

Evaluating Walkability in Budapest through Space Syntax Analysis

A Case Study of Egyetem Square and Corvin Promenade

Amir Hossein Sirjani^{1*}, Árpád Szabó¹

¹ Department of Urban Planning and Design, Faculty of Architecture, Budapest University of Technology and Economics, P. O. B. 91, H-1521 Budapest, Hungary

* Corresponding author, e-mail: amir.sirjani@urb.bme.hu

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Abstract

Walking is a fundamental and intuitive means of transportation both on an individual and urban scale, offering social and personal benefits like improved health, equity, and reduced greenhouse gas emissions. Despite these benefits, urban sprawl and increased car dependency remain significant challenges. To combat this trend, urban planners have emphasized walking as a way to reduce vehicle travel and emissions, while public health researchers recognize its potential to improve general health.

This study explores the concept of walkability and its relationship to urban design, with a specific focus on two recently renovated areas in Budapest, namely Egyetem Square and Corvin Promenade. Utilizing space syntax analysis, a promising approach to developing a walkability index, this research investigates the functional aspects of these urban spaces and their impact on walkability.

The study aims to demonstrate the potential of space syntax analysis in enhancing urban planning efforts aimed at promoting walkability. By analyzing the spatial configuration, visibility, and accessibility of the case studies, this research examines how the design and layout of these areas influence pedestrian movement patterns and the overall walkability experience.

By demonstrating the potential of space syntax analysis in informing urban planning decisions, this study provides insights into the relationship between spatial configuration and walkability. The findings highlight the importance of well-connected street networks, clear pathways, and visually appealing urban elements in creating walkable environments. The results of the analysis contribute to the understanding of how urban design factors can be leveraged to enhance walkability and create sustainable, livable cities.

Keywords

walkability, urban design, space syntax, spatial analysis

1 Introduction

Walking has been the subject of increased attention as a crucial factor in promoting healthier, environmentally friendly, and socially active communities. Various scientific fields, including architecture, urban planning, and transportation, have been developing reliable tools to objectively measure the walkability of streets, neighborhoods, and cities. This paper focuses on examining walkability in terms of urban design, specifically through the utilization of visibility and spatial configuration analysis.

Walkability can be defined as "how inviting a specific place is for pedestrians" (Forsyth, 2015:p.285), encompassing both utilitarian and leisure walking. However, the expansion of cities and urban sprawl have led to a greater reliance on vehicles, resulting in car dependency and

degraded spaces. Evaluating the appropriateness and attractiveness of the built environment for walking has been a significant topic in urban planning and related fields for many decades. This study aims to investigate walkability by exploring the influence of visibility and spatial configuration in urban design.

While most studies have focused on measuring walkability based on form and usage variables related to the environment surrounding urban elements, few studies have examined the impact of spatial configuration on walkability. This research seeks to further investigate the vision-based approach as a walkability index and compare it with actual behavior, emphasizing the importance of the surrounding space in influencing pedestrian movement patterns.

1.1 Research aims, and objective

Space syntax is usually related to the street network by identifying key connections that strengthen the internal connectivity and better connect the area to its broader environment. But it is also known to be related to the functional aspects of the urban space. It can be used as a tool to improve the existing street network, while making the least possible changes to the historic context.

In the second part of this paper, the aspects affecting the quality of the case studies in Budapest will be further analyzed to answer the question, whether the pedestrianization, and renewal of the streets has helped to improve the quality of the environment. In particular, we will try to find out whether these new interventions affected the walkability index of the analyzed urban spaces.

1.2 Research methodology

Firstly, the intervention goals for walkability which are to be included in the planning process are defined. These goals take into account the protection, appreciation of the built environment, the promotion and stimulation of economic activities, and the fulfilment of the needs of the population. Then, a preliminary plan is designed to promote an urban plan proposal that satisfies the previously defined goals, which at the same time assures that the project will have the potential to create a livable environment. In this process, OpenStreetMap (OpenStreetMap contributors) will provide the latest street network of the intervention zones.

Finally, by using Depthmap software (Space Syntax Lab - UCL), the selected areas are analyzed based on axial lines and isovists, or visible and movable spaces. The differences between the two methods will be further discussed.

2 Literature review

Walkability has become one of the fast-growing concepts in urban planning and urban design. It can be considered a relatively new phenomenon in urban design, and a useful concept for urban decision-makers. Walkability of an environment can be evaluated with several methods, which are usually dependent on large sets of data, which makes it difficult to apply them by urban designers in their daily practice.

Since the 1960s, the study of public space and its impact on people has become a well-established research field (Gehl and Svarre, 2013). This is due to the discovered impact that urbanized cities have on their citizens, from the streets to the parks (Project for Public Spaces Inc., 2012), which grew a hot topic in urban society after the 1960s. This effect was not taken into account when creating new spaces, but factors such as car roads,

factories and large residential complexes, which were measurable in terms of efficiency and numbers, were considered. Therefore, to counter these theories, a new goal had to be considered: "To create cities fit for people" (Gehl and Svarre, 2013:p.23). However, with this new goal, new methods emerged to provide a systematic process for measuring the impact of built structures on their inhabitants.

Kevin Lynch (1960) in his major work "The Image of the City" defined "Legibility" as the ease with which a city's parts can be recognized and organized into a coherent pattern. He was one of the first to study the impact of space on people and offers a theory that the surroundings orient people through "mental maps", that composed of five elements (paths, edges, districts, nodes, and landmarks), which are components for a legible city. As a result, due to the dependence of people on their surroundings, a relationship is composed between people and space (Lynch, 1960).

Jan Gehl (2011), on the other hand, theorizes in his book "Life Between Buildings: Using Public Space", that good architecture is a perfect interaction between public spaces and public life. His works are known as one of the most prominent in which the importance of people in cities is discussed. Although the constant changes of life are often ignored, he proposes a measurement model in which "anyone who decides to observe life in the city will quickly realize that you must act systematic, in order to gain useful knowledge from the complex fusion of life in public spaces" (Gehl and Svarre, 2013:p.5).

Building upon the foundations laid by these pioneering researchers, current literature continues to explore and advance the understanding of walkability and its implications for urban environments. Recent studies have investigated the social, environmental, and health benefits associated with walkable communities (Frank et al., 2006). Others have focused on developing new methodologies and metrics for assessing walkability, such as the use of Geographic Information Systems (GIS) and spatial analysis techniques (Handy et al., 2006).

By situating this investigation within the broader context of existing research, it becomes evident that there is a multi-disciplinary effort to unravel the complexities of walkability and its impact on urban design. This study aims to further investigate a vision-based approach to assess walkability and comparing it with actual behavior, thereby providing valuable insights for urban planning and design processes.

3 Spatial analysis using space syntax method

Space syntax measures are related to pedestrian movements. This concept which was built upon the works of

Hillier and Hanson (1984), was developed in the 1970s at the University College London. Several studies have shown a positive correlation between integration and the presence of pedestrians. A potential factor explaining the link between higher street integration and more pedestrians is land use along with street segments (Crucitti et al., 2006). Commercial land uses may exist alongside highly integrated streets as such streets are more accessible than elsewhere which is essential for commercial land uses. Therefore, it can be argued that more integrated street sections attract more pedestrians, because of the presence of commercial destinations along them (Hillier et al., 1993).

In walkability analysis, network connectivity plays a significant role. In addition, the role of access to different land uses, ease of pedestrian infrastructure, conviviality for socialization, conspicuousness for finding ways around, and coexistence with other modes of transportation can be mentioned (Moura et al., 2017).

In space syntax analysis, axial lines of the street network are used as the main input of the analysis, whilst walkability analysis considers broader factors including environmental features and land uses (Koohsari et al., 2016). This theory examines that the amount of movement on each path is influenced by its configuration and its relation to the other roads in the urban infrastructure. Therefore, the more the street is connected to the whole network, the more integrated it is (Pereira et al., 2015).

3.1 Axial lines, and isovists

In the space syntax model, the most commonly used representation is the axial line model, as it closely resembles computational studies of wayfinding (Kuipers, 1998). This model is particularly useful for analyzing the spatial configuration of an area. In contrast, the isovist model is based on the field of view from a particular point of preference, which is a horizontal slice through the field of view at eye level and parallel to the ground plane. The isovist model is more visual than the axial line model and allows for mapping based on the attenuation of local characteristics, which is especially useful in the arrangement of enclosed spaces.

By using the isovist model, it is possible to analyze the effect of visual cues on the perception of space. This is because the isovist model considers the visibility of a point from different locations in space. The attenuation of visual cues can also be measured using the isovist model, allowing for a more comprehensive understanding of the spatial characteristics of an area. On the other hand, the axial line model focuses on the spatial relationships between

different parts of a space, and how these relationships influence pedestrian movement (Dalton and Bafna, 2003).

Therefore, the choice of which model to use depends on the specific research questions being asked. If the aim is to understand how visual cues affect perception and movement in enclosed spaces, the isovist model may be more appropriate. However, if the focus is on the spatial configuration of an area and how this influences pedestrian movement, the axial line model may be a better fit.

3.2 Visibility in space

Space syntax theory posits that the spatial configuration of built environments plays a significant role in determining pedestrian movement. Hillier (2007) refers to this type of movement as "natural movement", and studies based on visibility confirm the correlation between spatial configuration and movement in buildings and cities.

Visibility graph analysis is a method of spatial modeling that has been closely linked to manifestations of spatial perception such as wayfinding, movement, and space use (Turner et al., 2001). The analysis involves abstracting architectural forms into a spatial system of barriers and permeabilities, dividing space into grids, and calculating the relationships of each cell with the system as a whole based on properties of its isovists. An isovist refers to the volume of space visible from a given point in space, along with a specification of the location of that point (Martino et al., 2019). Visibility graph analysis is useful for understanding spatial mobility, including how people move in spaces and how central and outer spaces are perceived (Benedikt and Burnham, 1985).

A novel approach in the current study is to combine measurements of visibility and movability as a single indicator. It is important to note that these measurements are not deterministic but rather represent probable fields of movement and interactions in space. It is assumed that people tend to move where they can see, while avoiding corners when moving through space. By combining the measurements of visibility and movability, the proposed approach allows for a more comprehensive understanding of the factors that influence pedestrian movement. This approach has the potential to inform urban design and planning efforts to create more walkable and accessible built environments.

4 Case studies

For this study, two case studies were conducted in Budapest, Hungary to analyze urban walkability. The selection of each case study was based on the spatial scale of the variables

used to measure pedestrian movement in a simulation model. This model employed a configurational approach that emphasized visibility and movability in space to evaluate the walkability of each area under investigation.

4.1 Egyetem Square, Budapest

The square has been named after the Eötvös Loránd University (ELTE) at the square. The university moved to the location in 1784, and the Faculty of Law has been present here since the start of the nineteenth century. After the public utility replacements, and public space renewals in 2010, the previously worn area got a special image with high-quality natural stone paving, and unique street furniture, to which smaller, and larger spaces are connected.

Using the space syntax method, the spatial layout of this area before the reconstruction of Egyetem Square in terms of connectivity, and accessibility was analyzed. Then, in comparison with the current situation, the simulation of the current arrangement is going to be made. The result shows us whether the reconstruction of this area has significantly improved the walkability of this square, or how successful this new spatial arrangement is in this regard.

4.1.1 Aims of design in Egyetem Square

The aims of design in Egyetem Square have been:

1. To make sure the space is accessible, and intelligible to all pedestrians, including people living, and working in Budapest, people visiting the Eötvös Loránd University (ELTE), and visitors in general.
2. To make sure that all the space in the square is used and well arranged to some degree.
3. To ensure everyday use of the square throughout the year by visitors, as well as its safety for special occasions.

4.1.2 Analysis of space use, and movement in the square

The objective in improving the quality of this area has been to establish the current pattern of pedestrian activity in the study area, identify the specific problems faced by pedestrians, and, from this analysis, generate design ideas that address these problems, and satisfy the overall aims of the project. The first impression, and observations of space used in Egyetem Square were:

1. The heart of the square was used almost exclusively by cars.
2. There was much informal road crossing by visitors, especially from the south side of Egyetem Square in, order to get to the best views from the University Church, and the university.

3. There was almost no stationary use of the square by visitors. Instead, most people walk around the edges of the square than across it.

At first sight, the main problem of Egyetem Square appeared to be that it was cut off from its surroundings by dense traffic. In fact, this was only a part of the story. Simply removing the traffic would not in itself led to significant improvements in pedestrian use. Space syntax analysis of this square shows that, while the effects of the traffic are significant, they are not nearly as important as the influence of design.

Recent research and experience have confirmed, that design can make the difference between well, and poorly used urban spaces, and that design means first, and foremost spatial design. Merely adding street furniture, and facilities to a poorly designed space will not make that space work. Good spatial design involves three key elements:

1. simple, with direct routes for pedestrian movement;
2. positions within the space from which people can see out in several directions;
3. facilities for eating, drinking, or resting which are located close to the main routes, but not disturbing the path of movement.

Our analysis shows that each of these elements was missing from the previous design of Egyetem Square. Instead, the old design of the space was directly responsible for the uneven pattern of use which we could observe. In particular, a detailed analysis of the visual "fields" available from Egyetem Square shows that the views available from the geometric center of the square (Fig. 1 (a)) are very constricted, and nowhere near as strategic as those from the city centre's traffic ring (Fig. 1 (b)).

Moreover, the existing street furniture alongside the new pedestrian pavement pattern in front of the university inhibits the kind of crisscrossing movement through the body of the space, which other studies have shown to be an essential characteristic of well-used squares.



Fig. 1 Visual field (a) from the geometric centre and (b) from city centre's traffic island

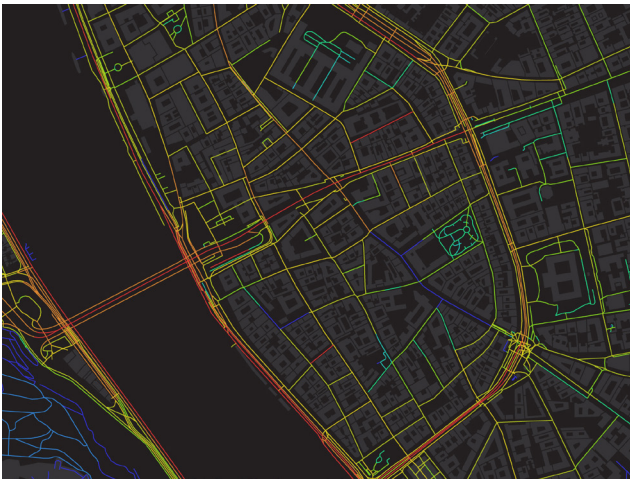


Fig. 2 Axial model of Egyetem Square before 2010

Computer modelling of the spatial layout of the square allows the precise relationship between spatial design, and pedestrian activity to be measured. In Fig. 2, the network of pedestrian routes in, and around Egyetem Square has been analyzed using Depthmap software (Space Syntax Lab - UCL).

The Depthmap software (Space Syntax Lab - UCL) calculates the relative accessibility of each spatial link in the network. It represents the most accessible routes as red lines, then, orange, yellow, and green, to the least accessible lines, which are blue. Accessibility is measured by calculating the shortest journey routes between each link, and all of the others in the network (defining "shortest" in terms of fewest changes of direction). Moreover, visual, and statistical comparison between the space syntax analysis of accessibility, and the actual pattern of pedestrian movement based on observations in Egyetem Square shows a high degree of correspondence.

In this way, space syntax analysis provides a design strategy with a powerful tool for understanding the current pattern of pedestrian activity in Egyetem Square, and demonstrating how this pattern is directly related to spatial design (Fig. 3). Having understood current activity, the method can then be used as a design tool, by simulating design changes, and evaluating the effects of these in terms of pedestrian activity.

This method shows that this analysis is also a design generator, highlighting areas which are either problematic (such as the area in front of the university main entrance), or which offer significant design potential (such as the area to the south of the square connecting to Calvin Square). When the spatial characteristics of an area have been pinned down, ideas for solutions begin to emerge in a process that is called "evidence-based design".

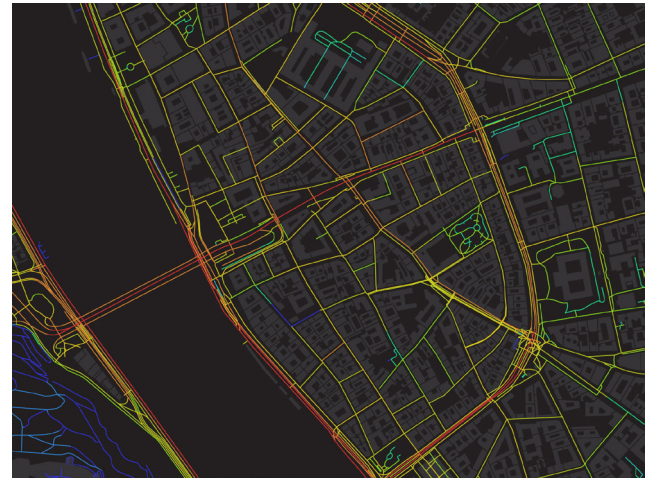


Fig. 3 Axial model of Egyetem Square after renovations in 2010

4.1.3 Proposed redesign based on space syntax analysis

The findings of the space syntax analysis have generated several key redesign ideas for Egyetem Square. These could be evaluated over the analysis process of the generated spatial models (some are illustrated in Fig. 4).

The redesign proposals include the southward extension of the square, and the creation of new, direct pedestrian crossings to the north-west corner of University Church, and the north side of Kecskeméti Street. The main effects/benefits of this will be:

1. To expand the area of the square which will be naturally used by visitors, decreasing the current congestion.
2. To make important views available for visitors to assist in, orientation, and movement. These include Kecskeméti Street towards the University Church, the ELTE towards Károlyi Street in the northern part, and Kecskeméti Street towards Károlyi Street in total.
3. To facilitate movement across the square for people living, and working in the area, so that the square becomes a natural part of their everyday journeys rather than the obstacle it was in the previous arrangement.
4. To facilitate movement by visitors to, and from the main squares in the southern (Calvin Square), and the northern (Ferenciek Square) parts of the square,

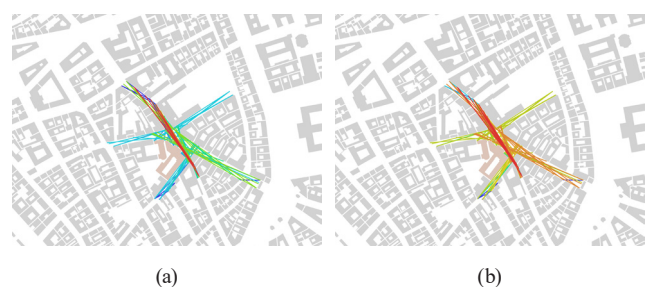


Fig. 4 Spatial model of integration (a), and connectivity (b)

allowing movement into these areas to approach from different directions.

5. Renovation of the street pavement pattern between the southern, and the northern part of the square, as an intrinsic part of Egyetem Square, thus increasing the prestige, significance, and reputation of the whole square.

The renovation of this space with its wonderful viewing potential will require the elimination of all everyday traffic (allowing occasional access for special visitors to the main entrance of the ELTE) from the north side of the square. However, this on its own, will not in itself realize the potential of the whole public space. This will also require the careful design of this space, and its relation to the main body of the square, since:

1. Movement will continue to be primarily on the university side of this space, and more generous provision will therefore have to be made for this movement on the edge of the University Church in the northern space.
2. The south side of the space will not be a significant movement space, but will offer wonderful opportunities for stationary uses, for people wishing to relax, and spend some time in the square.
3. A direct link between the two main squares in the northern, and the southern part of the square via a new pedestrian pathway.
4. Providing a more comprehensive route into the body of the square from the University Church via the least used part of Egyetem Square. Visitors to the University Church will use this space whereas they would not necessarily go into the University Church if they had to use the corner areas. This space will create a more localized link which will provide a convenient route for people going directly to, and from the University Church.
5. Creating a more popular facilities on the north–west side of the space (where there will be a higher, and more mixed local movement population).
6. And, in general, the creation of new, well used public space for visitors which are making space look more active, and pleasant.

Each of these design characteristics has emerged following numerous runs of the pedestrian computer model. Since processing times are very short, it has been possible to use the computer as a sketchpad for testing, and refining design ideas. Analysis of the redesign proposals indicates the extent to which pedestrian linkages in the square has been improved (Fig. 5).

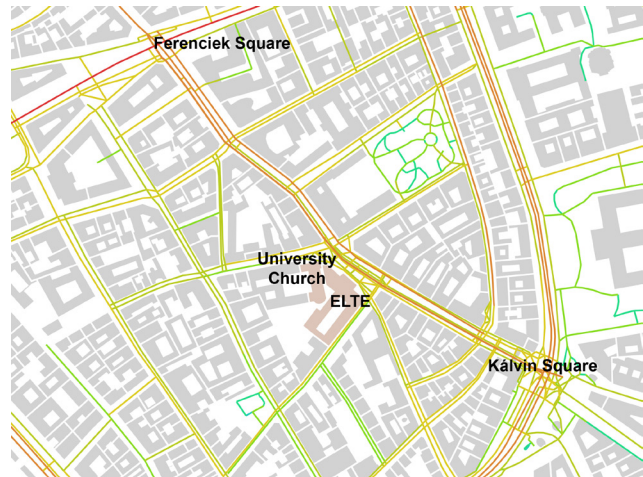


Fig. 5 Proposed space syntax computer model of Egyetem Square

4.2 Corvin Promenade, Budapest

Corvin Promenade is an integral part of the Corvin Quarter, Central, and Eastern Europe's largest urban renewal program. The development is part of Budapest's newest, iconic public space, based on the design of György Alfvöldi, and his team after a number of urban design competitions. The 36-meter wide, and 350-meter long, plant-lined, and pedestrianized Corvin Promenade has become the new center of social life. There are residential properties, office buildings, and alongside business units located on the ground floor level, as well as a wide range of restaurants, pubs, cafes, and a theatre.

The Corvin Promenade was chosen as a case study, because it has a reputation of being a complete walkable community. The spatial analysis of the area displays that all parts of this area as relatively walkable, when compared to its urban surroundings. With the help of the space syntax method, a study of the previous spatial layout structure of the neighborhood is going to analyze, then reviewed the proposed current situation of the area. The aim is to analyze spatial potentials to optimize the urban space, in particular with regard to the location, and accessibility of key public facilities.

4.2.1 Aims of design in Corvin Promenade

The Corvin Promenade project aimed to transform the existing urban space into a more walkable and accessible area for all pedestrians, including residents, visitors, and commuters. The design objectives included dividing the longitudinal building blocks into two separate sections by introducing a new walkable street, the promenade. This not only increased the level of accessibility to other parts of the neighborhood but also created an intelligible space that could be easily navigated by all users, including cars.

The design also aimed to improve the amount of movement on each street by reconfiguring the layout and establishing stronger connections between the roads. To enhance the walkability index of the zone, environmental features and land uses were audited and incorporated into the design.

Another important goal of the project was to ensure the everyday use of the promenade throughout the year by visitors and residents while maintaining safety during special occasions. To accommodate the diverse range of users, the design provided ample space for pedestrians to move freely, sit, and enjoy the surroundings. Overall, the Corvin Promenade project was successful in creating a vibrant and accessible urban space that caters to the needs of all users, while promoting sustainable modes of transportation and enhancing the quality of life in the neighborhood.

4.2.2 Analysis of space use in the promenade

The objective of improving the accessibility of this area has been to establish the current pattern of a walkable neighborhood in the study area, identify the specific problems faced by pedestrians, and generate design ideas that address these problems and satisfy the overall aims of the project. Fig. 6 represents the first impressions and observations of space use in the Corvin area are as follows:

1. Most of the buildings in this area were of low quality, and some were abandoned buildings. Since many of them were uninhabited, the feeling of safety in this area was very low.
2. The heart of the neighborhood was used almost exclusively by cars.
3. There was virtually no movement across the heart of the square. The access route from the west side of this area (Üllői Road) to the east side (Práter Street) was very long without crossing any road, greatly reducing the level of accessibility inside this neighborhood for its inhabitants.
4. There was almost no stationary use of the area by inhabitants. Instead, most of the inhabitants walked around the cinema area in the northern part.

There is a strong visual correlation between natural movement, and pedestrian movement patterns, mainly driven by the generous views to the Shopping center, and the integration of this center with the other parts of the neighborhood. Fig. 7 shows that the analysis is also a design generator, highlighting areas which offer significant design potential (such as the areas near the shopping center entrance).



Fig. 6 Space syntax model of axial analysis of the space before the development of the promenade



Fig. 7 Space syntax model of axial analysis of the space after development of the area

4.2.3 Expected results based on the space syntax analysis

Based on the space syntax visibility analysis, a proposed development plan generates a number of key ideas for redesigning the Corvin District. These can be assessed through the process of visible, and movable space model. The proposal for this area is to add a completely pedestrian street that will cut the north-south route of this place (Fig. 8).

The proposed development plan involves the implementation of a pedestrian street that will traverse the north-south direction of the neighborhood. This initiative will bring forth various benefits, such as the creation of a promenade that visitors can use and the establishment of a new public square that offers scenic views. Furthermore, the introduction of significant views for visitors will aid in their orientation and movement within the area. The plan will also



Fig. 8 Isovist area of visible space: the area of visible space from each cell is proportional to the number of cells directly visible from each cell. (Red: More isovist area, Blue: Less isovist area)

enhance the safety of the neighborhood, making it a more attractive destination for local visitors, and consequently, increasing its prestige and reputation. Additionally, the creation of a new north-south path will provide a quicker, more pleasant, and less hazardous route than the previous arrangement, thereby increasing the accessibility of the district and better connecting it with its surroundings.

Moreover, the proposed development will enable people living and working in the neighborhood to move more conveniently across the promenade, making it a natural part of their everyday journeys (Fig. 9). Visitors will also find it easier to access the new space from various directions. Furthermore, the proposed development will improve the aesthetic quality of the area by creating movement across the promenade in multiple directions, thereby generating stationary use within the promenade by visitors. Finally, the pavement pattern of the streets crossing the area will undergo renovation to ensure a cohesive urban design quality throughout the entire district.

5 Conclusion

The analysis highlights that walkability measurements may serve different purposes and scales according to their measurement methods. Firstly, while large-scale indexes can indicate neighborhoods that encourage walking as a main travel mode throughout the city, or to generally be more physically active, these measurements do not fully capture the human-scale relationships that strongly influence pedestrian preferences and routes. It is important to acknowledge that this study focused on spatial configuration analysis, specifically using the configurational model, which has its limitations. Further research is needed to explore complementary methods that consider additional

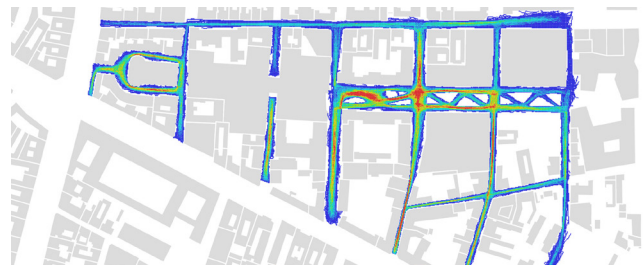


Fig. 9 Gate counts model, representing pedestrian flow in the Corvin Promenade

factors, including social and cultural aspects, to provide a more comprehensive understanding of walkability in different contexts.

Concerning "how inviting spaces are to pedestrians" as an aspect of walkability, the great views from the entrance at Corvin Plaza captured by the configurational model, closely matched this aspect as an actual walking pattern on the site, even though further research is needed to validate these findings. The limitations of this study include the need to assess other factors that may influence pedestrian movements, such as urban design infrastructure, environmental comfort, and proximity to amenities or landmarks. By incorporating these factors, the measurement and understanding of walkability can be refined.

In the context of the local case study, it is essential to consider the cultural significance of the findings. Hungarian culture values pedestrian-friendly environments and vibrant public spaces. The focus on spatial configuration and visibility in this study aligns with the cultural preferences of the Hungarian population, which appreciates attractive and welcoming urban environments. However, it is important to acknowledge that the results of this local case study may be culturally defined and may not be directly applicable to other cultural contexts. Future research should consider the cultural diversity of different cities to develop a more comprehensive and refined understanding of walkability that reflects the unique cultural values and preferences of each location.

Finally, this study emphasizes the limitations of current walkability measurement methods and the importance of considering human-scale relationships and cultural context in assessing walkability. By incorporating additional factors and cultural specificity, we can enhance our understanding of walkability and create more inclusive urban environments.

References

- Benedikt, M., Burnham, C. (1985) "Perceiving architectural space: from optic arrays to isovists", In: Warren Jr., W. H., Shaw, R. E. (eds.) *Persistence and Change: Proceedings of the First International Conference on Event Perception*, Lawrence Erlbaum Associates, pp. 103–114. ISBN 0-89859-391-3
- Crucitti, P., Latora, V., Porta, S. (2006) "Centrality in networks of urban streets", *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 16(1), 015113.
<https://doi.org/10.1063/1.2150162>
- Dalton, R., Bafna, S. (2003) "The syntactical image of the city: a reciprocal definition of spatial elements and spatial syntaxes", presented at 4th International Space Syntax Symposium, London, UK, Jun., 17-19.
- Forsyth, A. (2015) "What is a walkable place? The walkability debate in urban design", *Urban Design International*, 20(4), pp. 274–292.
<https://doi.org/10.1057/udi.2015.22>
- Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., Bachman, W. (2006) "Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality", *Journal of the American Planning Association*, 72(1), pp. 75–87.
<https://doi.org/10.1080/01944360608976725>
- Gehl, J. (2011) *"Life Between Buildings: Using Public Space"*, Island Press. ISBN 9781597268271
- Gehl, J., Svarre, B. (2013) *"How to study public life"*, Island Press. ISBN 978-1-61091-525-0
<https://doi.org/10.5822/978-1-61091-525-0>
- Handy, S., Cao, X., Mokhtarian, P. L. (2006) "Self-Selection in the Relationship between the Built Environment and Walking: Empirical Evidence from Northern California", *Journal of the American Planning Association*, 72(1), pp. 55–74.
<https://doi.org/10.1080/01944360608976724>
- 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), pp. 29–66.
<https://doi.org/10.1068/b200029>
- Hillier, B. (2007) *"Space is the Machine: A Configurational Theory of Architecture"*, The Press Syndicate of the University of Cambridge. ISBN 978-0-9556224-0-3
- Hillier, B., Hanson, J. (1984) *"The Social Logic of Space"*, Cambridge University Press. ISBN 9780511597237
<https://doi.org/10.1017/CBO9780511597237>
- Koohsari, M. J., Owen, N., Cerin, E., Giles-Corti, B., Sugiyama, T. (2016) "Walkability and walking for transport: characterizing the built environment using space syntax", *International Journal of Behavioral Nutrition and Physical Activity*, 13(1), 121.
<https://doi.org/10.1186/s12966-016-0448-9>
- Kuipers, B. (1998) "A Hierarchy of Qualitative Representations for Space", In: Freksa, C., Habel, C., Wender, K. F. (eds.) *Spatial Cognition: An Interdisciplinary Approach to Representing and Processing Spatial Knowledge*, Springer, pp. 337–350. ISBN 978-3-540-64603-7
https://doi.org/10.1007/3-540-69342-4_16
- Lynch, K. (1960) *"The Image of the City"*, MIT Press. ISBN 9780262620017
- Martino, N., Girling, C., Trigueiro, E. (2019) "Exploring Urban Walkability Models and Pedestrian Movement Trends in a Vancouver Neighborhood", In: *Proceedings of the Symposium on Simulation for Architecture and Urban Design*, Atlanta, GA, USA, 19.
- Moura, F., Cambra, P., Gonçalves, A. B. (2017) "Measuring walkability for distinct pedestrian groups with a participatory assessment method: A case study in Lisbon", *Landscape and Urban Planning*, 157, pp. 282–296.
<https://doi.org/10.1016/j.landurbplan.2016.07.002>
- OpenStreetMap contributors "OpenStreetMap", [map] Available at: <https://www.openstreetmap.org/> [Accessed: 21 June 2021]
- Pereira, R. H. M., Borges de Holanda, F. R., Soares de Medeiros, V. A., Barros, A. P. (2015) "The use of space syntax in urban transport analysis: Limits and potentials", *Institute for Applied Economic Research (ipea)*, Rio de Janeiro, Brasília, Discussion Paper No. 188.
- Project for Public Spaces Inc. (2012) "Placemaking and the Future of Cities", [pdf] UN-HABITAT Sustainable Urban Development Network (SUD-Net). Available at: https://assets-global.website-files.com/581110f944272e4a11871c01/5f0f1f9e47f9663f207396ac_59f1fb530aad1d00010a6186_PPS-Placemaking-and-the-Future-of-Cities.pdf [Accessed: 21 June 2021]
- Space Syntax Lab - UCL "DepthmapX, (Version 0.8.0)", [computer program] Available at: <https://github.com/SpaceGroupUCL/depthmapX/releases> [Accessed: 21 June 2021]
- Turner, A., Doka, M., O'Sullivan, D., Penn, A. (2001) "From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space", *Environment and Planning B: Planning and Design*, 28(1), pp. 103–121.
<https://doi.org/10.1068/b2684>