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Research paper

ENHANCING PEDESTRIAN CIRCULATION: QUANTIFYING SPATIAL INTEGRATION IN URBAN EVENT SPACES

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Abstract

Circulation within urban spaces refers to how people move through environments, and it plays a vital role in the design of pedestrian-friendly areas. The concept of circulation in architecture and urbanism is frequently equated with communication, as it enables the easy movement and connection between various elements of the urban landscape. Understanding how spaces function as integrated units allows for better design solutions that enhance both movement and comfort. In this context, spatial integration is crucial in determining how well different parts of a space function as a cohesive whole. When spaces are well integrated, they promote smooth interaction between different areas, facilitating walkability and contributing to a more connected urban landscape. However, the challenge lies in effectively assessing the integration of urban space, particularly in areas shaped by temporary structures or urban furniture during public events. Here it is shown that calculating the convex hull of the surface area of the space provides a reliable method for quantifying spatial integration, which directly impacts pedestrian circulation. The study used the Convex Hull tool in Grasshopper software to analyze key public spaces. By comparing the surface area of the original geometry to the convex hull, an integration index was calculated, with values ranging from 0 to 1. High integration was observed when fewer fragmented spaces existed, facilitating smoother pedestrian movement. These findings provide a quantitative approach to optimizing public spaces, leading to improved user experience by minimizing fragmentation and promoting spatial cohesion. This method offers immediate opportunities for architects and urban planners to design more efficient, user-friendly spaces.

Key words: *Circulation, Spatial Integration, Public Events, Temporary Structures, Spatial Layout*

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1. INTRODUCTION

The way people move through urban space has changed over time, influenced by social and economic shifts, regulations, and technological progress. Although industrialization and the growth of car use have shifted the focus toward vehicle traffic, often at the expense of pedestrians, walking still remains the most essential and common way people interact with the urban environment. As Diaconu [1] emphasizes, walking is not only a basic mode of locomotion but also a rhythmical, often unconscious activity that fosters a sensory and affective relationship with the city. Through movement and tactile perception, people develop a personal understanding of urban space, which transforms walking into a deeply aesthetic and exploratory experience.

The movement of people within cities has always been a key focus in architecture and urban planning. In contemporary urbanism, the concept of circulation, referring to how individuals and groups move through built environments, has emerged as a key factor in shaping the design of walkable, accessible, and socially engaging spaces [2, 3, 4]. As the movement of people becomes increasingly central to discussions on urban livability, understanding the spatial conditions that enable or hinder circulation is more crucial than ever. Circulation is not merely a matter of physical movement; it also embodies a form of communication, linking spatial elements and enabling interaction across various zones of the urban fabric [5].

The communicative aspect of circulation becomes especially important when viewed through spatial integration, a concept that shows how well different parts of an environment work together. Highly integrated spaces allow smooth movement, easy navigation, and effortless interaction between areas, making them more walkable and user-friendly. As Penn et al. [6] have argued, spatial integration serves as one of the most reliable predictors of pedestrian flow and density along pathways in urban space. It is seen as a quality that allows a space to be immediately comprehensible to individuals, even those with no prior knowledge of its overall layout [7]. On the other hand, fragmented or poorly integrated spaces create barriers both physical and perceptual that limit accessibility and reduce spatial coherence. Therefore, the integration of spatial layout is not just a qualitative issue but a measurable aspect of urban design that directly affects the user experience. The quality of public spaces depends not only on how well they support movement, but also on how they encourage people to gather and interact. As Shaftoe [8] points out, good public spaces allow for informal and spontaneous social activities. In event settings, the way standing areas are arranged can strongly influence both how easily people move and how they connect with one another.

Despite its importance, assessing the integration of urban space, particularly with temporary structures and urban furniture during public events, presents a methodological challenge. These temporary elements can significantly change the flow and perception of space, making traditional spatial analysis tools inadequate for capturing the temporary changes in how people move through space. As a result, new approaches are needed to assess how temporary spatial arrangements affect pedestrian movement and connectivity.

The aim of this research is to propose and test a computational method for quantifying spatial integration using the convex hull as a geometric index, thereby offering a reliable and adaptable tool for evaluating possibility of pedestrian circulation in urban environments shaped by temporary structures.

This paper presents a method implemented in the Grasshopper environment that uses the Convex Hull as a geometric metric to compare a space's original footprint with its minimal enclosing shape. By applying this method to event-configured public spaces, the study offers urban designers a data-driven tool to assess spatial cohesion and improve navigability.

In summary, this research introduces an innovative, quantitative tool for assessing and optimizing spatial integration in rapidly changing urban spaces. While the tool provides measurable insights, its results should be interpreted with an awareness of the methodological boundaries. The intention is not to offer a fully comprehensive model of spatial experience during events, but to establish a structured basis for evaluating spatial coherence as one dimension of a complex and time-sensitive urban phenomenon.

2. METHODOLOGY

To ground the methodological approach in a real-world context, the study was applied to a representative urban square frequently used for hosting diverse public events.

2.1. Site Context and Event Dynamics

The study focuses on Liberty Square, located in the central urban core of Novi Sad, Serbia. Surrounded by iconic architectural structures, the square accommodates a large pedestrian traffic and remains deeply rooted in the city's cultural and civic identity. Its central location and accessibility make it an ideal setting for hosting various large-scale public events that activate the space throughout the year. Over the past decades, Liberty Square has evolved into a multifunctional event space, supporting a broad spectrum of public activities, including cultural festivals, trade fairs, concerts, national celebrations, sporting events, and civic gatherings.

To validate the relevance of this site and ensure the representativeness of the spatial layouts evaluated, the research draws upon empirical data collected by Mitrovic et al. [9], who analyzed 17 events held at Liberty Square between 2017 and 2022. The dataset includes details on event types, durations, the use of temporary structures, and their typical spatial configurations. The analysis revealed that trade fairs and festivals accounted for 53% of all events hosted during the observed period, followed by entertainment and music events (each at 17.6%), and sports events (11.8%). Notably, trade fairs and festivals typically span over two weeks, generating more extensive and enduring spatial transformations compared to short-term events. The most commonly used temporary structures include exhibition stands and kiosks.

2.2. Theoretical Framework for Spatial Integration Analysis

This study introduces a geometric approach for evaluating the spatial cohesion of urban public spaces affected by temporary structures, using the convex hull as the core analytical tool. By comparing the surface area of functional pedestrian zones to the area of their convex hull, a simple spatial integration index is derived, reflecting the degree of continuity and connectivity in the spatial layout.

While conventional spatial integration analyses often rely on graph-based techniques such as axial or visibility graph analysis, this research adopts a more geometric and flexible approach, better suited to the dynamic nature of event environments. The convex hull is used as an indicator of spatial cohesion and navigability. This interpretation aligns with principles from space syntax theory, which associates spatial openness and continuity with higher levels of integration. Space syntax, developed to explore how spatial configurations affect human behavior, particularly movement, interaction, and accessibility, defines integration as a topological measure indicating how close a space is to all others within a spatial system. It is typically calculated as the inverse of the average depth from one space to all others, making it a proxy for centrality and spatial accessibility [10, 11].

2.3. Analytical Workflow and Methodological Tools

The analysis was conducted using the Grasshopper plugin within the Rhinoceros 3D, which offers parametric design capabilities and real-time computation of geometric relationships.

The workflow consists of the following key steps:

1. Spatial Input Preparation:
   The first step involves defining the boundaries of the event space and placing temporary structures based on event-specific layouts. Access zones between these structures are then identified. The remaining areas, intended for active or passive use such as gathering, pausing, or informal interaction, are designated as standing zones. These zones are modeled as closed planar surfaces in Rhinoceros 3D based on the spatial configuration of the site.
2. Convex Hull Calculation:
   For all resulting standing surfaces, the Convex Hull component was used to generate the smallest enclosing convex polygon. This envelope represented the theoretical limit of spatial cohesion for the given configuration.
3. Spatial Integration Index Calculation:
   The area of the geometry of the identified standing zones was compared with the area of its convex hull. From this, the integration index (I) was derived using the formula:
   $$\mathrm{I} = \frac{Aoriginal}{Ahull} \quad (1)$$
   This ratio ranges from 0 to 1, where values closer to 1 indicate high spatial integration, reflecting a strong correspondence between the occupied space and its convex boundary, while lower values suggest fragmentation and discontinuity.
4. Weighted Index of Integration Calculation:
   To evaluate the overall integration index of the entire event space, a weighted average method was applied. Rather than treating each standing area equally, the calculation considers the relative surface area of each zone. This ensures that larger spaces, which have greater capacity for user movement and interaction, exert a proportionally higher influence on the final result. Total integration index (I_{total}) is calculated by multiplying the integration index value (I) of each standing surface by its corresponding area ($A_{original}$), summing the results, and then dividing by the total area of all standing surfaces:
   $$\mathrm{Itotal} = \frac{\Sigma Aoriginal(i)\ x\ I(i)}{\Sigma Aoriginal(i)} \quad (2)$$
   This approach provides a more accurate reflection of spatial cohesion and user experience across the entire layout.

The analytical process began by importing the 2D layout of the event space from AutoCAD into Rhinoceros 3D, ensuring that real-world dimensions were preserved. Once imported, the geometry served as the basis for parametric analysis in Grasshopper. Within

Grasshopper, custom definitions were created to determine key spatial parameters and calculate the integration index based on the convex hull method. Parameters such as the position and shape of temporary structures, their dimensions, the distances between them, and the space occupation ratio were used to define the base geometry. These inputs enabled the generation and manipulation of spatial configurations in a parametric environment. The tool also provided real-time visual feedback and allowed iterative adjustments to the spatial layout. After the analysis was completed, visual outputs were returned to Rhinoceros 3D for further refinement, documentation, and presentation.

3. APPLICATION AND EVALUATION

The method was applied to different layouts of temporary structures on Liberty Square in Novi Sad. Four different configurations were analyzed, each containing 36 temporary structures. Layout 1 presents a grouped arrangement consisting of a single cluster with four

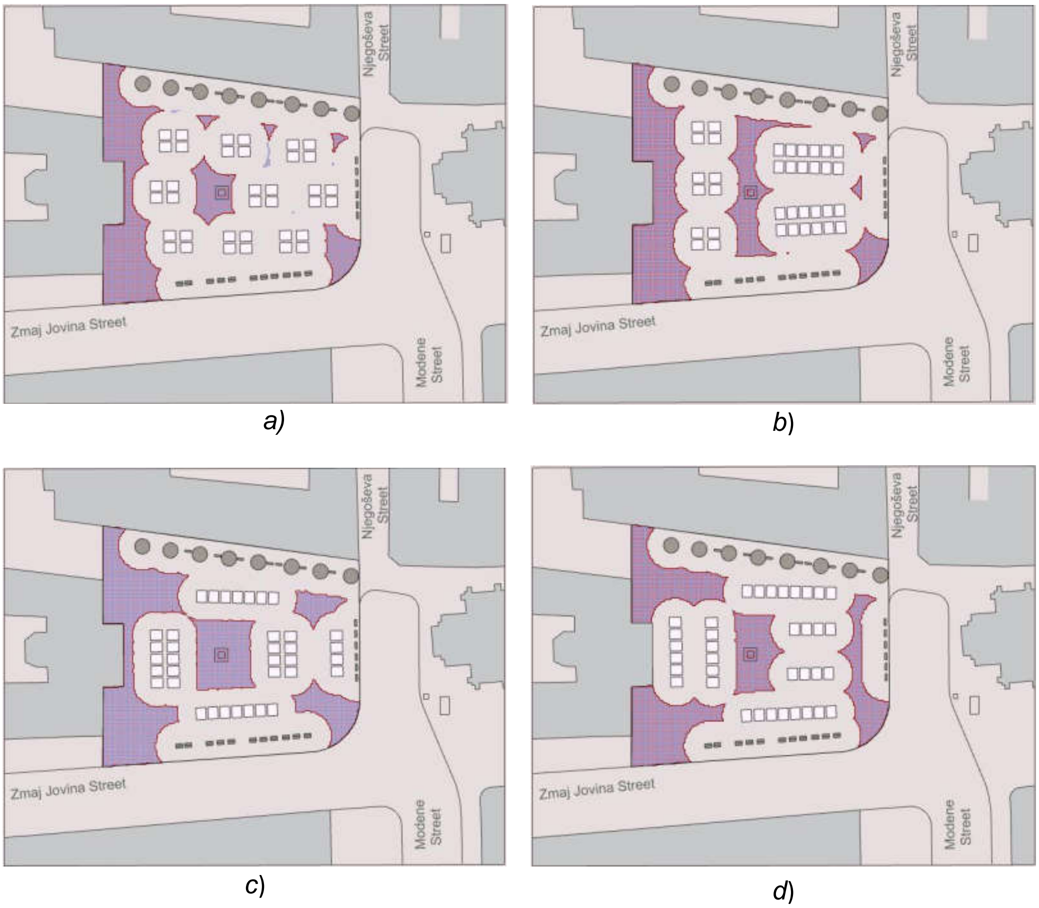


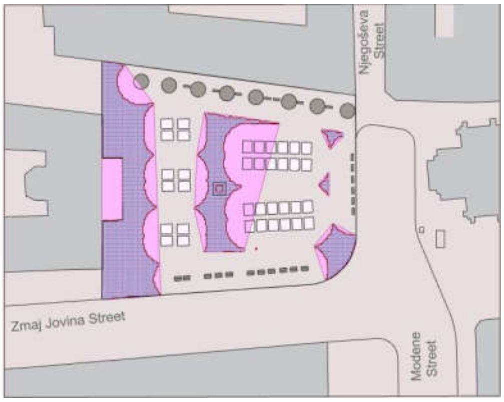
Figure 1. Visualization of standing area configurations corresponding to the following temporary structure layouts: a) Layout 1 b) Layout 2 c) Layout 3 d) Layout 4, source: author

temporary structures. Layout 2 includes three dominant groups composed of 4 and 12 structures, respectively. Layout 3 combines both linear and grouped arrangements, while Layout 4 follows a fully linear configuration. The boundary of the analyzed area was defined based on years of practice in placing temporary structures within a specific part of the square. Initially, standing areas were identified by leaving an access space of 2 meters on each side of the temporary structures, as illustrated in Figure 1.

After identifying the standing zones, their spatial configuration was analyzed using the Convex Hull method. This technique involves constructing the smallest convex polygon that completely encloses each standing zone, effectively capturing the outer boundaries of the usable space. The results of this process are shown in Figure 2.

The analysis offered insight into how temporary interventions reshape the spatial structure of public areas. These findings are further supported by numerical data, as evidenced by the integration index presented in the following tables (Table 1, 2, 3, 4). The index was calculated for each identified standing area according equation (1).

a)



b)

c)

d)

Figure 2. Implementation of the Convex Hull approach to analyze standing surfaces across the following temporary structure layouts: a) Layout 1 b) Layout 2 c) Layout 3 d) Layout 4, source: author

Table 1. Calculation of the integration index (I) for each identified standing surface (A_i) in Layout 1

Layout 1	A_1	A_2	A_3	A_4	A_5	A_6	A_7
$A_{original}$ (m^2)	489.33	111.41	8.62	6.37	2.24	80.61	8.50
A_{hull} (m^2)	847.59	149.13	12.05	9.59	3.23	97.61	13.02
I	0.58	0.75	0.72	0.66	0.69	0.83	0.65

Table 2. Calculation of the integration index (I) for each identified standing surface (A_i) in Layout 2

Layout 2	A_1	A_2	A_3	A_4	A_5
$A_{original}$ (m^2)	541.26	220.71	71.76	7.55	10.27
A_{hull} (m^2)	788.99	563.40	96.17	9.94	16.28
I	0.69	0.39	0.75	0.76	0.63

Table 3. Calculation of the integration index (I) for each identified standing surface (A_i) in Layout 3

Layout 3	A_1	A_2	A_3	A_4
$A_{original}$ (m^2)	592.84	235.81	121.45	63.26
A_{hull} (m^2)	1097.14	276.39	176.62	80.53
I	0.54	0.85	0.69	0.79

Table 4. Calculation of the integration index (I) for each identified standing surface (A_i) in Layout 4

Layout 4	A_1	A_2	A_3	A_4
$A_{original}$ (m^2)	260.24	281.72	178.92	160.63
A_{hull} (m^2)	410.84	370.45	229.40	343.25
I	0.63	0.76	0.78	0.47

Based on the integration index values presented in the tables above, the total integration index (I_{total}) for each layout was calculated using the weighted average method, as shown in equation (2). This approach takes into account both the degree of integration and the area of each individual standing area, ensuring that larger and more spatially significant areas are proportionally represented in the final index. The resulting values are presented in Figure 3.

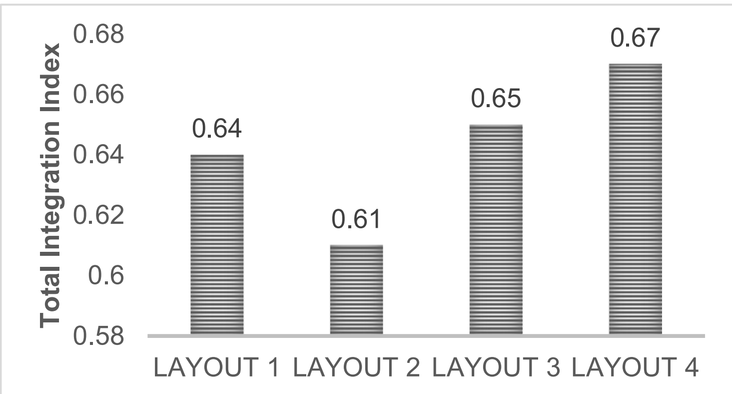


Figure 3. Graph illustrating total integration index of standing areas for each temporary structure layout, source: author

These results present the integration values of standing areas based on the application of the Convex Hull method across different configurations of temporary structures. Among the examined layouts, Layout 4 achieved the highest total integration index of 0.67, suggesting that its linear arrangement supports a more cohesive and accessible spatial structure. This layout appears to reduce fragmentation, and enhance overall spatial legibility.

In contrast, Layout 2 recorded the lowest integration index of 0.61, indicating a more fragmented spatial configuration. It is also noticeable that layouts with a smaller number of identified standing spaces (Layout 3 and 4) have a higher value of the integration index.

The variation between these results highlights the crucial role that spatial configuration plays in enhancing or hindering integration. Even relatively small changes in the arrangement of temporary structures can significantly impact the overall cohesion of public space. Consequently, these findings highlight the need for thoughtful design strategies that prioritize spatial integration, especially in event-based or temporarily transformed urban environments. Such approaches not only improve navigation and user experience but also support the creation of more inclusive and functionally efficient public spaces.

4. DISCUSSION

The analysis of the integration index in four different layout configurations reveals the key role of spatial layout in influencing the cohesion and usability of event spaces. The study demonstrates that temporary structures, despite their impermanence, have a significant spatial logic that can either facilitate or hinder movement, visibility, and intuitive orientation. These findings contribute to an expanding body of literature emphasizing the dynamic interaction between event-specific design and the performance of public space [3, 10].

Layout 4, with its linear structure, produced the highest total integration index. This finding reinforces the notion that spatial continuity, particularly when aligned with natural pedestrian flows, enhances spatial legibility and coherence. These results are consistent with established principles in space syntax theory [11, 12, 13], where spatial integration is closely associated with pedestrian movement and spatial comprehension, even in short-term or unfamiliar spatial contexts [6].

In contrast, Layout 2, composed of large, clustered groups, displayed the lowest integration values indicating a fragmented spatial experience. This underscores how even subtle changes in spatial configuration, such as the spacing or grouping of temporary elements, can significantly impact space cohesion. Such observations coincide with findings in research on pop-up urbanism [14], where ephemeral spatial arrangements can dramatically alter user experience and behavior depending on their spatial logic.

While the integration index offers useful insight into navigability and cohesion, it captures only one layer of public space performance. The quality of experience in public space is inherently multidimensional, encompassing not only circulation and movement but also opportunities for social engagement, psychological comfort, inclusivity, and spatial adaptability [3, 4].

The variation in integration levels across layouts reinforces the idea that even small changes in spatial configuration can lead to measurable shifts in spatial performance. These results resonate with studies in space syntax research [5, 7], which have consistently demonstrated that the configuration of elements within a system has a direct impact on how space is experienced and used. Although much of this literature focuses on permanent urban form, our findings suggest that similar principles apply to temporary settings, where the logic of layout remains crucial to spatial efficiency.

Moreover, by applying a weighted index that takes into account the area of each standing surface, the analysis advances conventional integration metrics by integrating both spatial quality and quantity. This methodological adjustment ensures that larger, highly efficient surfaces contribute proportionally more to overall spatial performance. While similar techniques have been used in architectural modeling and simulations [15], their application to temporary urban layouts remains limited, making this study a novel contribution.

Ultimately, this discussion positions the proposed method as a bridge between theoretical frameworks like space syntax and real-world design needs in dynamic urban contexts. By doing so, it lays the groundwork for more responsive, evidence-based strategies in designing adaptable public spaces.

5. CONCLUSION

This study introduces a geometric approach to assessing spatial integration in public spaces during events by applying the convex hull method to analyze different layouts of temporary structures. The results highlight the significant impact that spatial configurations can have on pedestrian movement and overall spatial efficiency. While the values derived from this analysis should not be regarded as absolute or definitive, they hold particular value in comparative assessments. The strength of the method lies in its simplicity, adaptability, and ease of implementation, making it particularly useful for evaluating temporary or frequently reconfigured urban environments. This has practical relevance in contexts where urban spaces are frequently reconfigured for temporary uses such as markets, fairs, festivals or civic gatherings, and where permanent redesign is not always feasible.

However, the applied method of measuring spatial cohesion has limitations, particularly in capturing more complex spatial dynamics such as user clustering, edge conditions, or visual barriers. Additionally, the changing nature of events may affect the consistency of the results across different settings. Events vary not only in their physical configuration but also in their rhythms, durations, crowd dynamics, and intended programs, all of which shape how space is experienced.

Despite its limitations, this study advances the discourse on flexible urbanism by offering a structured method for assessing how temporary layouts affect movement and integration. It provides a practical tool for improving navigability and coherence in event-based spaces. Future research should expand the empirical base with behavioral data and test the method across varied contexts, while also integrating metrics like visibility, proximity, and spatial entropy to enhance its robustness.

In conclusion, this research offers a significant contribution to understanding how temporary spatial configurations influence the coherence and navigability of urban environments. With further methodological refinement and application in varied urban environments, future studies can support more inclusive and efficient design strategies in public space planning.

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