale for Visibility Graph Analysis

A space syntax approach called Visibility Graph Analysis (VGA) is used to evaluate the inter-visibility connections in buildings or urban networks (Koutsolampros et al., 2019). Different hues in VGA represent different levels of integration and connectivity in a physical environment. For example, blue may suggest lesser degrees of connectedness and integration (least visible areas), whereas red, orange, yellow, and green may indicate high levels of connectivity and integration (most visible areas). VGA operates on two levels: eye level, indicating what individuals can observe, and knee level, revealing how individuals can manoeuvre through spaces, which are crucial for understanding spatial arrangements (Yamu et al., 2021). It relies on isovists, geometric representations of what is visible from specific viewpoints within a given space.

5 Result of Analysis

The layout of the building in the case study is examined according to the kinds of individuals it accommodates. It is categorised into two primary groups: visitors and guest athletes, denoted by blue numbering labels, and staff and training athletes, distinguished by green, grey, and yellow numbering labels.

The justified graph displays a three-depth level for the site plan (Figure 3), featuring a well-designed accessibility layout to disperse traffic effectively. All areas are linked to their origin space within a symmetric spatial arrangement. Road 2 serves as the primary thoroughfare, connecting roads 1 and 4 before leading to a deeper level of space represented by road 3. Road '1' connects to 'A', the main public entrance 1, while roads '2' and '3' are linked to 'B', the secondary public entrance 2. Road '4' connects to 'C', the private entrance serving as the building's back-of-house area. 'A', designated as public ingress 1, and 'B', denoted as public ingress 2, are public with good permeability areas within the site, facilitating human movement and serving as public areas. In contrast, 'C', the private ingress, exhibits semi-public characteristics with a deeper level of permeability, exclusively catering to staff and competitive athletes. The level of wayfinding for 'A', public ingress 1, and 'B', public ingress 2, is elementary, enhancing the overall simplicity of navigation. Conversely, 'C', the private ingress, exhibits a straightforward level of wayfinding compared to 'A' and 'B'.

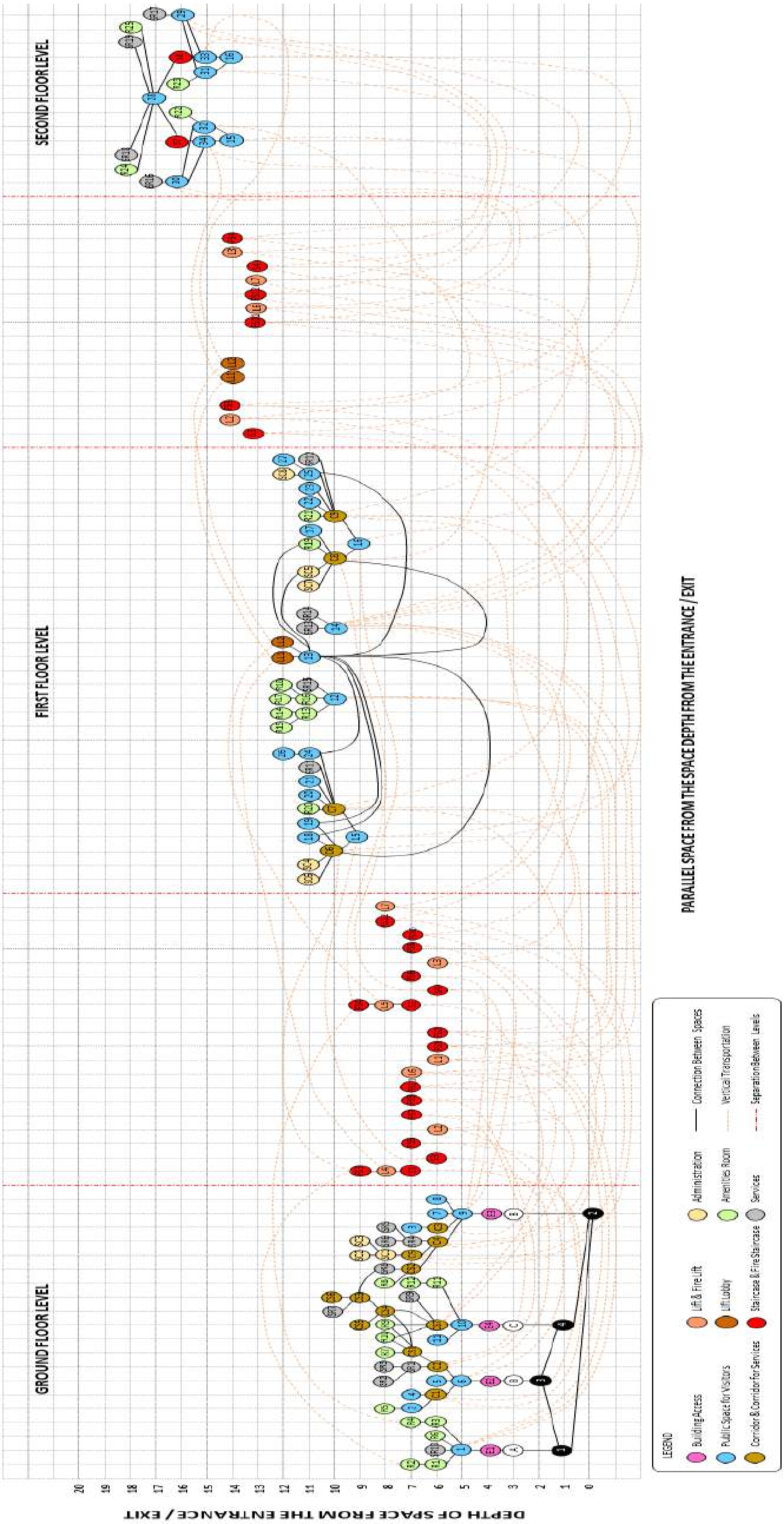


Figure 3: Overall Justified Graph for Zhejiang Huanglong Aquatics Centre

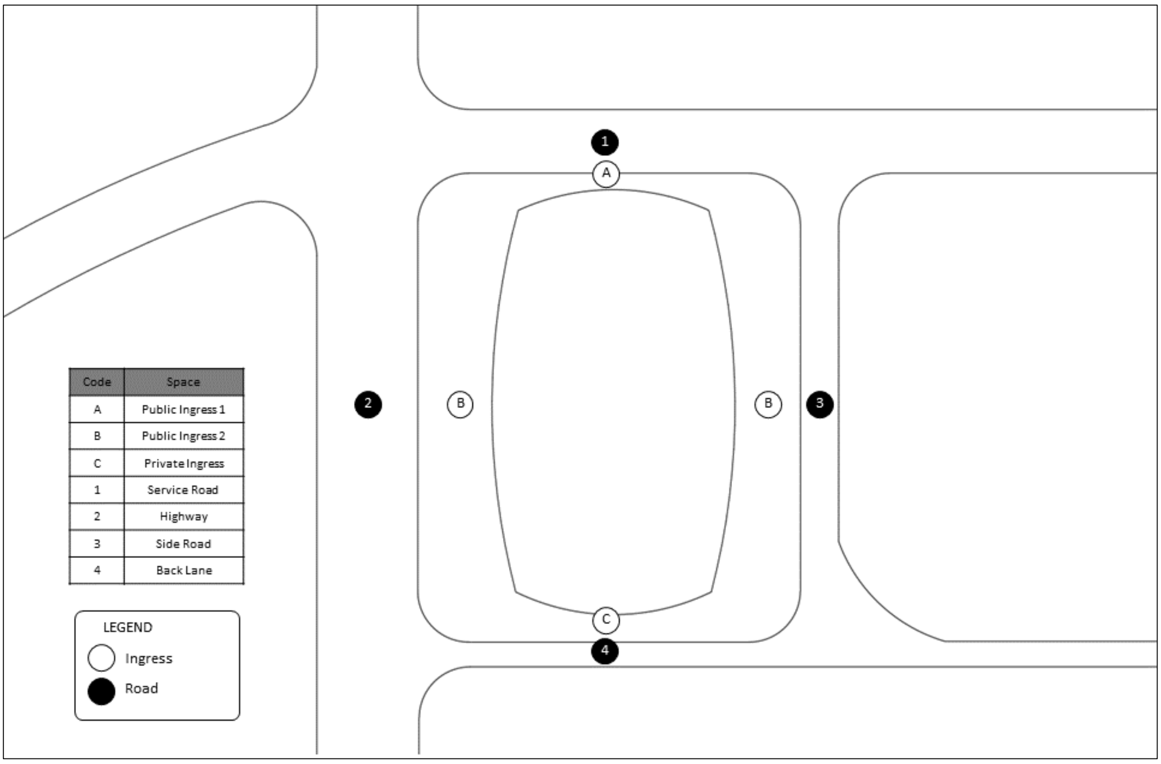
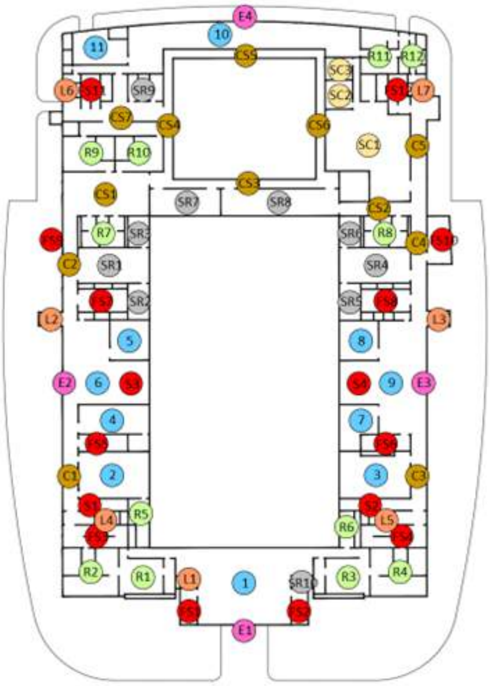


Figure 4: Site Plan with SOA. Drawn by Goh Zhen Yi. Source: Archdaily,2019



Code	Space	Code	Space	Code	Space	Code	Space
E1	Entrance 1	C5	Corridor 5	FS1	Fire Staircase 1	R5	Storeroom 1
E2	Entrance 2	CS1	Service Corridor 1	FS2	Fire Staircase 2	R6	Storeroom 2
E3	Entrance 3	CS2	Service Corridor 2	FS3	Fire Staircase 3	R7	Toilet 3
E4	Entrance 4	CS3	Service Corridor 3	FS4	Fire Staircase 4	R8	Toilet 4
1	Main Entrance Hall 1 & Reception	CS4	Service Corridor 4	FS5	Fire Staircase 5	R9	Locker 3 & Shower 3
2	Swimmer's Room	CS5	Service Corridor 5	FS6	Fire Staircase 6	R10	Locker 4 & Shower 4
3	Swimmer's Room	CS6	Service Corridor 6	FS7	Fire Staircase 7	R11	Toilet 5
4	Retail 1	CS7	Service Corridor 7	FS8	Fire Staircase 8	R12	Toilet 6
5	Gift Shop 1	L1	Lift 1	FS9	Fire Staircase 9	SR1	Service Room 1
6	Entrance Hall 1	L2	Lift 2	FS10	Fire Staircase 10	SR2	Service Room 2
7	Retail 2	L3	Lift 3	FS11	Fire Staircase 11	SR3	Service Room 3
8	Gift Shop 2	L4	Lift 4	FS12	Fire Staircase 12	SR4	Service Room 4
9	Entrance Hall 2	L5	Lift 5	SC1	Office 1	SR5	Service Room 5
10	Rear Entrance Hall	L6	Lift 6	SC2	Manager Room	SR6	Service Room 6
11	Foyer	L7	Lift 7	SC3	Staff Storeroom	SR7	Service Room 7
C1	Corridor 1	S1	Staircase 1	R1	Locker 1	SR8	Service Room 8
C2	Corridor 2	S2	Staircase 2	R2	Shower 1 & Toilet 1	SR9	Service Room 9
C3	Corridor 3	S3	Staircase 3	R3	Locker 2	SR10	Service Room 10
C4	Corridor 6	S4	Staircase 4	R4	Shower 2 & Toilet 2		

Figure 5: Ground Floor Plan with SOA. Drawn by Goh Zhen Yi. Source: Archdaily,2019

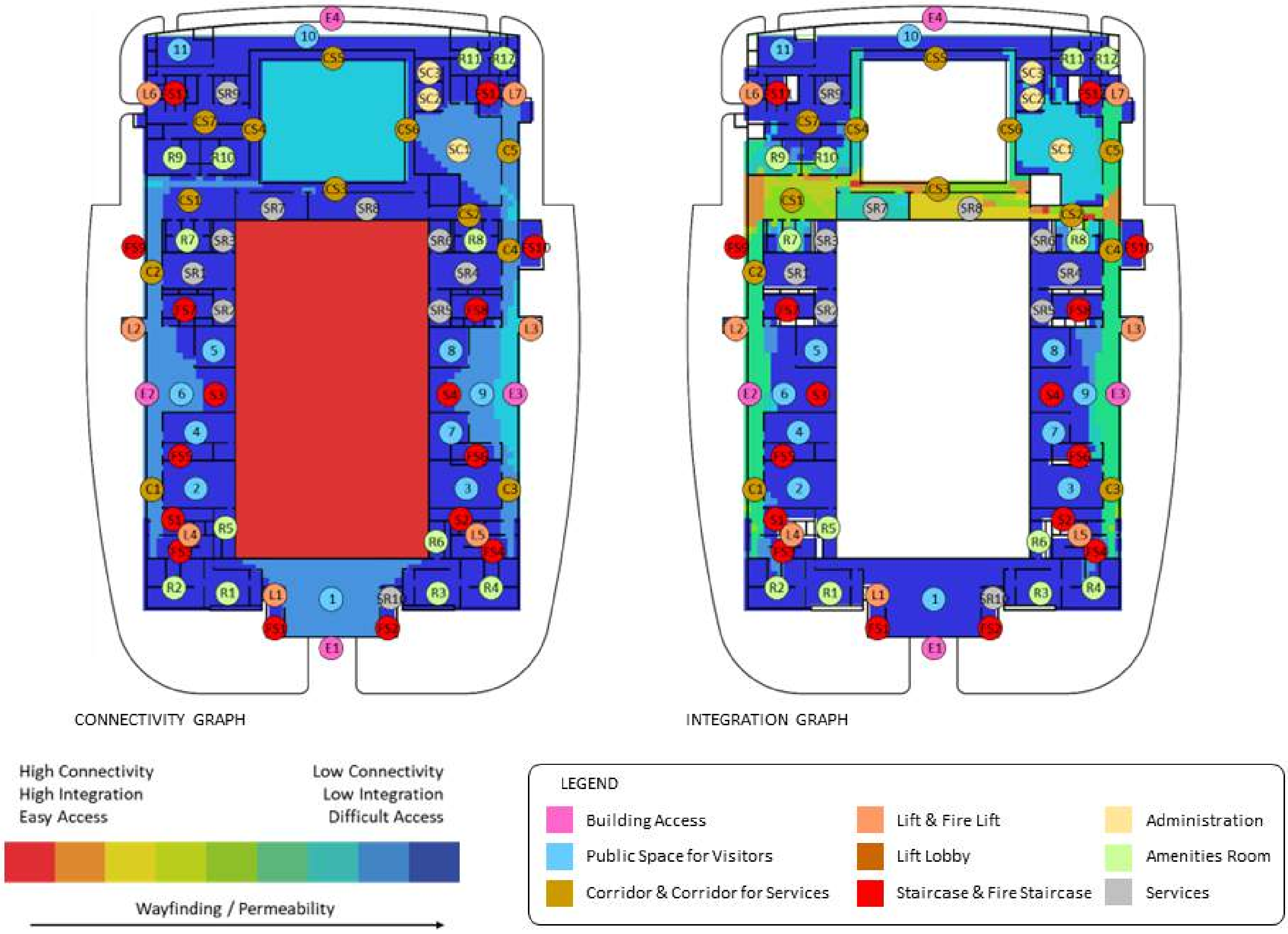
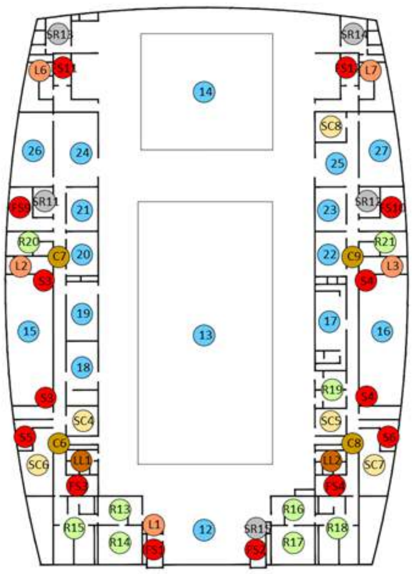


Figure 6: Visibility Graph Analysis for VGA Connectivity Graph and VGA Integration Graph of Ground Floor Plan of Zhejiang HuangLong Aquatics Center. (Drawn by Goh Zhen Yi. Source: Archdaily,2019).

Table 3: Likert Scale on Space Analysis for Ground Floor Plan

Code of Space	Depth Level	Level of Permeability	Level of Wayfinding
E1,E2,E3,E4	4	Public	Very easy / straightforward
1,6,9,10	5	Public	Very easy / straightforward
R1,SR10,R6,R3,C1,5,C2,11,CS7,R11,C4,C3,7,8	6	Public	Very easy / straightforward
R2,R4,2,4,SR1,CS1,SR9,R12,CS2,C5,SR4,3	7	Semi-Public	Easy / straightforward
R5,SR2,SR3,R7,R10,R9,CS4,R8,SR8,SC1,SR6,SR5	8	Semi-Public	Easy / straightforward
CS5,CS3,SC2,SC3	9	Semi-Public	Easy / straightforward
SR7,CS6	10	Semi-Private	Average

The justified graph illustrates six depth levels from level 5 to level 10 for the ground floor, as illustrated in Figure 3. The ground floor plan in Figure 5 employs colour labelling to delineate well-organised public-private zoning. In blue, public spaces are demarcated from private spaces allocated for staff, indicated in green, grey, and yellow. Referring to the justified graph in Figure 3, depth levels 4 to 6 are categorised as public spaces, 7 to 9 as semi-public spaces, and 10 to 12 as semi-private. The aquatic centre features four entrances: E1, E2, and E3 serve the public, while E4 is designated as the private entrance for staff and services. Entrance 1 (E1) connects to the main entrance hall (1) and branches out to Locker 1 (R1), Service Room 10 (SR10), Locker 2 (R3), and Storeroom 2 (R6), further leading to semi-public spaces like Shower 1 & Toilet 1 (R2) and Shower 2 & Toilet 2 (R4). Entrance 2 (E2) links to Entrance Hall 1 (6) and extends to Locker 1 (5), Service Room 10 (C1), and Locker 2 (C2), branching into various semi-public spaces, amenities rooms, services, and corridors. Entrance 3 (E3) connects to Entrance Hall 2 (9) and branches into several public spaces, service rooms, corridors, and administrative spaces exclusively for staff. Entrance 4 (E4) connects to the Rear Entrance Hall (10), providing staff direct access to staff amenities and semi-public and semi-private spaces such as Service Room 8 (SR8), Service Room 7 (SR7), Service Corridor 3 (CS3), Service Corridor 4 (CS4), Service Corridor 5 (CS5), and Service Corridor 6 (CS6), all designated for service purposes. All entrances are the primary root spaces for horizontal access and user movement patterns. According to the overall permeability graph and the Likert scale table (Table 3), the level of permeability ranges from public to semi-private.



Code	Space	Code	Space	Code	Space	Code	Space
12	Register Area	27	Retail 4	S6	Staircase 6	R14	Locker 5
13	Competition Pool	C6	Service Corridor 1	FS1	Fire Staircase 1	R15	Shower 5 & Toilet 7
14	Diving Pool	C7	Service Corridor 2	FS2	Fire Staircase 2	R16	Changing Room 2
15	Audience Hall 1	C8	Service Corridor 3	FS3	Fire Staircase 3	R17	Locker 6
16	Audience Hall 2	C9	Service Corridor 4	FS4	Fire Staircase 4	R18	Shower 6 & Toilet 8
17	Gymnasium	L1	Lift 1	FS9	Fire Staircase 9	R19	Toilet 9
18	Swimmer's Room 3	L2	Lift 2	FS10	Fire Staircase 10	R20	Toilet 10
19	Swimmer's Room 4	L3	Lift 3	FS11	Fire Staircase 11	R21	Toilet 11
20	Activity Room 1	L6	Lift 6	FS12	Fire Staircase 12	SR11	Service Room 11
21	Activity Room 2	L7	Lift 7	SC4	Comms Room	SR12	Service Room 12
22	Activity Room 3	LL1	Lift Lobby 1	SC5	Life Guard's Room	SR13	Service Room 13
23	Activity Room 4	LL2	Lift Lobby 2	SC6	Office 2	SR14	Service Room 14
24	Lobby 1	S3	Staircase 3	SC7	Office 3	SR15	Service Room 15
25	Lobby 2	S4	Staircase 4	SC8	Information Center		
26	Retail 3	S5	Staircase 5	R13	Changing Room 1		

Figure 7: First Floor Plan with SOA. (Drawn by Goh Zhen Yi. Source: Archdaily, 2019).

The ease of wayfinding within the spaces ranges from very easy to average. The spatial layout of the ground floor primarily follows an asymmetric spatial system characterised by a higher proportion of less integrated spaces. According to Table 3, depth levels 4 to 6 exhibit a very straightforward wayfinding quality, attributed to the low differentiation of the spatial environment within the asymmetrical spatial system. Figure 6 illustrates that Entrance Hall 1 (6) and Entrance Hall 2 (9) possess higher connectivity and integration levels. Consequently, spaces falling within depth level 5 are deemed to have very straightforward wayfinding access, while depth levels 7 to 9 are classified as having straightforward wayfinding quality, as confirmed by the VGA. Despite their increased spatial complexity and higher depth levels, these areas are considered easy to access. Depth level 8 demonstrates straightforward wayfinding quality due to the concentration of end rooms rather than vertical access at that particular depth level. The majority of spaces exhibit the lowest connectivity and integration levels. Consequently, spaces within depth levels 7 to 10 are justified to have straightforward and average accessibility.

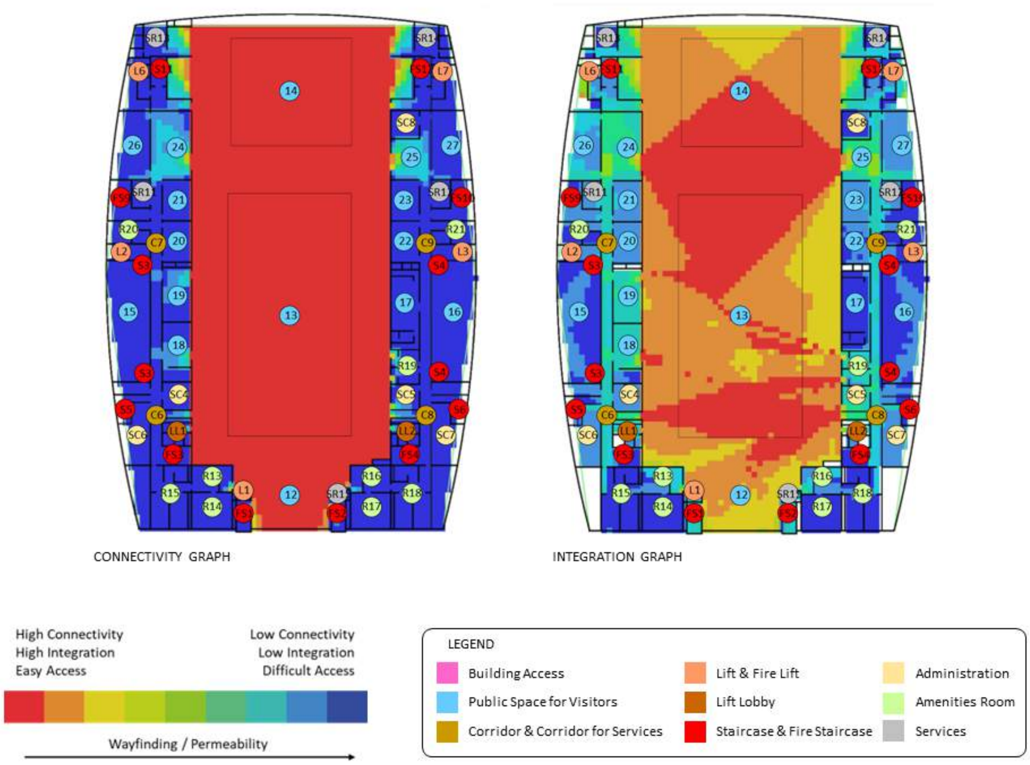
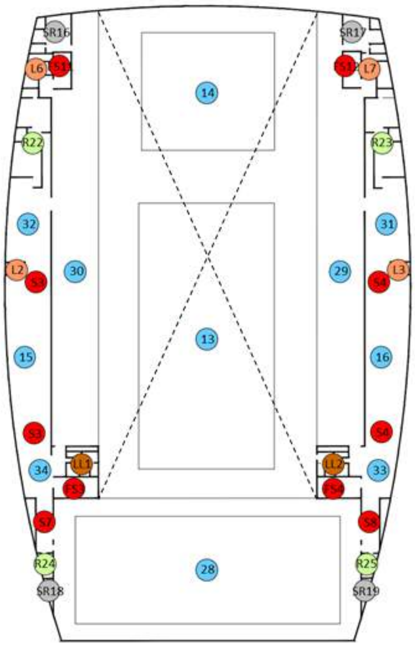


Figure 8: Visibility Graph Analysis for VGA Connectivity Graph and VGA Integration Graph of First Floor Plan of Zhejiang HuangLong Aquatics Center. (Drawn by Goh Zhen Yi. Source: Archdaily,2019)

Table 4: Likert Scale on Space Analysis for First Floor Plan

Code of Space	Depth Level	Level of Permeability	Level of Wayfinding
15,16	9	Semi-Public	Easy / straightforward
C6,C7,12,14,C8,C9	10	Semi-Private	Average
SC6,SC4,18,19,R20,20,21,SR11,24,R13, R16,SR15,13,SR13,SR14,SC7,SC5,R19,17,R21,22,23,25,SR12	11	Semi-Private	Average
26,R15,R14,R17,R18,LL1,LL2,SC8,27	12	Semi-Private	Average

The justified graph in Figure 3 indicates four depth levels spanning from level 9 to level 12 for the first-floor level. Concerning the justified graph illustrated in Figure 3, depth level 9 is classified as semi-public space, whereas depth levels 10 to 12 are classified as semi-private. Lift 1 (L1), Fire Staircase 1 (FS1), and Fire Staircase 2 (FS2) are the primary vertical public access connecting to the first floor Register Area (12), which falls into depth level 10 under the semi-private spaces category. Lift 6 (L6), Lift 7 (L7), Staircase 11 (S11) and Staircase 12 (S12) is directed towards Diving Pool (14) whereas Lift 2 (L2), Fire Staircase 9 (FS9) Fire Staircase 3 (FS3) and Staircase 3 (S3) is directly connected to Corridor 6 (C6), Corridor 7 (C7), at depth level 10. On the other side, Lift 3(L3), Fire Staircase 10 (FS10), Fire Staircase 4 (FS4), and Staircase 4 (S4) are directly connected to Corridor 8 (C8), Corridor 9 (C9), at depth level 10. Corridor 6 (C6) is connected to Office 2 (SC6), Comms Room (SC4), Swimmer's Room 3 (18), and Swimmer's Room 4 (19) at depth level 11, which have connections with Competition Pool (13) at the similar depth level. Corridor 7 (C7) is connected to Toilet 10 (R20), Activity Room 1 (20), Activity Room 2 (21), Service Room 11 (SR11), and Lobby 1 (24) at depth level 11, which further connects to Retail 3 (26) at depth level 12. Corridor 8 (C8) is connected to Office 3 (SC7), the lifeguard's room (SC5), the gymnasium (17), and Toilet 9 (R19) at depth level 11. Corridor 9 (C9) is connected to Toilet 11 (R21), Activity Room 3 (22), Activity Room 4 (23), Service Room 12 (SR12), and Lobby 2 (25) at depth level 11, which further connects to Information Centre (SC8) and Retail 4 (27) at depth level 12. Register Area (12) branched out to Changing Room 1 (R13), Changing Room 2 (R16), and Shower 5 & Toilet 7 (SR15), and further diverges to a depth level 12 with Locker 5 (R15), Locker 7 (R14), Locker 6 (R17), Shower 6 & Toilet 8 (R18). Diving Pool (14) diverges to Service Room 13 (SR13) and Service Room 14 (SR14). Competition Pool (13) at depth level 11 connected from Corridor 6 (C6) and Corridor 8 (C8) has a similar depth level connection with Swimmer's Room 3 (18), Swimmer's Room 4 (19), Lobby 1 (24), Life Guard's Room (SC5), and Toilet 9 (R19). Based on the overall permeability graph and the Likert scale table (Table 4), the level of permeability ranges from semi-public to semi-private.



Code	Space	Code	Space	Code	Space
13	Competition Pool	L3	Lift 3	FS12	Fire Staircase 12
14	Diving Pool	L6	Lift 6	FS4	Fire Staircase 4
15	Audience Hall 1	L7	Lift 7	FS11	Fire Staircase 11
16	Audience Hall 2	LL1	Lift Lobby 1	FS12	Fire Staircase 12
28	Training Pool	LL2	Lift Lobby 2	R22	Toilet 12
29	Audience Seats 1	S3	Staircase 3	R23	Toilet 13
30	Audience Seats 2	S4	Staircase 4	R24	Toilet 14
31	Lobby 3	S7	Staircase 7	R25	Toilet 15
32	Lobby 4	S8	Staircase 8	SR16	Service Room 16
33	Lobby 5	FS3	Fire Staircase 3	SR17	Service Room 17
34	Lobby 6	FS4	Fire Staircase 4	SR18	Service Room 18
L2	Lift 2	FS11	Fire Staircase 11	SR19	Service Room 19

Figure 9: Second Floor Plan with SOA. (Drawn by Goh Zhen Yi. Source: Archdaily,2019)

The level of wayfinding within the spaces varies from straightforward to average. The spatial layout of the first floor predominantly follows a symmetric spatial system characterised by a high proportion of highly integrated spaces. According to the justified graph depicted in Figure 3, depth level 9 is categorised as straightforward wayfinding spaces with high navigability and wayfinding quality. In contrast, depth levels 10 to 12 are classified as average wayfinding spaces with moderate navigability and wayfinding quality. These spaces conform to a symmetrical spatial system, with Audience Hall 1 (15), Register Area (12), Diving Pool (14), and Audience Hall 2 (16) serving as the root space. The VGA further supports this observation, confirming high visual connectivity and spatial integration within these areas.

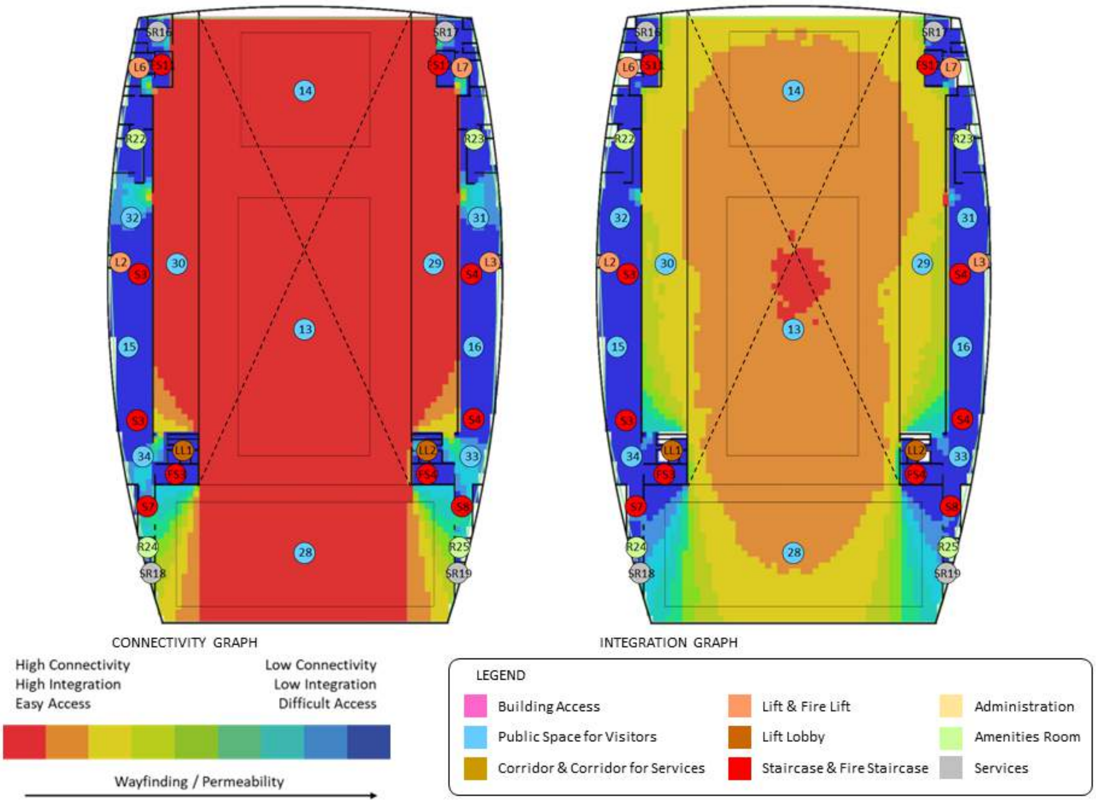


Figure 10: Visibility Graph Analysis for VGA Connectivity Graph and VGA Integration Graph of Second Floor Plan of Zhejiang HuangLong Aquatics Centre. (Drawn by Goh Zhen Yi. Source: Archdaily,2019)

The justified graph in Figure 3 shows five depth levels ranging from level 13 to level 17 for the second floor. According to the justified graph illustrated in Figure 3, depth levels 13 to 15 are classified as private space, while depth levels 16 to 17 are classified as highly private. Lift Lobby 1 (LL1), Fire Staircase 3 (FS3), and Staircase 3 (S3) directly connect to Lobby 6 (34) at depth level 14. Similarly, Lift Lobby 2 (LL2), Fire Staircase 4 (FS4), and Staircase 4 (S4) directly connect to Lobby 5 (33) at depth level 14, serving as the primary vertical public access points to the second-floor level. Lift 2 (L2) and Staircase 3 (S3) are directly connected from Audience Hall 1, extending to Lobby 4 (32) at depth level 14. Conversely, Lift 3 (L3) and Staircase 4 (S4) are directly connected from Audience Hall 2, leading to Lobby 3 (31) at depth level 14. Lobby 6 (34) and Lobby 4 (32) share a similar connection to Audience Seats 2 (30) at depth level 15, further connecting to Service Room 16 (SR16) at depth level 16. Similarly, Lobby 5 (33) and Lobby 3 (31) connect to Audience Seats 1 (30) at depth level 15, which further links to Service Room 17 (SR17) at depth level 16. Lobby 6 (34) and Lobby 5 (33) are linked through Staircase 7 (S7) and Staircase 8 (S8) to the Training Pool (28), which further branches to Toilet 14 (R24), Service Room 18 (SR18), Service Room 19 (SR19), and Toilet 15 (R25) at depth level 17, the highest depth level in the justified graph (Fig. 3). These spaces with a level of permeability classified as extremely private are designated for the training athletes only. Based on the overall permeability graph and the Likert scale table (Table 5), the level of permeability ranges from private to highly private.

Table 5: Likert Scale on Space Analysis for Second Floor Plan

Code of Space	Depth Level	Level of Permeability	Level of Wayfinding
15,16	13	Private	Difficult
34,32,31,33	14	Private	Difficult
30,R22,R23,29	15	Private	Difficult
SR16,28,SR17	16	Extremely Private	Very Difficult
R24,SR18,SR19,R25	17	Extremely Private	Very Difficult

The wayfinding within the spaces varies from difficult to very difficult. The spatial layout of the second floor primarily adheres to a symmetric spatial system characterised by a high percentage of highly integrated spaces. Referring to the justified graph in Figure 3, depth levels 13 to 15 are categorised as difficult wayfinding spaces with low navigability and wayfinding quality. These spaces form a symmetrical spatial system with Lobby 6 (34), Lobby 4 (32), Audience Hall 1 (15), Lobby 3 (31), Lobby 5 (33), and Audience Hall 2 (16) serving as the root space. The VGA indicates high visual connectivity and spatial integration at higher depth level spaces such as the Training Pool (28), Audience Seats 1 (29), and Audience Seats 2 (30), as these spaces are located at a private to extremely private level of permeability as per the building program. Depth levels 16 to 17 are classified as having tough wayfinding quality due to their higher depth level, low visual connectivity, and low spatial integration. The VGA shows low visual connectivity and spatial integration for spaces located at depth levels 16 to 17, excluding the Training Pool (28).

6 Discussion

The overall justified graph, depicted in Figure 3, presents a complex tree-like model characterised by numerous asymmetrical structures. Public entrances (E1, E2, and E3) serve as root spaces, while entrance 2 (E4) is primarily designated for private use, catering to staff and training swimmers. This distinction reflects the aquatic centre's design intent to balance public and private access, ensuring a welcoming and accessible environment for all visitors. With an asymmetrical structure as its foundation, each branch interconnects, offering multiple alternative routes to various spaces.

The spatial arrangement appears in a predominantly semi-public building layout. Private spaces are concentrated in the earlier lower-depth levels. They are relatively easily accessible, while public spaces are positioned in the latter, higher depth levels, presenting more challenges in accessibility, as indicated by the Visual Graph Analysis (VGA) results. This configuration aligns with the aquatic centre's typology, accommodating both public visitors and private users. The asymmetrical structure highlights spatial complexity, with high spatial integration and connectivity located deeper within the spaces, facilitating controlled internal circulation and regulated access to public-private zones.

Table 6: Number and Percentage of Spaces Based on Level of Permeability and Wayfinding

Level of Permeability and Wayfinding	Level	Spaces	Number	Percentage (%)
Public / Very Easy (0-6)	Site Plan	1,2,3,4,A,B,C,D	8	
	Ground Floor Plan	E1,E2,E3,E4,1,6,10,9,5,11,7,8,R1,SR10, R6,R3,C1,5,C2,11,CS7,R11,C4,C3,7,8	26	
	First Floor Plan	-		
	Second Floor Plan	-		
				28
Semi-Public / Easy (7-9)	Site Plan	-		
	Ground Floor Plan	R2,R4,2,4,SR1,CS1,SR9,R12,CS2,C5,SR4,3,R5,SR2,SR3,R7,R10,R9,CS4,R8,SC1, SR6,SR5,CS5,CS3, SC2,SC3	27	
	First Floor Plan	15,16	2	
	Second Floor Plan	-		
				24
Semi-Private / Average (10-12)	Site Plan	-		
	Ground Floor Plan	SR7,CS6	2	
	First Floor Plan	C6,C7,12,14,C8,C9,SC6,SC4,18,19,R20, 20,21,SR11,24,R13,R16,SR15,13,SR13, SR14,SC7,SC5,R19,17,R21,22,23,25,SR12,26,R15,R14,R17,R18,LL1,LL2,SC8,27	39	
	Second Floor Plan	-		
				34
Private / Difficult (13-15)	Site Plan	-		
	Ground Floor Plan	-		
	First Floor Plan	-		
	Second Floor Plan	15,16,34,32,31,33,30,R22,R23,29	10	
				8
Extremely Private / Very Difficult	Site Plan	-		
	Ground Floor Plan	-		
	First Floor Plan	-		
	Second Floor Plan	SR16,28,SR17,R24,SR18,SR19,R25	7	
				6
		TOTAL		100
			121	

6.1 Level of Permeability

As outlined in Table 6, semi-private spaces constitute the largest percentage of the overall schedule of accommodation. The case study building allocates 28% of its space to public areas, while semi-public spaces account for 24%, semi-private spaces for 34%, private spaces for 8%, and extremely private spaces for 6%. This distribution underscores the significance of prioritising public space allocation while ensuring the provision of necessary private areas in the aquatic centre's design. This approach guarantees that all visitors can access public areas while training athletes and staff members have appropriate access to semi-private, private, and extremely private spaces.

Table 7: Number and Percentage of Spaces Based on Connecting Spaces

Spaces	Justified Graph Depth Level					Percentage (%)
	0,1,2,3,4 ,5,6	7,8,9	10,11,12	13,14,15	16,17	
Single Connecting Space & End Room	5, 7, 8, 11, R6, R6, R7, R8, SR10	3, 4, CS5, CS6, R5, R7, R8, R12, SC2, SC3, SR2, SR3, SR5, SR6, SR7, SR9	17, 20, 21, 22, 23, 26, 27, R14, R15, R17, R18, R20, R21, SC4, SC6, SC7, SC8, SR11, SR12, SR13, SR14, SR15	R22, R23	R24, R25, SR16, SR17, SR18, SR19	36
Double Connecting Space	R1, R3, R11	2, R2, R4, R10, SR8	18, 19, R19, SC5			7
Triple Connecting Space	C3	CS2, CS4, SC1, SR1, SR4	R13, R16, 24, 25	15,16		7
Multi-Connecting Space	C1, C2, C4, CS7	15, 16, C5, CS1, CS3	12, 13, 14, C6, C7, C8, C9	29, 30, 31, 32, 33, 34	28	15
Access Road	1,2,3,4					3
Entrance & Lobby	1, A, B, C, D, E1, E2, E3, E4, 6, 9, 10					7
Staircase & Elevator	FS1, FS2, L1, L2, L3, S3, S4	FS10, FS11, FS212, FS3, FS4, FS5, FS6, FS7, FS8, FS9, L4, L5, L6, L7, S1, S2	LL1, LL2	FS11, FS12, FS3, FS4, L2, L3, L6, L7, LL1, LL2, S3, S4, S7, S8		25

6.2 Level of Wayfinding

The analysis in Table 6 indicates that the case study building achieves a 28% rating for "very easy" wayfinding. It suggests that the spatial layout is meticulously planned to facilitate public access for visitors and competitive athletes. However, it also highlights that 14% of the wayfinding experience is rated as "difficult" and "very difficult" for training athletes and staff, including administrative personnel, technicians, and lifeguards.

Multi-connecting spaces, facilitating seamless circulation between adjacent areas like the Diving Pool and Competition Pool, constitute 15% of the total area. Meanwhile, 36% of spaces, including toilets and building services rooms, consist of single connecting spaces and end rooms. Double connecting rooms, comprising 7% of the spaces, have the potential to enhance the visitor experience by fostering a sense of continuity and fluidity throughout the aquatic centre, thereby simplifying navigation for visitors. Vertical connectors such as staircases and elevators are strategically distributed across various depth levels, serving specific public and private functions and access points.

7 Conclusion

The planning of the Zhejiang HuangLong Aquatics Centre showcases a commendable level of permeability and wayfinding, which is noteworthy for an aquatic centre. Design elements like the three primary entrances directing users through the internal buffer area before reaching the main pool area facilitate smooth circulation for the public, minimising congestion during busy periods. The first floor, linked to the central pool area, offers direct public and private users access via various circulation paths, including corridors and spaces between semi-private areas.

The objective of the research paper is to evaluate the permeability of the architectural space within the Zhejiang HuangLong Aquatics Centre and analyse its spatial configurations. The spatial layout of the case study building, designed as an aquatic centre, is deemed suitable regarding its permeability level and wayfinding quality, as evidenced by the justified graph and VGA analysis. The overall space syntax performance indicates a semi-private nature, characterised by vertical and horizontal public-private spatial zoning.

According to the data in Table 6, the aquatic centre’s overall spatial performance heavily depends on the prevalence of semi-private spaces, comprising 34% of the total building area, characterised by average wayfinding. This abundance of semi-public areas influences the overall spatial dynamics and helps alleviate congestion within the aquatic centre. Moreover, the significant presence of single connecting spaces and end rooms, constituting 36% of the total area, plays a crucial role in providing semi-private and private areas such as the swimmer’s room, lifeguard’s room, and gymnasium with secluded spaces, effectively separating them from semi-public and public areas.

Additionally, the intentional layout of public and semi-public spaces, accessible only after traversing through corridors and various semi-public areas, fosters a heightened sense of community and cohesion at the higher depth levels.

The overall wayfinding experience within the aquatic centre is average throughout the building. However, the notable challenge lies in providing visitors with easier navigation towards the audience seats. On the other hand, frequent users, such as training athletes and staff, encounter a relatively smoother wayfinding as they navigate towards semi-private and private spaces.

The abundance of highly permeable public spaces with excellent wayfinding quality at elevated depth levels has notably increased exposure for private users within the semi-private areas, fostering a connection with the public in higher-depth spaces like the Competition Pools, Diving Pools, and Register Area. Following a path through various semi-private spaces, these areas are deliberately designed as passageways, maximising their functionality by providing a range of engaging activities through the accommodation schedule.

However, the semi-private and private spaces at a lower depth level, specifically on depth level 13, exhibit lower spatial integration and visual connectivity than the second floor. It leads to unplanned congestion for visitors, who may encounter difficulties navigating the area and accessing the audience seats from the entrance. To improve the visitor experience in these zones, enhancing the visual connectivity between the ground and second floors can create a more open and interconnected space. For instance, adjusting the entrance to the first-floor level to bypass the semi-private and private areas on the ground floor could be considered.

However, solely depending on quantitative data in the study may overlook the qualitative dimensions of user experience, which encompass emotional reactions to the building design and arrangement. Addressing this drawback is crucial to undertaking thorough research that blends qualitative data collection techniques like interviews or on-site observations. By incorporating richer data sources, the study can attain a more thorough and nuanced analysis, elevating the overall calibre and depth of the research outcomes.

8 Availability of Data and Materials

All information is included in this article.

9 Acknowledgement

This research is under financial support from ITJEMAST publisher for a joint research study with Universiti Sains Malaysia from the industrial grant No 304 /PPBGN /6501356 /I158 titled ‘A Study on Social Contexts of Building Space Syntax’.

10 References

Abdul Nasir, N.A.B., Hassan, A.S., Khozaei, F. and Abdul Nasir, M.H.B. (2021). Investigation of spatial configuration management on social distancing of recreational clubhouse for COVID-19 in Penang, Malaysia. *International Journal of Building Pathology and Adaptation*, *39*(5), 782-810, doi: 10.1108/IJBPA-08-2020-0072

ArchDaily. (2019). Zhejiang HuangLong Aquatics Center / CSADI. Retrieved February 2024, from http://www.archdaily.com/926218/zhejiang-huanglong-aquatics-center-csadi

Elizondo, L. (2021). A Justified Plan Graph Analysis of Social Housing in Mexico (1974–2019): Spatial Transformations and Social Implications. *Nexus Network Journal, 24*(1), 25–53. DOI: 10.1007/s00004-021-00568-7

Hanani, E. (2017). The Study on Value of Recreational Sports Activity of Urban Communities. *Jurnal Kesehatan Masyarakat*, 12, 286-291. http://doi.org/10.15294/kemas.v12i2.5813

Hassan, A. S. (2004). *Issues in Sustainable Development of Architecture in Malaysia*. Universiti Sains Malaysia.

Hillier, B., & Hanson, J. (1984). *The Social Logic of Space*. Cambridge: Cambridge University Press.

Khaw, S.C., Hassan, A. S. and Hafeez, M. Arab, Y., and Witchayangkoon, B. (2023). Analysis of Permeability and Wayfinding of University Library: Case Study on SCCC Learning Resource Center. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, 14(1), 14A1N, 1-15. http://TUENGR.COM/V14/14A1N.pdf DOI: 10.14456/ITJEMAST.2023.14

Knoll, M., Li, Y., Neuheuser, K., & Rudolph-Cleff, A. (2015). Using Space Syntax to analyse stress ratings of open public spaces. http://doi.org/10.13140/RG.2.1.3917.3202/1

Koutsolampros, P., Sailer, K., Varoudis, T. & Haslem, R. (2019). Dissecting visibility graph analysis: the metrics and their role in understanding. *Proc. of the 12th Space Syntax Symposium Workplace Human Behaviour*.

Lee, J. H. (2020). Reinterpreting Sustainable Architecture: What Does It Mean Syntactically?. *Sustainability*, 12(16), 6566.

Mallen, C., Adams, L., Stevens, J., & Thompson, L. (2010). Environmental Sustainability in Sport Facility Management: A Delphi Study. *European Sport Management Quarterly*, *10*(3), 367–389. https://doi.org/10.1080/16184741003774521

Nasab, A. M., Pilechiha, P. & Hajian, M. (2019). A Justified Plan Graphical Mathematical Analysis of Traditional Houses in the Moderate and Humid Climate of Iran. Bu-Ali Sina University. DOI: 10.14456/ITJEMAST.2019.113

Natapov, A., Kuliga, S., & Dalton, R. (2015). Building Circulation Typology and Space Syntax Predictive Measures. http://doi.org/10.13140/RG.2.1.1054.1843

Ooi, E. L., Hassan, A. S., Arab, Y., Witchayangkoon, B. (2022). Permeability and Wayfinding Analysis on Putuo Mountain New Passenger Transportation Centre. Universiti Sains Malaysia. DOI: 10.14456/ITJEMAST.2023.19

Riekstins, A. (2018). Teaching parametricism as a standard skill for architecture. *Journal of Architecture and Urbanism*.

Sadalla, E. K., & Magel, S. G. (1980). The Perception of Traversed Distance. Environment and Behavior. https://doi.org/10.1177/0013916580121005

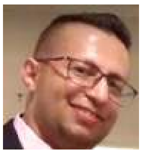
Goh Zhen Yi is a Master of Architecture Program student at the Universiti Sains Malaysia. He received his Bachelor of Science (Hons) in Architecture (LAM Part 1) from UCSI University in 2020 and Master of Architecture from Universiti Sains Malaysia in 2024. His research interest is on a space syntax study about user behaviour.

Professor Dr. Ahmad Sanusi Hassan is a Professor in the Architecture Programme at the School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia. He obtained a Bachelor's and Master's of Architecture degrees from the University of Houston, Texas, USA, and a PhD from the University of Nottingham, United Kingdom. His research focuses on Sustainable Architecture and Urban Design for Southeast Asia, the history and theory of Architecture, Computer-Aided Design (CAD) and Computer Animation.

Dr. B. Witchayangkoon is an Associate Professor at the Department of Civil Engineering at Thammasat University. He received his B.Eng. from King Mongkut's University of Technology Thonburi with Honors in 1991. He continued his PhD at the University of Maine, USA, where he obtained his PhD in Spatial Information Science and Engineering. Dr. Witchayangkoon's current interests involve applications of emerging technologies to engineering.

Dr. Muhammad Hafeez Abdul Nasir is a university lecturer at the School of Housing Building and Planning, Universiti Sains Malaysia, Penang, Malaysia. He obtained a Bachelor of Design Studies and a Master of Architecture from the University of Adelaide, Australia. His research interests are in the fields of Architectural Sciences and Engineering.

Ts. Dr. Jestin Nordin is a Lecturer at the School of Housing, Building and Planning, Universiti Sains Malaysia (USM), Penang, Malaysia. He obtained his Master of Science in Project Management and a Bachelor of Architecture from Universiti Sains Malaysia (USM), Penang, Malaysia. Dr Jestin received his Ph.D. in Architecture from Victoria University of Wellington, New Zealand, focusing on Architectural Disaster. He is a keen person working on the role of architecture and architects and tackling the issues of the impact of natural disasters on buildings and other structures in the built environment.



Dr. Yasser Arab is an Assistant Professor at Dhofar University, Sultanate of Oman. He obtained his Bachelor of Architecture from Ittihad Private University, Aleppo, Syria, and a PhD in Sustainable Architecture from Universiti Sains Malaysia (USM), Penang, Malaysia. His research focused on the Environmental Performance of Residential High-Rise Buildings' Façade.