JOURNAL OF ARCHITECTURE, PLANNING & CONSTRUCTION MANAGEMENT
Volume 16 Issue 1, 2026 E-ISSN: 2462-2222 ISSN: 2231-9514

ALIGNING CURATORIAL INTENT WITH PERCEPTION-BASED NAVIGATION: SOM AND ISOVIST APPROACHES IN EXHIBITION DESIGN

Received: 02 Mar 2026 | Revised: 14 May 2026 | Accepted: 15 May 2026 | Available Online: 30 Jun 2026
DOI: 10.31436/japcm.v16i1.101071

Sajid I Awal [1*]

[1] Alumni UCL, UK; Alumni Chulalongkorn University, Thailand*

Corresponding author: **Sajid I Awal*

Corresponding author's email: sajidiawal1992@gmail.com

ABSTRACT

Designing intuitive indoor exhibition spaces requires aligning the intended narrative sequence with visitors' spontaneous movement. Evaluating this alignment before construction remains a challenge in architectural planning. This research presents a computational framework to assess spatial layouts by comparing planned exhibition routes with simulated visitor behaviour. The study employs two complementary computational approaches within a temporary indoor exhibition context: the Self-Organising Map (SOM) and Isovist-based agent simulation. The SOM algorithm generates an optimised sequence of exhibit nodes, representing the intended visitor route, while the Isovist simulation predicts movement based on spatial geometry, visibility, and obstacle avoidance. An image-based, pixel-level comparison using OpenCV quantifies the overlap between SOM-generated paths and Isovist trajectories, revealing areas of alignment and divergence. Results show partial overlap, indicating that while SOM captures structured circulation, natural visitor movement is more adaptive and variable. The methodology highlights spatial inefficiencies and navigational bottlenecks, providing architects and planners with a diagnostic tool to optimise exhibition layouts, enhance circulation, and ensure key points of interest are naturally discoverable.

Keywords: Visitor movement, Isovist simulation, SOM algorithm, indoor navigation

1.0 INTRODUCTION

Indoor navigation within exhibition spaces is a critical field of study for understanding how spatial configurations influence visitor movement. Historically, research has focused on tracking exhibit engagement time (Melton, 1935; Serrell, 1998) and analysing how display layouts impact visitor pathways (Bourdeau and Chebat, 2001). While traditional studies relied on observational methods or questionnaires, advancements in computational algorithms now enable the simulation of movement patterns to model and predict complex spatial behaviours. Algorithms such as random walk, A*, and ant-colony optimisation have been employed to model movement (Yoshimura et al. 2019; Pasandi et al. 2021), while others investigate shortest-path solutions for emergency planning (Marzouk and Hassan, 2022). Despite the importance of navigation in both urban and indoor contexts, a gap remains in evaluating the alignment between design intent and algorithmic predictions in complex temporary environments.

This research proposes a comparative framework between two computational algorithms—SOM and Isovist-based simulation—to evaluate the intuitive nature of exhibition layouts. These algorithms represent fundamentally different models of navigation: global sequence optimisation versus locally informed, perception-driven movement. In this study, the SOM algorithm generates an optimised intended path, with major exhibits serving as sequential nodes (Kohonen, 1990), while the Isovist simulation operates as an independent predictive agent, navigating the space based on visibility, geometry, and obstacle avoidance (Benedikt, 1979). By comparing these two distinct approaches, the study assesses whether the physical arrangement of a space naturally supports the curator's intended visitor experience.

The simulated paths are analysed using an image-based, pixel-level comparison in OpenCV to quantify spatial overlaps and divergences. This method provides an objective measure of alignment between the intended sequence and predicted movement patterns, enabling systematic evaluation without relying on observational data. To guide the investigation, the study poses the following research question:

To what extent does simulated visitor movement (Isovist) correspond with the optimised and intended exhibition sequence (SOM)?

By bridging the gap between design intent and algorithmic prediction, this research offers a comprehensive understanding of visitor navigation in indoor spaces. The study introduces a computational method for evaluating navigational intuitiveness prior to construction. It provides insights for optimising space design and improving navigation systems in exhibition contexts, ensuring that critical points of interest are naturally accessible within the spatial flow.

2.0 LITERATURE REVIEW

Research on pedestrian movement has traditionally focused on indoor navigation and wayfinding within the context of evacuation planning, navigation systems, and agent-based simulations. Indoor navigation involves spatial perception, decision-making, and movement within enclosed environments, shaped by spatial configuration, environmental constraints, and user behaviour rather than purely shortest-path logic (Jayakanth et al., 2020; Marzouk and Hassan, 2022). The increasing complexity of indoor environments, such as museums and commercial spaces, has driven the development of computational models capable of predicting movement patterns (Yan et al., 2021).

Agent-Based Modelling (ABM) has been widely used to analyse visitor interaction with exhibition layouts. It also helps evaluate experiential discrepancies between intended and actual spatial use (Liu et al., 2024). In evacuation contexts, simulations often combine behavioural models with Computational Fluid Dynamics to represent environmental hazards (Kasereka et al., 2018; Luh et al., 2012). Cellular automata, social force models, and floor-field approaches represent pedestrians as agents influenced by attraction, repulsion, and spatial constraints (Burstedde et al., 2001; Helbing et al., 2000; Tan et al., 2015). These approaches, while effective for modelling crowd dynamics, primarily address efficiency and safety rather than the exploratory movement characteristic of exhibition environments.

Pathfinding algorithms, such as A* and its variants, are used in indoor navigation, especially in obstacle-dense environments (Pasandi et al., 2021). Studies show that spatial geometry and obstacle configuration shape route selection (Ni et al., 2020; Cui et al., 2023). However, shortest-path optimisation misses experiential navigation, where visitors may deviate to explore visually accessible points of interest.

Visibility-based spatial analysis offers an alternative, perception-based framework. The Isovist (Benedikt, 1979) describes the visible spatial field from one location and strongly influences navigation and exploration (Wiener et al., 2007). Isovist simulations model navigation as a process shaped by geometry, visibility, and obstacles, not predetermined paths.

In contrast, machine-learning approaches such as the Self-Organising Map (SOM) provide global optimisation capabilities. Originally developed as a neural network clustering and ordering algorithm (Kohonen, 1990), SOM has been adapted to travelling-salesman-type routing problems, generating optimised visitation sequences when multiple destinations must be visited in a structured order (Yan et al., 2021). In exhibition design, this capability enables SOM to represent an intended narrative sequence defined by relationships among exhibit nodes.

Despite significant advances, existing research rarely compares optimised routing structures with visibility-driven movement predictions within a single analytical framework. Most studies treat navigation either as behavioural simulation or route optimisation independently, leaving unresolved whether architectural layouts inherently support intended visitor sequences. This limitation is particularly critical in temporary exhibition environments, where the spatial configuration must intuitively guide visitors without relying on signage or post-occupancy corrections.

This research addresses this gap by comparing SOM-optimised routes, which represent design intent, with Isovist-based simulations that predict geometry-driven visitor pathways. Using an image-based, pixel-level

comparison in OpenCV, the study quantifies the overlap and divergence between these models to evaluate the navigational intuitiveness of exhibition layouts. By reframing navigation as a measurable relationship between intended sequencing and spatial perception, the framework provides a proactive computational tool for assessing exhibition design prior to construction.
The following table summarises key studies reviewed in this research, highlighting the computational algorithms employed and the specific navigation or movement-related challenges each study addresses.

Table 1: Summary of Reviewed Studies: Algorithms Applied and Navigation Issues Addressed

Author(s)	**Algorithm / Method Used**	**Issues Tackled**
Jayakanth et al. (2020)	Indoor navigation modelling	Influence of spatial configuration and pedestrian characteristics on navigation decisions
Marzouk & Hassan (2022)	Shortest path / evacuation modelling	Route optimization and emergency navigation efficiency
Yan et al. (2021)	Indoor navigation systems; SOM-based routing	Limitations of shortest-path logic; multi-destination navigation behaviour
Liu et al. (2024)	Agent-Based Modelling (ABM)	Gap between exhibition layout design and visitor experience
Kasereka et al. (2018); Luh et al. (2012)	CFD + behavioral simulation	Evacuation dynamics under environmental hazards
Burstedde et al. (2001)	Cellular Automata (CA), Floor-field model	Crowd movement and interaction dynamics
Helbing et al. (2000)	Social force / multi-grid models	Emergent pedestrian behaviour through force-based interactions
Tan et al. (2015)	Force-based agent simulation	Context-driven collective movement patterns
Pasandi et al. (2021)	Modified A* (MASA)	Navigation in obstacle-rich environments
Said et al. (2012)	Geometric path analysis	Relationship between building geometry and route selection
Ni et al. (2020)	Multi-navigation simulation	Movement in multi-obstacle environments
Cui et al. (2023)	Newtonian motion-based algorithm	Dynamic obstacle avoidance
Formolo & van der Wal (2017)	Behavioral/social modelling	Psychological factors in navigation (limited spatial modelling)
Benedikt (1979)	Isovist analysis	Visibility-driven spatial perception
Wiener et al. (2007)	Visibility-based navigation studies	Influence of visual fields on route choice
Kohonen (1990)	Self-Organizing Map (SOM)	Neural-network ordering and sequence optimization

2.2 Research Gap and Contribution

Existing studies on indoor navigation predominantly examine either behavioural simulation models that predict pedestrian movement based on spatial perception and environmental interaction, or optimisation algorithms that generate efficient routing sequences between destinations. Visibility-based approaches, such as Isovist analysis, effectively explain locally driven navigation decisions influenced by geometry and visual access, while optimisation methods, including SOM, generate globally ordered visitation sequences. However, these paradigms have largely been investigated in isolation, leaving a limited understanding of whether architectural layouts inherently support a designer's intended experiential sequence. Moreover, prior research often relies on post-occupancy observation or evacuation-driven scenarios, offering limited applicability to temporary exhibition environments where intuitive navigation must emerge directly from spatial configuration.

This research addresses this gap by introducing a comparative computational framework that evaluates the alignment between SOM-optimised exhibition routes and Isovist-simulated visitor pathways. Using an image-based, pixel-level comparison in OpenCV, the study quantifies spatial overlap and divergence between the two models, providing an objective measure of navigational alignment. This approach offers a proactive diagnostic tool for designers, enabling the assessment of route intuitiveness and identification of spatial inefficiencies during early-stage design, prior to physical implementation or observational data collection.

3.0 METHODOLOGY

This research employs a computational framework comprising SOM simulation**,** Isovist-based movement simulation, and comparative analysis to evaluate indoor exhibition navigation. SOM represents *top-down curatorial cognition*, while Isovist represents *bottom-up embodied perception*. The methodology is designed to examine how the spatial arrangement of exhibits aligns with both the intended visitor sequence and natural, perception-driven movement patterns.

1. **SOM Simulation**

The SOM algorithm provides a global optimisation approach, generating an intended visitation sequence that reflects the designer's narrative plan for the exhibition (Kohonen, 1990). SOM adapts a neural-network clustering framework to sequence multiple exhibit nodes, producing an optimised. The algorithm identifies the Best Matching Unit (BMU) for each exhibit node and iteratively updates node weights to refine the sequence. A one-dimensional circular SOM with a ring topology is employed, where node proximity is defined by index distance rather than Cartesian spatial coordinates.

The SOM algorithm is used to generate an optimised visitor route through an exhibition that reflects the designer's intended narrative sequence. The algorithm clusters and sequences exhibit nodes iteratively, producing a path that aligns design intent with potential visitor movement. The pseudocode is as follows.

1. Initialization:
   - Collect all exhibit locations as input points.
   - Initialise a set of SOM nodes with random positions (weights).
   - Set initial learning rate, neighbourhood radius, and iteration counter.
2. Best Matching Unit (BMU) Identification:
   - For each input exhibit point, find the SOM node whose position is closest to the point (Euclidean distance in weight space).
   - This node is designated as the BMU for that point.
3. Node Weight Update:
   - Update the BMU and its neighbouring nodes to move slightly toward the input point.
   - The amount of adjustment decreases with distance from the BMU (Gaussian neighbourhood influence).
   - The learning rate and neighbourhood size decrease gradually over iterations to facilitate convergence.
4. Iteration:
   - Repeat BMU identification and weight update for all input points over multiple iterations until the map stabilises.
5. Route Construction (Visualisation):
   - Arrange SOM nodes along a circular 1D topology (ring).
   - Define proximity between nodes based on their positions along the ring, ensuring that the first and last nodes are neighbours.
   - Connect nodes sequentially to form a closed polyline representing the optimised visitor path through the exhibition.

1. **Isovist Simulation**

Isovist simulation models, locally informed and visibility-driven, predict how visitors might navigate an exhibition based on spatial geometry and visibility polygons (Benedikt, 1979). Unlike SOM, this approach does not impose a global path but allows agents to make incremental movement decisions influenced by field of view, obstacles, and spatial configuration (Turner et al. 2001; Ha & Lykotrafitis, 2012).

Isovist simulation models how visitors might move through an exhibition based on visibility and spatial geometry. Unlike SOM, which produces a global route, this approach allows agents to make incremental movement decisions influenced by their field of view, obstacles, and surrounding space. The pseudocode is as follows.

1. Initialization:
   - Place an agent at a starting location with an initial viewing direction.
   - Define agent parameters: field-of-view angle, sensing range, and movement detail (number of rays).

2. Observation Step:
    - Generate a set of rays within the agent's vision cone to simulate the visible area (Isovist).
    - For each ray:
        a. Detect intersections with nearby walls, obstacles, or exhibit features.
        b. Identify the closest intersection point along the ray.
3. Decision Step:
    - From all rays, select the direction corresponding to the maximum visible distance (the most open path).
    - Update the agent's direction by slightly adjusting toward this maximum visibility vector.
    - Normalise the direction to ensure consistent movement.
4. Movement Step:
    - Move the agent forward by a fixed step size along the updated direction.
    - Record the new position to build the agent's movement trail.
5. Iteration:
    - Repeat the observation, decision, and movement steps for the desired number of iterations or until the agent reaches a boundary.
6. Data Output:
    - Collect the agent's path (trail) for visualisation.
    - Record intermediate data such as ray intersections and visibility distances for analysis.

1. **Alignment Analysis**

To evaluate navigational alignment, the SOM-optimised path is compared with the Isovist-simulated pathways using an image-based spatial framework. By combining SOM and Isovist data with an image-based comparison using the OpenCV library, NumPy for mathematical calculations, and matplotlib for graph visualisation. This methodology provides a proactive framework to evaluate exhibition navigation before construction or observational data collection. SOM represents the designer's intended path, Isovist simulates perception-driven visitor movement, and the comparison quantifies alignment, providing insights into the intuitiveness and efficiency of the layout.

<u>Method: Quantifying Overlap Between SOM and Isovist Areas</u>

To measure the degree of spatial overlap between SOM-optimised visitor routes and Isovist-simulated movement pathways in a plan or diagram, providing an objective assessment of how well the designed sequence aligns with simulated human behaviour. The pseudocode is as follows.

1. <u>Image Preparation</u>

The diagram is loaded as an image and converted to a standard RGB colour space, allowing accurate identification of the SOM and ISO areas.

2. <u>Feature Identification</u>

For each feature (SOM and ISO), a mask is created to visually isolate it. Each pixel is examined: if its colour closely matches the target colour for the feature, it is marked as part of that area; otherwise, it is treated as background.

3. <u>Mask Refinement</u>

To remove small gaps and inconsistencies, a morphological dilation is applied to both masks. This slightly expands the identified regions to ensure a continuous and robust representation of each area.

4. <u>Overlap Analysis</u>

The overlap between the SOM and ISO areas is determined by identifying the regions where the two masks coincide using a logical intersection.

5. <u>Quantification</u>

The proportion of the SOM area that overlaps with the ISO area is calculated, providing a clear metric of alignment between the design intent and simulated visitor movement.

6. <u>Spatial Distribution Visualisation</u>

The 2D masks are processed into 1D density profiles by summing pixel frequencies. These are plotted on a line chart, with the intersection area highlighted to visually demonstrate the spatial overlap.

7. <u>Interpretation</u>

The resulting percentage and distribution graph indicates how much of the intended route corresponds to naturally visible and accessible pathways, allowing designers to assess and refine exhibition layouts before construction.

1. **Selection of Context**

The context for this research was chosen based on visitor accessibility. A portion of a temporary indoor exhibition, located on the second floor of the Bartlett School of Architecture at UCL during its Summer Show 2023 in London, UK, was selected. This exhibition displayed student architectural projects, attracting both students and the public interested in architecture. A smaller section of the exhibition was chosen to ensure efficiency and maintain control over the algorithmic simulations.

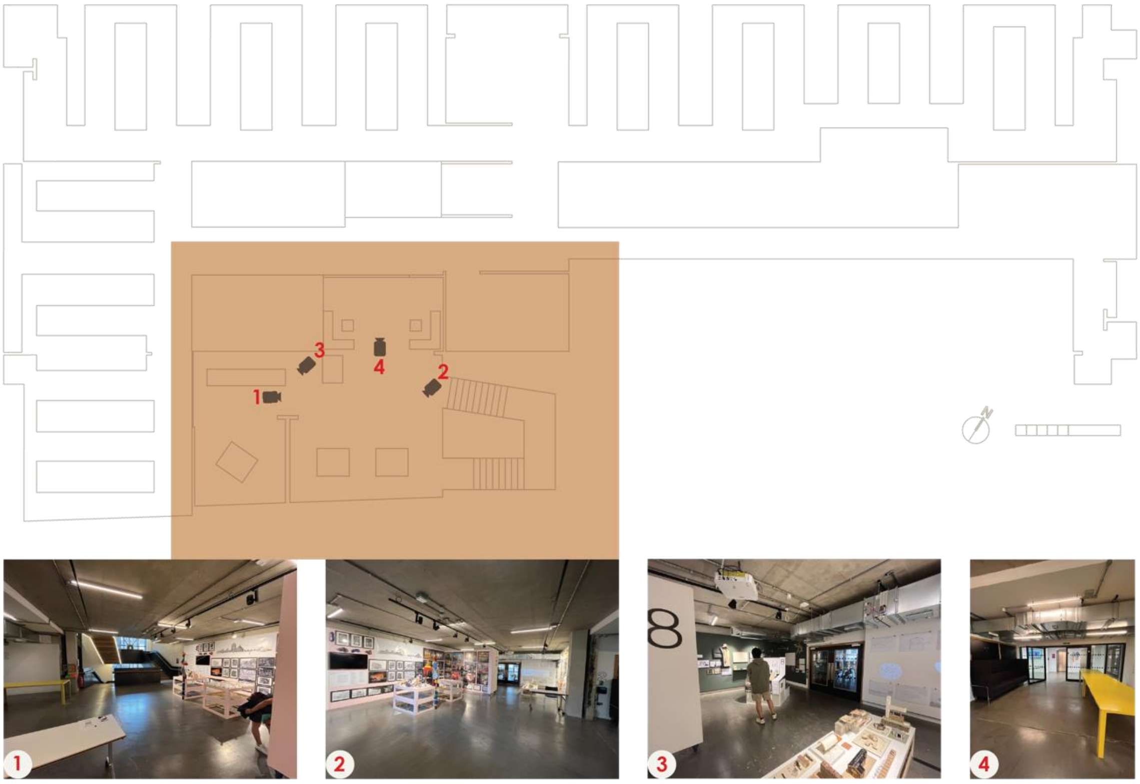

Fig. 1: Context of the research space, with photos captured from multiple perspectives.

4.0 RESULTS

The research is conducted using computational tools such as Grasshopper3D within Rhino3D for algorithm development in C#, while graphical presentations were prepared using Adobe Illustrator. For the comparative alignment phase, the OpenCV library was employed within VS Code. The result section consists of three parts: SOM simulation, Isovist simulations, and a simulation alignment analysis. The key steps and findings are as follows:

1. **SOM Simulation**

For the SOM simulation, several points were defined to act as nodes through which the path would be generated. The starting point was set near the staircase, with most nodes placed along the walls near the exhibits. A total of nine points were positioned, and the SOM algorithm progressively developed a path that gradually connected all the nodes. The final output ensured that every defined node was included in the generated route.

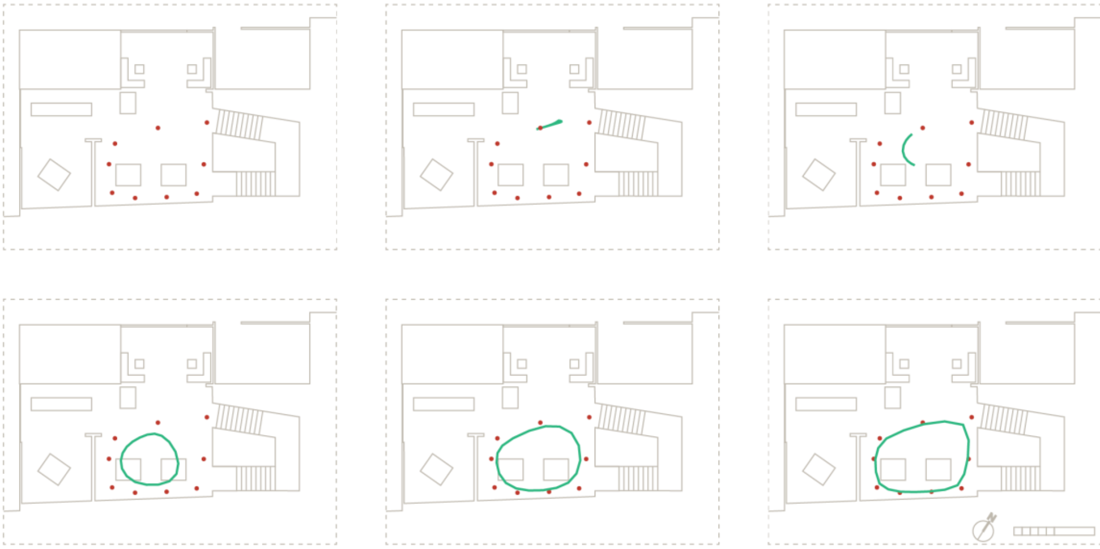

Fig. 2: SOM simulation development

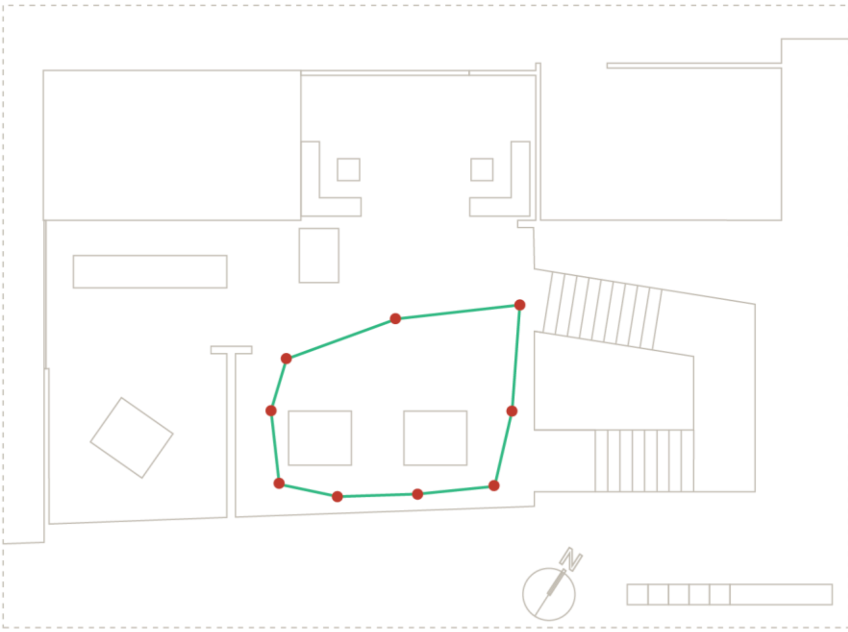

Fig. 3: SOM simulation output

4.2 Isovist Simulation

The research is conducted using computational tools such as Grasshopper3D within Rhino3D for algorithm development in C#, while graphical presentations were prepared using Adobe Illustrator. For the comparative alignment phase, the OpenCV library was employed within VS Code. The result section consists of three parts: SOM simulation, Isovist simulations, and a simulation alignment analysis. The key steps and findings are as follows:

1. **SOM Simulation**

For the SOM simulation, several points were defined to act as nodes through which the path would be generated. The starting point was set near the staircase, with most nodes placed along the walls near the exhibits. A total of nine points were positioned, and the SOM algorithm progressively developed a path that gradually connected all the nodes. The final output ensured that every defined node was included in the generated route.

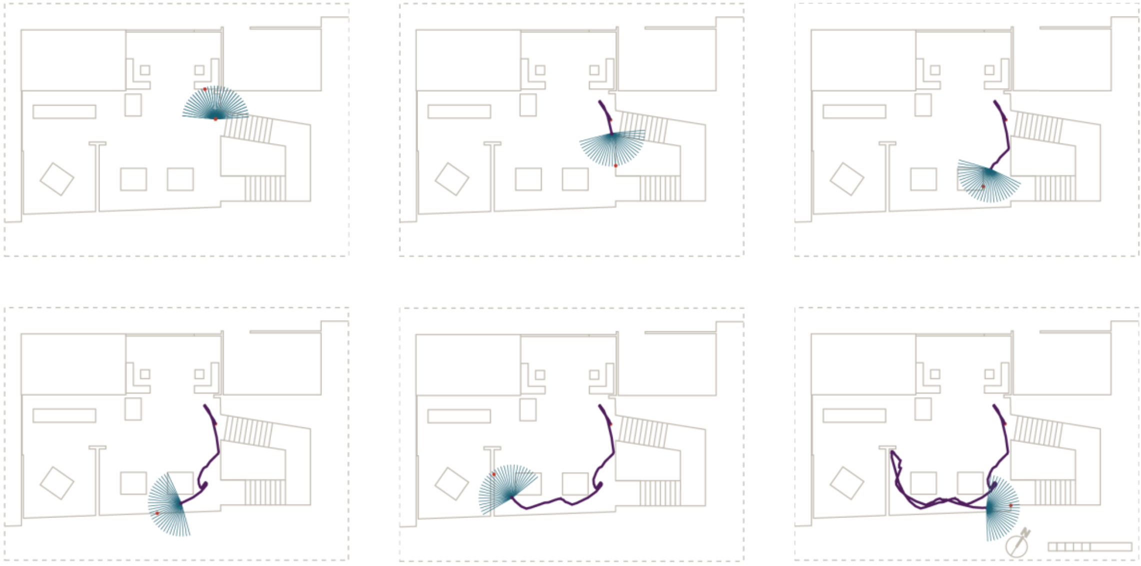

Fig. 4: Isovist simulation development

Fig. 5: A collection of 30 isovist simulation

4.3 Simulation Alignment

The results show that about 40.52% of the 30 Isovist rays overlap with the SOM simulation, reflecting the variability in visitor movement patterns. This partial overlap suggests that while SOM captures a general navigational trend, the Isovist simulations reveal the unpredictability and flexibility of actual visitor pathways within the space.

Fig. 6: Parallel Simulation Results: SOM and Isovist

With the help of the 'matplotlib' library, the following graph represents the horizontal spatial distribution of the SOM and ISO features by summing masked pixels along with the vertical axis to generate a 1D profile. The ISO density is notably higher due to the greater number of samples than in the SOM samples. By mapping this distribution simultaneously, a clear column-by-column cross-section is provided showing overlaps between the two distinctive datasets.

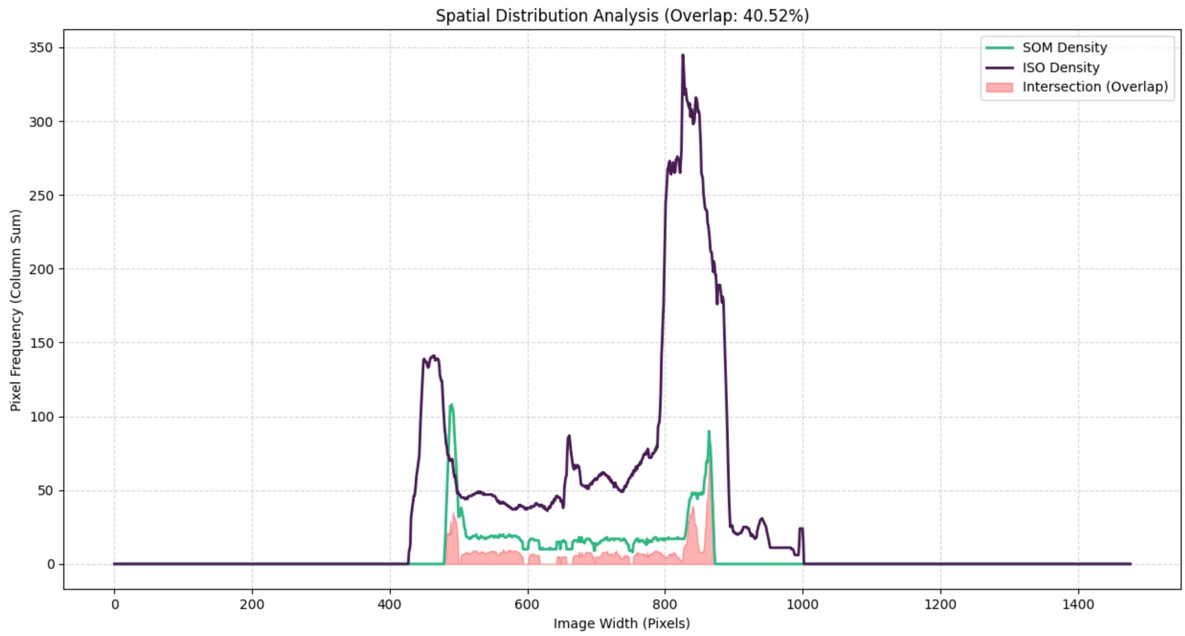

Fig. 7: Spatial Distribution Analysis of Intersection

5.0 DISCUSSIONS

The study shows that while the SOM-generated paths provide a structured, optimised route through the exhibition, the Isovist simulations capture the more unpredictable, free-flowing nature of visitor movement. The alignment between the two is partial, reflecting that simulated visibility-based navigation aligns with the intended exhibition sequence only to a limited extent. This indicates that while SOM can guide the overall flow, real or simulated visitor behaviour—modelled through Isovist—tends to deviate from the model due to the agent's tendency to follow edges, avoid repetition, and respond dynamically to spatial constraints. The framework's novelty lies in treating optimisation and visibility-driven models as measurable, complementary perspectives rather than isolated methods, enabling designers to test route intuitiveness before construction.

In practice, several limitations influenced the findings. Isovist simulations were stopped when paths began to loop or when agents approached the staircase, reflecting natural exit behaviour. Unlike SOM, Isovist paths are not closed loops and are influenced by randomness, environmental cues, and changes in mathematical values, making direct path-to-path comparisons challenging. Additionally, the SOM paths are biased by the predefined node placement, which controls the trajectory and may not fully represent spontaneous movement patterns. Finally, comparing the two simulations using alignment metrics provides a useful but partial perspective, as it does not capture differences in movement dynamics, attention, or dwell time.

Future work could address these limitations by incorporating additional behavioural parameters into the Isovist simulation, such as varying attention, preferred walking speed, or dwell times at exhibits. Adaptive SOM methods could also be explored to allow dynamic node placement based on visitor behaviour. Furthermore, integrating real-world tracking data could validate the simulations and align the designed routes with actual visitor movement. These extensions would provide a more comprehensive framework for evaluating the interaction between spatial design intent and emergent visitor behaviour.

6.0 CONCLUSION

This research investigated the extent to which simulated visitor movement, modelled through Isovist, aligns with an optimised exhibition sequence generated by SOM within an indoor exhibition context. By applying SOM to define structured paths through key nodes and Isovist to simulate visibility-driven, adaptive navigation, the study provided insights into the interplay between designed spatial intent and emergent movement patterns.

The findings indicate that while SOM produces predictable, node-connected routes that ensure coverage of all key exhibits, Isovist captures the more spontaneous, free-flowing behaviour of visitors. Approximately 40% of the Isovist paths aligned with SOM-generated routes, reflecting partial alignment between planned and emergent navigation. This demonstrates that while designed circulation can guide visitor flow, natural movement is influenced by visibility, spatial configuration, and dynamic environmental cues, which SOM alone cannot fully capture.

The study also highlighted several limitations. Isovist simulations were sensitive to parameters such as movement step size, steering responsiveness, and visibility range, which affect path variability. The SOM paths, constrained by predefined nodes, may introduce biases that do not fully reflect real-world movement. Comparing the two simulations through overlap metrics provides a useful but partial assessment of alignment.

Despite these limitations, the research establishes a computational framework for evaluating indoor exhibition navigation. Isovist simulations offer potential for applications requiring adaptability, such as visibility-driven analysis or emergency evacuation modelling, while SOM can inform route optimisation, exhibit placement, and targeted circulation planning. Future work could integrate real visitor tracking, adaptive node placement, dynamic environmental factors, and richer behavioural parameters to enhance predictive accuracy and applicability.

Overall, the study demonstrates that combining structured optimisation (SOM) with visibility-based simulation (Isovist) provides complementary perspectives for understanding, predicting, and designing visitor movement, offering valuable insights for exhibition layout, spatial planning, and the design of engaging indoor environments.

REFERENCES

Benedikt, M. L. (1979). To Take Hold of Space: Isovists and Isovist Fields. *Environment and Planning B*, 6, 47–65.

Bourdeau, L., & Chebat, J. C. (2001). An empirical study of the effects of the design of the display galleries of an art gallery on the movement of visitors. *Museum Management and Curatorship*, 19, 63–73.

Burstedde, C., Klauck, K., Schadschneider, A., & Zittartz, J. (2001). Simulation of pedestrian dynamics using a two-dimensional cellular automaton. *Physica A: Statistical Mechanics and its Applications*, 295(3–4), 507–525. https://doi.org/10.1016/s0378-4371(01)00141-8

Chun, J., Schieck, A. F., Psarras, S., & Koutsolampros, P. (2019). Agent-based simulation for "Choice of Seats": A study on the human space usage pattern. In *Proc. 12th International Space Syntax Symposium*, Beijing, China.

Cui, Z., Cai, M., Xiao, Y., Zhu, Z., & Chen, G. (2023). Influences of obstacle factors on the transmission trends of respiratory infectious diseases in indoor public places. *Journal of Building Engineering*, 64, 105706. https://doi.org/10.1016/j.jobe.2022.105706

Formolo, D., & van der Wal, C. N. (2017). Simulating collective evacuations with social elements. In *Computational Collective Intelligence* (pp. 160–171). https://doi.org/10.1007/978-3-319-67074-4_16

Gjestland, R. (2020). *How to Design a Cinema Auditorium*. Brussels, Belgium: International Union of Cinemas (UNIC). Available: https://unic-cinemas.org/fileadmin/CinemaAuditoriumDesign_v1.0.pdf

Grajewski, T., & Vaughan, L. (2001). *Space Syntax Observation Manual*. London, UK: UCL Bartlett and Space Syntax Ltd.

Ha, V., & Lykotrafitis, G. (2012). Agent-based modelling of a multi-room multi-floor building emergency evacuation. *Physica A: Statistical Mechanics and its Applications*, 391(8), 2740–2751. https://doi.org/10.1016/j.physa.2011.12.034

Helbing, D., Farkas, I. J., & Vicsek, T. (2000). Simulating dynamical features of escape panic. *Nature*, 407, 487–490. https://doi.org/10.1038/35035023

Jayakanth, K., AbdelGhani, K., Somaya, A., & Abdulla, A. (2020). Indoor positioning and wayfinding systems: A survey. *Human-centric Computing and Information Sciences*, 10(18), 26. https://doi.org/10.1186/s13673-020-00222-0

Kasereka, S., Kasoro, N., Kyamakya, K., Goufo, E. F. D., Chokki, A. P., & Yengo, M. V. (2018). Agent-based modelling and simulation for evacuation of people from a building in case of fire. *Procedia Computer Science*, 130, 10–17. https://doi.org/10.1016/j.procs.2018.04.006

Khotbehsara, E. M., Askarizad, R., Mehrinejad, M., Nasab, S. N., & Somasundaraswaran, K. (2023). The impact of COVID-19 on visitors' wayfinding within healthcare centers. *Ain Shams Engineering Journal*, 14(5), 101957. https://doi.org/10.1016/j.asej.2022.101957

Kohonen, T. (1990). The self-organizing map. *Proceedings of the IEEE*, 78(9), 1464–1480. https://doi.org/10.1109/5.58325

Liu, Y., Chen, L., Xu, Y., & Yang, J. (2024). Exhibition space circulation in museums from the perspective of pedestrian simulation. *Buildings*, 14(3), 847. https://doi.org/10.3390/buildings14030847

Luh, P. B., Wilkie, C., Chang, S.-C., & Marsh, K. L. (2012). Modeling and optimization of building emergency evacuation considering blocking effects on crowd movement. *IEEE Transactions on Automation Science and Engineering*, 9(4), 687–700. https://doi.org/10.1109/tase.2012.2200039

Lyu, K., Globa, A., Brambilla, A., & de Dear, R. (2023). An immersive multisensory virtual reality approach to the study of human-built environment interactions: Technical workflows. https://doi.org/10.2139/ssrn.4439246

Marzouk, M., & Hassan, F. (2022). Modeling evacuation and visitation proximity in museums using agent-based simulation. *Journal of Building Engineering*, 56, 104794. https://doi.org/10.1016/j.jobe.2022.104794

Melton, A. W. (1935). *Problems of Installation in Museums of Art*. Washington, DC: American Association of Museums Monograph New Series No. 14.

Ni, Z., Liu, Z., Liu, T., Chai, Y., & Liu, C. (2020). Simulation model of crowd evacuation navigation in a multi-obstacle environment. *Transportation Research Record: Journal of the Transportation Research Board*, 2675(4), 90–104. https://doi.org/10.1177/0361198120971264

Pasandi, L., Hooshmand, M., & Rahbar, M. (2021). Modified A* algorithm integrated with ant colony optimization for multi-objective route-finding; case study: Yazd. *Applied Soft Computing*, 113, 107877. https://doi.org/10.1016/j.asoc.2021.107877

Said, H., Kandil, A., & Cai, H. (2012). Agent-based simulation of labour emergency evacuation in high-rise building construction sites. In *Proc. Construction Research Congress 2012: Construction Challenges in a Flat World*. https://doi.org/10.1061/9780784412329.111

Serrell, B. (1998). *Paying Attention: Visitors and Museum Exhibitions*. Washington, DC: American Association of Museums.

Song, W., Xu, X., Wang, B.-H., & Ni, S. (2006). Simulation of evacuation processes using a multi-grid model for pedestrian dynamics. *Physica A: Statistical Mechanics and its Applications*, 363(2), 492–500. https://doi.org/10.1016/j.physa.2005.08.036

Tan, L., Hu, M., & Lin, H. (2015). Agent-based simulation of building evacuation: Combining human behavior with predictable spatial accessibility in a fire emergency. *Information Sciences*, 295, 53–66. https://doi.org/10.1016/j.ins.2014.09.029

Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From isovists to visibility graphs: A methodology for the analysis of architectural space. *Environment and Planning B*, 28(1), 103–121.

Was, J., & Kułakowski, K. (2010). Agent-based approach in evacuation modeling. In *Proc. Agent and Multi-Agent Systems: Technology and Applications* (pp. 325–330). https://doi.org/10.1007/978-3-642-13480-7_34

Wiener, J. M., Franz, G., Rossmanith, N., Reichelt, A., Mallot, H. A., & Bülthoff, H. H. (2007). Isovist analysis captures properties of space relevant for locomotion and experience. *Perception*, 36(7), 1066–1083. https://doi.org/10.1068/p5587

Yan, J., Zlatanova, S., Lee, J. (B.), & Liu, Q. (2021). Indoor traveling salesman problem (ITSP) path planning. *ISPRS International Journal of Geo-Information*, 10(9), 616. https://doi.org/10.3390/ijgi10090616

Yoshimura, Y., Sintara, R., Krebs, A., & Ratti, C. (2019). Analysis of visitors' mobility patterns through random walk in the Louvre Museum. *Journal of Ambient Intelligence and Humanized Computing*, 15(2), 1643–1658. https://doi.org/10.1007/s12652-019-01428-6