Assessment of the Circulation Impact of Furniture in Industrial Building through Space Syntax

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Abstract. This paper explores the impact of furniture and machines on spatial organization and circulation systems in industrial buildings using space syntax analysis. While space syntax research covers various settings, industrial buildings have received limited attention. This study aims to address this gap by examining how machines and furniture influence spatial organization and circulation in two industrial buildings: A Nitrile Glove manufacturing facility and a textile manufacturing factory. The furnished and unfurnished floor plans were analyzed using space syntax software, DepthMapX, with connectivity and agent-based analyses. The results indicate that unfurnished plans have centrally located connectivity values, whereas furnished plans create subspaces with varying connectivity. Agent-based analysis reveals that unfurnished spaces have high density in the center, while furnished spaces distribute density more evenly, resulting in more uniform circulation. This study concludes that industrial building spatial configurations result from a combination of architectural design and the placement of machines and furniture.

Keywords: Industrial Building, Space Syntax, Connectivity, Agent-Based Analysis, Furnished-Unfurnished plans

1 Introduction

Architectural spaces are not just physical elements like walls and floors; they are shaped by human behaviors, impacting spatial quality (Afshar et al., 2022). Understanding the link between human activities and spatial configuration is crucial (Bafna, 2003). The space syntax method introduced by Hillier and Hansen (1970) analyzes how space influences social organization. In industrial buildings, circulation design is essential for safety and efficiency. Considerations include traffic flow, congestion minimization, clear signage (Gath-Morad et al., 2021), and accessibility for individuals with disabilities.

Lighting, emergency exits, noise reduction, and vibration mitigation are also vital (Teicholz, 2001). This paper applies space syntax to study spatial configuration and circulation in industrial buildings, aiming to enhance safety and user experience through empirical data and case studies.

1.1 Spatial Cognition in Industrial Building Design

Spatial cognition refers to the mental capacity to perceive, understand, and navigate the spatial aspects of the environment (Emelin & Tkhostov, 2018). It involves recognizing shapes, distances, directions, remembering spatial layouts, manipulating mental images, and finding routes to different locations (Emelin & Tkhostov, 2018). This cognitive ability is essential for tasks like reading maps, routing, and solving spatial problems (Griffin et al., 2020), and it holds particular significance in fields such as architecture, engineering, urban planning, and transportation (Ma, 2022).

Awareness of spatial cognition allows architects and engineers to optimize spatial layouts for utilization, workflow, and safety (Hajji, 2019). In industrial settings, understanding spatial relationships enhances productivity, reduces errors, and improves operational performance (Azzali & Sabour, 2018). By applying this knowledge, designers can create intuitive navigation systems, collaborative spaces, and safety-oriented layouts. Workers benefit from easy access to resources and workstations, while clear signage and wayfinding systems minimize errors and the likelihood of getting lost (Bischoff et al., 2014). Additionally, spatial awareness improves safety preparedness, aiding in identifying potential hazards and evacuation routes (Liu et al., 2021).

1.2 Space Partition, Machines, Furniture and Circulation in Industrial buildings

Proper organization of machines, equipment, and space partition within industrial building can optimize workflow, minimize congestion, and improve overall efficiency and provides a smooth flow of materials within the industrial building (Boenzi et al., 2016; Rajput et al., 2019). The spatial configuration of furniture within industrial buildings has a significant effect on the circulation system. The strategic placement of furniture can create open pathways and clear sightlines, promoting safe and efficient movement throughout the space.

2 Problem Statement

Industrial building design requires a comprehensive circulation strategy concerning both infrastructures and machines. Successful implementation not only enhances operational efficiency but also ensures a safer and more productive environment for workers.

Industrial building design in architecture poses a significant challenge when it comes to efficiently managing human and goods circulation alongside infrastructures and machines (Reisinger et al., 2022). The intricate balance between these elements provides smooth operations, productivity, and safety within industrial spaces. Architects must consider factors such as foot traffic patterns, ergonomics, and safety protocols. Efficiently designed walkways, staircases, and access points are essential to prevent bottlenecks and streamline movement. Besides effective flow design of goods throughout the facility contributes to the circulation system (Zerbino et al., 2019). Heavy machinery, raw materials, and finished products are the integral parts of the industrial building which directly effects the overall circulation within industrial building. Hence the circulation design inputs within any industrial building are not solely the morphology of the space but also are the infrastructure of the building. Infrastructure and its interaction with the morphological space are the tectonics of the industrial space. The awareness of the effects of these tectonics significantly contributes the functioning of the space. This paper aims to demonstrate the circulation effects of furnished and unfurnished industrial building layout through two industrial buildings.

3 Methodology

In this study, space syntax software DepthMap X is utilized to analyze spatial structures. In the first step, we decided on two industrial buildings as case for space syntax analysis. After cleaning the selected industrial building plans on a computer aided design tool, we carried out two analyses consecutively; connectivity analysis and agent-based analysis to understand the effect of furniture on the circulation system within industrial building. Throughout the text furniture stands for both machinery and furniture of industrial buildings.

3.1 Architectural Plan Data

The data collection process for this research involves selecting two industrial building cases—a nitrile gloves manufacturing factory and a textile production factory. Two distinct 2D spatial structure plans for each case are drawn using CAD software.

The Nitrile Glove manufacturing factory, chosen for research, is a large industrial building with a construction area of 14,715 square meters (Fig. 1). In this paper, the ground floor of the factory is selected for analysis purposes. The main production area, with offices, storage, and laboratory spaces on the left side. The top floor houses machines, equipment storage, and shelters, while the left part contains raw material stock and loading/unloading areas.

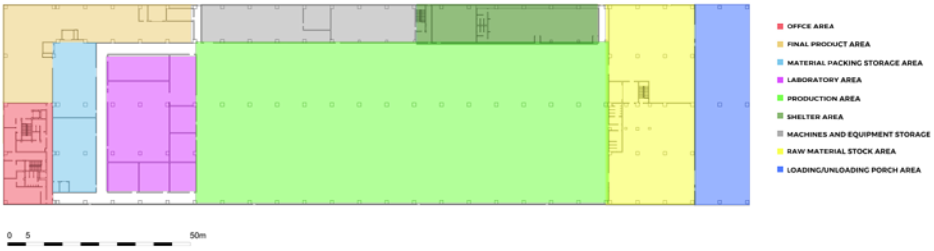

Figure 1. General Arrangement of Different Spaces on the Nitrile manufacturing factory's Ground Floor. (Adopted and modified by author)

The Textile production factory is the second case study. It has three distinct functional spaces: Office area, production areas, and storage areas (Fig. 2). The main Office area is in the left-bottom corner, with dress sewing on the left, fabric cutting in the middle-bottom, and textile automatic printing on the top-middle. Storage areas include finished product, semi-finished product, accessory, and embroidery workshop areas.

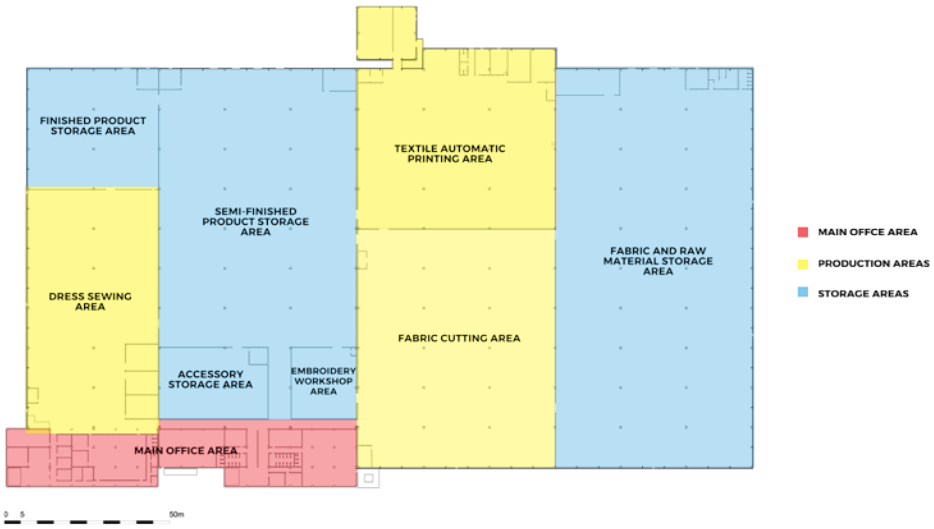

Figure 2. General Arrangement of Different Spaces on the Textile production factory's Ground Floor. (Adopted and modified by author)

3.2 Connectivity Analysis

Connectivity analysis is a spatial analysis technique used to examine the level of integration and accessibility within a built environment. In the context of industrial buildings, it assesses the interconnectedness and flow of spaces, pathways, and nodes. By creating a visual map of the building's layout and analyzing its topological structure, connectivity analysis helps identify key circulation patterns, potential bottlenecks and isovist areas (Li & Huang, 2020). Isovist is a geometric term used to describe the visual field from a certain perspective point within a space in the context of space syntax and connectivity analysis. The isovist analysis involves calculating the isovist area, which is the total visible area from the vantage point, and the perimeter, which represents the boundary of the visible area (Yin et al., 2021). Also, this analysis is performed on two case studies, the Nitrile glove manufacturing factory and the Textile production factory.

3.3 Agent-Bases Analysis

Agent-Based analysis simulates the human behaviors within a built environment. Each agent follows predefined rules based on real-world behaviors, such as path preferences and interactions with furniture and obstacles. By running the simulation, researchers can observe and analyze the dynamic movement patterns of the agents (Meng et al., 2021). Agent-Based Analysis provides valuable insights into how furniture placement and spatial configurations influence circulation and user interactions, helping to optimize industrial building designs for enhanced functionality and flow efficiency (Krejcar et al., 2019).

4 Circulation Analysis

4.1 Nitrile Gloves Manufacturing Factory

Connectivity Analysis: Connectivity analysis in figure 3 provides valuable insights into the integration of factory subspaces. The production area acts as a central hub, facilitating smooth material and product movement. Furniture and equipment create physical barriers or enablers affecting accessibility and communication within the factory. The furnished plan shows improved connectivity, particularly in previously disconnected areas like final product storage, loading/unloading porch area and laboratory area. Office connectivity enhances communication and coordination with production and loading zones. Strategically placed furniture optimizes connectivity between the warehouse and loading/unloading zones, streamlining material flow and storage. This interconnectedness optimizes factory operations and boosting efficiency. It leads to making processes faster and more streamlined, ultimately leading to increased productivity. The designated product transfer area ensures seamless material flow in the furnished graph version.

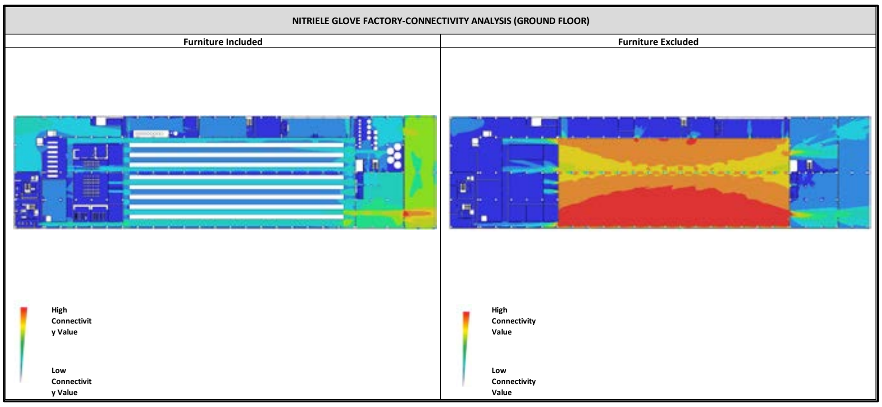

Figure 3. Connectivity Comparison Visual Graphs Table -Ground Floor (Figure by author)

Agent Based Movement Analysis: Agent-Based Movement Analysis of a factory's ground floor and first floor (Fig. 4) reveals insights into agent behavior and space optimization. The central production area has high agent density due to machine lines as barriers, but a well-connected corridor attracts movement. Strategic furniture placement transforms less preferred areas into green and yellow zones, indicating improved accessibility. The raw material storage and loading area becomes a frequently utilized circulation space.

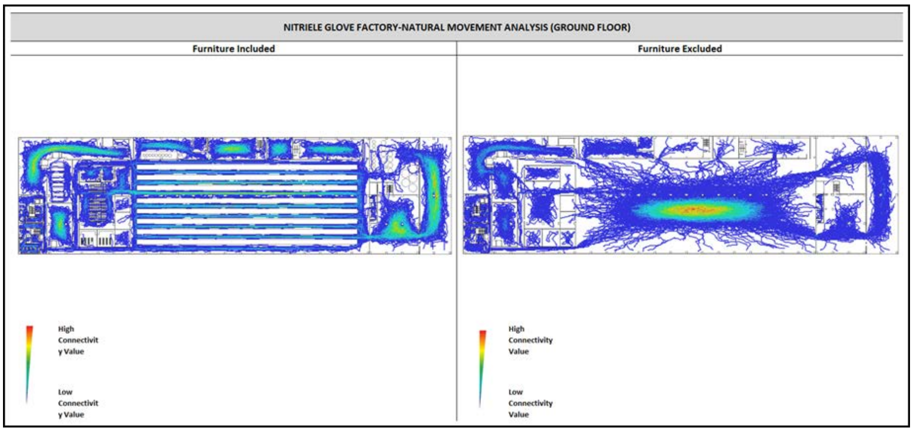

Figure 4. Agent-Based Movement Comparison Visual Graphs Table -Ground Floor. (Figure by author)

4.2 Textile Production Factory

Connectivity Analysis: Figure 5 represents the connectivity values of textile factory. The unfurnished version depicts the office area as a dark blue isovist space, isolated from the factory. Brighter blue areas indicate better connectivity with other regions. The automatic textile fabric printing area stands out with the highest connections in light green and yellow. In the furnished version, the office retains its dark blue isovist spaces, while connections with other areas become more apparent in lighter blue. Furniture affects connectivity in the dress sewing and textile printing areas. The fabric cutting area remains highly connected. Warehouse areas show varying connectivity potential due to furniture impact.

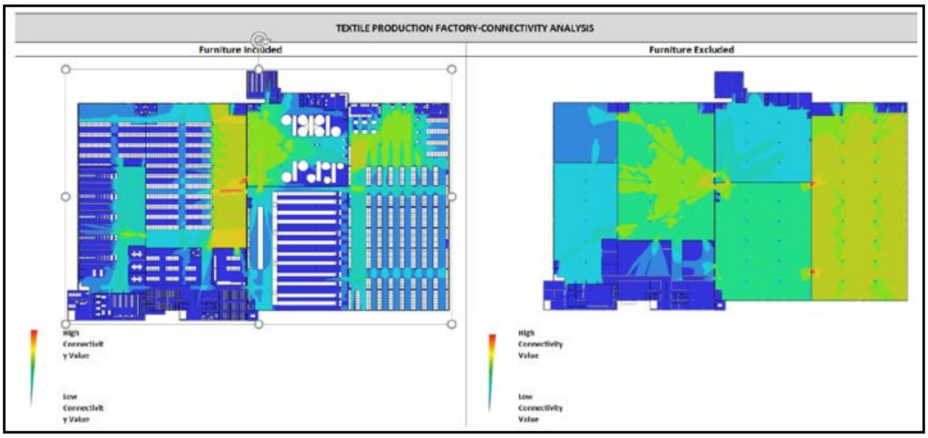

Figure 5. Connectivity Comparison Visual Graphs Table. (Adopted and modified by author)

Agent-Based Movement Analysis: The impact of furniture on agent movement in a factory was analyzed through agent-based movement analysis. Two scenarios were considered: one without furniture and the other with furniture and equipment. In the unfurnished scenario, agents showed reluctance to move to the areas like main office area and factory's surrounding area, resulting in low movement density, while in the furnished scenario, furniture influenced movement patterns that acted as both a guide, directing agents' movement in specific paths, and a barrier, limiting access to some other areas (Fig. 6). Different factory areas exhibited varying flow densities based on furniture placement, with the connection part between two areas as semi-finished product storage area and textile automatic printing area showing higher movement flow due to furniture arrangement and task-specific activities. Optimizing furniture layout not only enhances efficiency and circulation but also increases the flow of movement density in the connection parts between two areas, resulting in a more productive working environment for agents.

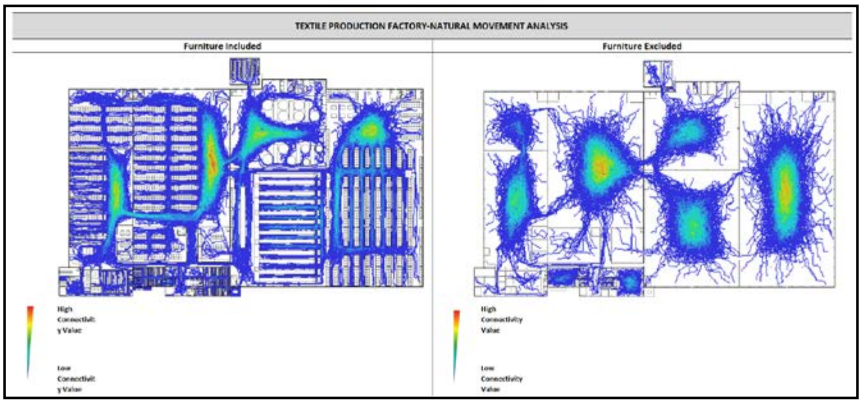

Figure 6. Agent-Based Movement Comparison Visual Graphs Table. (Adopted and modified by author)

5 Findings

The connectivity analysis of unfurnished plans in the manufacturing factories revealed valuable insights into spatial relationships. The production area on the ground floor emerged as a crucial hub, facilitating smooth material and product flow. However, furniture and equipment introduced physical barriers or facilitators that impacted accessibility and communication between different sections. Surprisingly, furniture placement improved connectivity in previously disconnected areas, enhancing communication and coordination. The office area particularly benefited from better connections with the production and loading areas, streamlining operations. Similarly, well-placed furniture improved the warehouse area's connectivity with the loading/unloading zone, optimizing material flow and storage.

In the furnished connectivity analysis, the office area still emerged as an important hub with improved connections to other parts of the factory. The corridor between the office area and production zone remained a strong link after even furniture placement. Furthermore, designated areas for product transfer had a significant impact on ensuring seamless material flow. The analysis highlighted how furniture placement can strategically influence connectivity, promoting efficient spatial relationships within the factory.

In the agent-based analysis of the unfurnished scenario, agents showed reluctance to move towards certain parts of the main office area because there was no furniture to serve as a guidance role, leading to less defined paths and less attraction to those areas. Also, similar patterns were observed in other sections, where the absence of furniture limited agent movement. However, on the ground floor, a central path between machine lines served as a well-connected corridor, attracting agents for movement. Furniture placement guided agent-based movement, transforming previously less preferred areas into green and yellow zones, indicating improved accessibility and successful space optimization. Notably, certain spaces, such as raw material storage and loading zones, became popular circulation areas, further validating the impact of furniture placement.

In the furnished agent-based analysis, furniture placement impacted agent flow in various areas. The main office area experienced a shift in movement density due to furniture placement. Certain areas, such as the fabric cutting area, had agents influenced by furniture and machines as barriers Certain areas, like the fabric cutting area, had agents influenced by furniture and machines as barriers, with distributing the central flow density over the entire area. In contrast, other areas such as connection part between semi-finished product storage area, fabric cutting and automatic printing area exhibited higher flow density due to the intersection of movements from different areas. Understanding agent movement patterns in response to furniture placement can assist in creating a more efficient and optimized layout within the factory, enhancing the overall performance of the manufacturing process.

6 Discussion

The method employed for the connectivity analysis of unfurnished plans in manufacturing factories yielded valuable insights, shedding light on how spatial arrangements influence agent movement and interactions. While the production area on the ground floor emerged as a crucial hub, furniture and equipment introduced physical barriers or facilitators impacting accessibility and communication between sections. Surprisingly, furniture placement proved instrumental in improving connectivity in previously disconnected areas, leading to enhanced communication and coordination. Notably, the office area experienced substantial benefits with better connections to the production and loading zones, streamlining operations. Additionally, well-placed furniture optimized material flow and storage in the warehouse area, further contributing to overall factory efficiency.

This study significantly contributes to the field of factory layout optimization. Analyzing both unfurnished and furnished scenarios, we emphasize the critical role of furniture placement in influencing connectivity and agent-based movement patterns. Our findings provide a foundation for future research to explore comprehensive strategies for enhancing factory layouts. Researchers can investigate various types of furniture and equipment configurations, evaluating their effects on overall productivity. Moreover, understanding the implications of connectivity on worker interactions and material handling processes can lead to continuous improvements in manufacturing facilities.

This knowledge will aid in designing more efficient and productive factories, ultimately enhancing the manufacturing industry's overall performance.

7 Results

The connectivity analysis for the Nitrile Gloves Manufacturing Factory reveals the crucial role of furniture and equipment in shaping the network of connections and optimizing operations. Strategically placed furniture improves connectivity, especially in previously disconnected areas like product storage and loading zones, streamlining material flow and storage. This integrated approach enhances communication and coordination, leading to faster and more streamlined processes, ultimately boosting productivity. The furnished plan shows significant improvements in connectivity, resulting in a more efficient and productive working environment within the factory.
The agent-based movement analysis further examined agent behavior and space optimization. In both factories, the presence of furniture influenced agent flow, with strategic furniture placement leading to improved accessibility and circulation. The textile production factory's analysis also highlighted agents' preferences in different areas that in the unfurnished environment, agents were hesitant to move to particular areas, while furniture influenced movement patterns in the furnished scenario. It is indicating how furniture arrangement can impact their movement patterns. As a result, the connectivity and agent-based analysis show that furnishing is an integral part of the spatial organization and circulation system within industrial buildings. Hence proper furniture and equipment placement can optimize factory operations and create a more productive working environment for agents.

References

Adam JA., Hausmann K., Jüttner F., Daniels K. (2004). Industrial Buildings (A Design Manual), Birkhauser Architecture.

Afshar, S.V., Eshaghi, S., Kim, I. (2022) Pattern Analysis of Virtual Landscape within Educational Games, JoDLA - Journal on Landscape Architecture, 7, pp. 435–442. http://dx.doi.org/10.14627/537724042

Azzali, S., & Sabour, E. A.. (2018, January 1). The Way-Finding in Educational Modular Buildings: The Case of the Male Engineering Building at Qatar University. Advances in Civil Engineering, 2018, 1-10. https://doi.org/10.1155/2018/6076021

Bafna, Sonia (2003), “Space Syntax A Brief Introduction to Its Logic and Analytical Techniques”, Environment and Behaviour, Vol. 35 No. 1, January 2003 17-29.

Bischoff, H., Sinay, J., & Vargová, S.. (2014, September 1). Integrated Risk Management in Industries from the Standpoint of Safety and Security. https://scite.ai/reports/10.2478/tvsbses-2014-0005

Boenzi, F., Digiesi, S., Facchini, F., Mossa, G., & Mummolo, G.. (2016, January 1). Greening Activities in Warehouses: A Model for Identifying Sustainable Strategies in Material Handling. https://scite.ai/reports/10.2507/26th.daaam.proceedings.138

Bunnarong, S., & Upala, P.. (2018, May 24). Spatial Analysis to Identify Pedestrian Crash Zones: A Case Study of School Zones in Thailand. https://scite.ai/reports/10.2174/1874447801812010167

Djenaihi, W., Zemmouri, N., Djenane, M., & Nes, A. V.. (2021, October 4). Noise and Spatial Configuration in Biskra, Algeria—A Space Syntax Approach to Understand the Built Environment for Visually Impaired People. Sustainability, 13(19), 11009. https://doi.org/10.3390/su131911009

Emelin, V., & Tkhostov, A.. (2018, January 1). COGNITIVE VS TECHNOLOGICAL MAPS OF GEOSPACE. Праξημα Journal of Visual Semiotics, 125-141. https://doi.org/10.23951/2312-7899-2018-4-125-141

Gath-Morad, Michal et al. (2021, September 23). Visibility matters during wayfinding in the vertical. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-98439-1

Griffin, E., Picinali, L., & Scase, M. O.. (2020, May 22). The effectiveness of an interactive audio-tactile map for the process of cognitive mapping and recall among people with visual impairments. Brain and Behavior, 10(7). https://doi.org/10.1002/brb3.1650

Hajji, A. M.. (2019, January 1). Toward energy efficiency measures for design of the IDB-funded integrated classroom building in Universitas Negeri Malang. Matec Web of Conferences, 276, 06023. https://doi.org/10.1051/matecconf/201927606023

Hillier, B. (2007). Space is the machine: a configurational theory of architecture. Space Syntax.

Hillier, B., Leaman, A., Stansall, P., & Bedford, M. (1976). Space syntax. Environment and Planning B: Planning and design, 3(2), 147-185.

Hillier, B., Penn, A., Hanson, J., Grajewski, T., & Xu, J., (1993), “Natural movement: Or, configuration and attraction in urban pedestrian movement”, Environment and Planning B: Planning and Design, 20 (1), 29 – 66.

Jamshidi, Mahmoud, (2012), "Considerations on the theory of space layout analysis", 20-25, urban studies.

Jang, K., Kim, J., Ju, K., & An, Y.. (2021, November 3). Infrastructure BIM Platform for Lifecycle Management. Applied Sciences, 11(21), 10310. https://doi.org/10.3390/app112110310

Jin, S., Ye, H., Shaobin, W., & Sedki, A.. (2022, July 1). Preservation and utilisation of historic buildings in old district of Guangzhou from the perspective of space syntax. Applied Mathematics and Nonlinear Sciences, 7(2), 931-956. https://doi.org/10.2478/amns.2021.2.00208

Kamalipour, H., Arab, A. D., Soltani, S., Alavi, S. N., & Mirzaei, E.. (2013, January 1). Understanding Continuity and Change in the Persian Vernacular Settlements: A Comparative Syntactic Analysis of Urban Public Spaces in a Case Study. Current Urban Studies, 01(04), 130-138. https://doi.org/10.4236/cus.2013.14014

Li, R., & Huang, H.. (2020, February 3). Visual Access Formed by Architecture and its Influence on Visitors' Spatial Exploration in a Museum. Interdisciplinary Journal of Signage and Wayfinding, 4(1). https://doi.org/10.15763/issn.2470-9670.2020.v4.i1.a55

Liu, Z., Yang, Z., & Osmani, M.. (2021, October 17). The Relationship between Sustainable Built Environment, Art Therapy and Therapeutic Design in Promoting Health and Well-Being. https://scite.ai/reports/10.3390/ijerph182010906

Ma, Y.. (2022, July 13). Optimization Algorithm of Urban Rail Transit Network Route Planning Using Deep Learning Technology. Computational Intelligence and Neuroscience, 2022, 1-10. https://doi.org/10.1155/2022/2024686

Meng, Q., Liu, W., Li, Z., & Hu, X.. (2021, March 5). Influencing Factors, Mechanism and Prevention of Construction Workers’ Unsafe Behaviors: A Systematic Literature Review. International Journal of Environmental Research and Public Health, 18(5), 2644. https://doi.org/10.3390/ijerph18052644

Nie, X.. (2022, March 8). Cross-Border E-Commerce Logistics Transportation Alternative Selection: A Multiattribute Decision-Making Approach. https://scite.ai/reports/10.1155/2022/4990415

Rajput, Islam, Hira et al. (2019, June 30). Prevalence of work-related neck and shoulder pain among office receptionists of Karachi. https://scite.ai/reports/10.16899/jcm.571620

Reisinger, J., Kugler, S., Kovacic, I., & Knoll, M.. (2022, February 2). Parametric Optimization and Decision Support Model Framework for Life Cycle Cost Analysis and Life Cycle Assessment of Flexible Industrial Building Structures Integrating Production Planning. https://scite.ai/reports/10.3390/buildings12020162

Teicholz, E. (2001). Facility design and management handbook. McGraw-Hill Education.

Vaughan, L (2007), “The spatial syntax of urban segregation”, Progress in Planning, No 67, pp 205–294.

Yin, L., Wang, T., & Adeyeye, K.. (2021, April 2). A Comparative Study of Urban Spatial Characteristics of the Capitals of Tang and Song Dynasties Based on Space Syntax. https://scite.ai/reports/10.3390/urbansci5020034

Zerbino, P., Aloini, D., Dulmin, R., & Mininno, V.. (2019, August 18). Towards Analytics-Enabled Efficiency Improvements in Maritime Transportation: A Case Study in a Mediterranean Port. https://scite.ai/reports/10.3390/su11164473