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Highlighting Pedestrian Equity Considerations Using Walkability Space Syntax: A Case from Suburb in India

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Abstract: Increasing urbanization has led to uncontrolled growth along the periphery of urban areas, particularly in developing countries. This has led to the formation of suburban areas around the metropolis, which are characterized by low-density neighborhood with the places of activities like education, and work, usually far off from one another. Walking is the predominant mode of transport across the world, but the facilities for pedestrians, while planning and implementation, are usually overlooked. Hitherto, ample amount of literature has been found to be centric to the pedestrian analysis in core city under different purviews, but only some studies highlight pedestrian inequity in suburban diorama. To highlight these pedestrian issues, a study was conducted in Kajlikheda, a suburb area of Bhopal, which is the capital city of Madhya Pradesh, a central state of India. The paper highlights the pedestrian equity concern through Walkability Space Syntax (WSS). WSS of street integration and pedestrian choice analysis is used for understanding the walking pattern in a neighborhood. A reconnaissance survey was conducted to find out the available pedestrian infrastructure and facilities, post which absence of these facilities was observed. To establish the share of pedestrians in traffic and reinforce the findings, a Traffic Volume Count was conducted, and pedestrian share was found to be substantial. In cognizance to the laid standards, volume to capacity ratio was calculated for automobiles and pedestrians for quantifying the Level of Service (LoS) for both the modes. Through statistical analysis, the paper attempts to express the need to take adequate consideration to provide better pedestrian facilities, which can be generalized in various suburban scenarios across the globe. The research also brings a new dimension to the pedestrian equity studies by integrating concepts of space syntax to answer the modality.

Keywords: pedestrian, equity, policies, walkability space syntax

1. Introduction

A sustainable transportation system has been defined as "the current transport and mobility needs without compromising the ability of future generations to meet their needs" (Black, 1997; Richardson, 1999). A sustainable transportation system is one that offers transportation and mobility using renewable fuels, while limiting emissions harmful to the local and global environment, and avoiding unnecessary fatalities, injuries, and traffic jams (Black, 1997). A more elaborated definition was given by Rohács & Simongáti (2007) furthered in Awasthi et al. (2011), emphasizing the development needs of individuals, companies, and societies, optimized on a equilibrium with human and ecosystem health sustained between and within successive generations. In cognizance to the same, reinforcing toward competitive economy, affordable pricing, and offering choice of transport modes for balanced regional development, it limits emissions and waste with a focus on renewable resources. Reducing automobile journeys and promoting alternate modes including public transportation, walking, and cycling should be the main goals of transportation policy (Babalik-Sutcliffe, 2013). Because walking and biking have good effects on people's health, they should be encouraged (Rosenberg et al., 2009; Van Dyck et al., 2011). The most typical and fundamental kind of transportation and urban mobility in a city might be walking. Every person, at some point throughout their journey, is a pedestrian (NCSC, 2022). Walking makes it very simple to link activities that are close together. When compared to other modes of transportation, especially motor vehicles, walking allows one to experience and engage with the local environment and larger cultures in ways that are not conceivable (Kelly et al., 2020).

In addition to promoting the development of livable, walkable, and sustainable communities, walking has several good effects on one's health, the environment, and the economy as well as sociocultural advantages for the person and the community (Pedestrian and Bicycle Information Centre, 2010). According to Spinney et al. (2012), walking has substantially contributed to achieve recommended levels of physical activity among all its different arenas. Concurrent to this, Banister (2008) and Sallis et al. (2004) have evidently highlighted that walking has come in forefront of the urban and transport planning discussions under

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the purview of social and environmental sustainability. In terms of energy consumption, walking and cycling being subsets of active transportation modes are most efficient in nature and tend to be emission-free (Duffy & Crawford, 2013). According to Curtis & Scheurer (2010) and Hanson (2010), walking is upheld as being the most democratic form of mobility due to its universal accessibility; in essence regardless of gender, age, ethnicity, and socioeconomic status, everyone can avail its benefits. On the similar lines, El-Geneidy & Levinson (2011) and Marquet & Miralles-Guasch (2014) exemplify that social inequalities caused by the unequal access to other transportation options can be reduced in an urban diorama favorable to pedestrian activities.

Although a substantial amount of literature elucidating importance of walkability in different scenarios has been found, yet there exist dearth of evidences centric to pedestrian inequity as a function to the quality of infrastructure. Arellana et al. (2021) put forth a case of Barranquilla and Soledad, Columbia, where it is found that the quality of infrastructure is a major hindrance to the pedestrian trips creating inequity. Also, Lee et al. (2017) have underlined the pivotal role of active transportation in bridging the inequity gap prevalent in a contemporary society. The study through a trans-disciplinary technique attempts to paint a clear picture of the pedestrian inequity in the Suburbs of the city of Bhopal, India. It exemplifies the trial of amalgamating traditional techniques like traffic volume count (TVC) surveys and reconnaissance surveys with more technologically advanced apparatus of space syntax to understand the logic behind current situation of a spatial region, a suburban neighborhood in this context. Simultaneously, the study also opens a new arena of research furthering into transportation equity in rural context keeping active mobility in the forefront of the planning discussions.

2. Literature Review

Walking is a prominent mode of transport not only in India but also across the world. It improves accessibility of a neighborhood as the dependence of commuter for commute is on no one, and it offers end-to-end connectivity. A pedestrian-oriented neighborhood is considered to offer high degree quality of life as walkability has been regarded as an essential component of the quality of life (Baobeid et al., 2021; Jaśkiewicz & Besta, 2014).

2.1. Environmental impacts of walking

One of the main environmental effects of walking over owning a private vehicle is the reduction in carbon emissions. The transportation sector is a major contributor to greenhouse gas emissions, and the use of personal vehicles is a significant contributor to this. According to the Environmental Protection Agency, the average passenger vehicle emits around 4.6 metric tons of carbon dioxide per year. By walking or using alternative modes of transportation such as public transit or biking, individuals can significantly reduce their carbon footprint. Walking has an advantage over driving in terms of the environment since less air pollution is produced. Particulate matter, nitrogen oxides, and hydrocarbons are just a few of the pollutants that are released by motor vehicles and can have a negative impact on human health and the quality of the air (Sukarno et al., 2016). But walking is far cleaner than other modes of transportation since it produces no pollution. Reduced land requirements for transportation infrastructure can also be achieved by walking. Roadways and parking lots are needed for private automobiles, both of which can occupy significant amounts of territory (Adbelhamid et al., 2018). People may lessen demand for these resources and help maintain green space by opting to walk.

The quantity of energy required for transportation can be decreased by walking. Fossil fuels are produced and used for transportation, which harms the environment and contributes significantly to climate change (Sukarno et al., 2016). People may lessen their need for fossil fuels and their energy usage by walking or using other forms of transportation. It has been demonstrated that walking has advantageous effects on one's health in addition to the environmental advantages (Pedestrian and Bicycle Information Centre, 2010). The Centers for Disease Control and Prevention claim that regular exercise, such as walking, can help lower the chance of developing chronic conditions including heart disease, diabetes, and obesity. By opting to walk instead of driving, people may advance their personal health and wellbeing while also doing their part for the environment (Olafsdottir et al., 2020). Walking is also a much more sustainable form of transportation compared to private vehicles. The production of cars requires a significant number of resources, including raw materials and energy, and their disposal can also have negative environmental impacts. By choosing to walk instead of drive, individuals can reduce their impact on the environment and support sustainable practices. The decrease in noise pollution is another advantage of walking for the environment. Private automobiles may produce a lot of noise, which can be annoying and be harmful to people's health (Jacyna et al., 2017). Walking is a more ecologically friendly and sustainable mode of transportation since it is significantly quieter than other modes of transportation. Walking has individual environmental advantages, but it may also assist alleviate traffic congestion and increase the overall effectiveness of transportation systems if alternate modes of transportation are widely adopted (Abdulkareem et al., 2020). People may help reduce the number of automobiles on the road, improve the efficiency of transportation, and lessen their overall impact on the environment by opting to walk or utilize alternate forms of transportation. Finally, walking can contribute to the development of more livable and pedestrian-friendly neighborhoods. People may encourage the growth of walkable neighborhoods and communities that put a priority on pedestrian comfort and safety by deciding to walk rather than drive (Kelly et al., 2020). This might contribute to the development of more ecologically conscious, sustainable communities that are better for both people and the environment.

2.2. Pedestrian in regional context

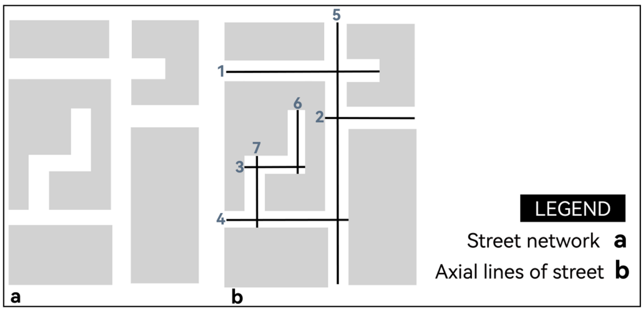
India is emerging as one of the fastest-growing countries in the world, which has led to rapid urbanization and in turn has resulted in the formation of suburban areas in the periphery of almost all the metropolitan cities of the country. These suburbs depend upon metropolitan cities for their needs and have different associated requirements of transportation. The accessibility of services outside the suburb neighborhood, or across wider areas of the metropolis, can be referred to as regional accessibility. Since, accessing regional destinations by public transport may provide more opportunity for walking than using a car (Barr et al., 2019), therefore pedestrians become a critical component for augmenting intra- or inter-neighborhood accessibility. Access to jobs and urban facilities is also dependent upon pedestrian infrastructure as walking is usually the fastest and most convenient mode for short-distance trips, to access local facilities (Anciaes, 2011). It can also be said that everyone is a pedestrian at some point of time in the day, as most trips begin and end with walking. The very recent pandemic has also shown that walkability is more important than ever. With lockdowns and restrictions on movement of personal and public modes of transport like trains, interstate buses, and taxi in all the cities to control the impact of pandemic, the workers of India set out on foot for villages hundreds of miles away (Subbarao & Kadali, 2022). India is a land of festivals because of its different religions and cultures, where walking has been observed as the main mode of transport, taking an instance from Kumbh Mela, a mass religious gathering in India held in year 2019 over a 240.01 million pilgrims walked miles to attend this event, which is considered as the world's largest gathering (Verma et al., 2018). The same study case area has incorporated space syntax as a tool to understand the effects of visual accessibility on walking behavior of pilgrims (Karthika et al., 2022). Reviewed literature stated that pedestrians are of vital importance for a region and yet they face many obstacles to their safe, easy, and convenient environment. This inconvenience is because of poorly maintained and unplanned pedestrian infrastructure in the suburban region of Indian cities.

2.3. Space syntax as a measure of walkability

Walkability refers to how pedestrian-friendly is an area to walking. According to Southworth (2005), a place is termed to be walkable when "the built environment supports and encourages walking by providing for pedestrian comfort and connecting people with varied destinations within a reasonable amount of time." Lo (2009) stated that walkability can be linked to the quality of the built environment, connectivity, safety, and desirability to walk. Therefore, to ensure walkability, it is necessary to measure the relation of built environment with pedestrian movement (Guo & Chen, 2007; Sallis et al., 2004).

Space Syntax is a concept developed by the Hillier and Hanson (1988) for understanding the impact of built form on people's movement. Certainly, the travel behavior and the route choice of pedestrians are instinctive in nature, specifically choosing direct/straight routes in a system. Some evidence from Hill (1982) has highlighted that cumulative fewest turns cognitively impact the assessment of distance made by human mind. Hillier & Iida, (2005), Lerman et al. (2014), and Penn et al. (1998) have shown strong associations of pedestrian movement with integration, choice, and other space syntax measures. Measurement of distance is typically the topological relation of streets through intersection (Longley & Batty, 2003), where pedestrian choice is mostly the shortest paths between two points (Seneviratne & Morrall, 1985). Jansen-Osmann & Wiedenbauer (2004) and Turner (2009) show a highly positive correlation between perceived distance and directional change, effectively substantiating the fact that route with the least directional changes is apparently the shortest route. In the similar lines, angularity affects the route choice decisions for pedestrians in normal conditions (Hillier & Hanson, 1988; Penn et al., 1998). This concept is fundamentally concerned with the street network but is also a function to the urban morphology (Koohsari et al., 2016b). It shows how accessible is the street segment among all the streets based on its topological form, i.e., how axial lines are connected. Axial lines are the lines of sight in the middle of the street as shown in Figure 1. These axial lines act themselves as a node, so that each line was considered connected with the other lines that it intersects. These intersections point shows how well integrated each line is with respect to others, i.e., the connectivity of street with other streets (Turner, 2004).

Figure 1
Axial lines in street network of sample neighborhood
Source: (Koohsari et al., 2016b)



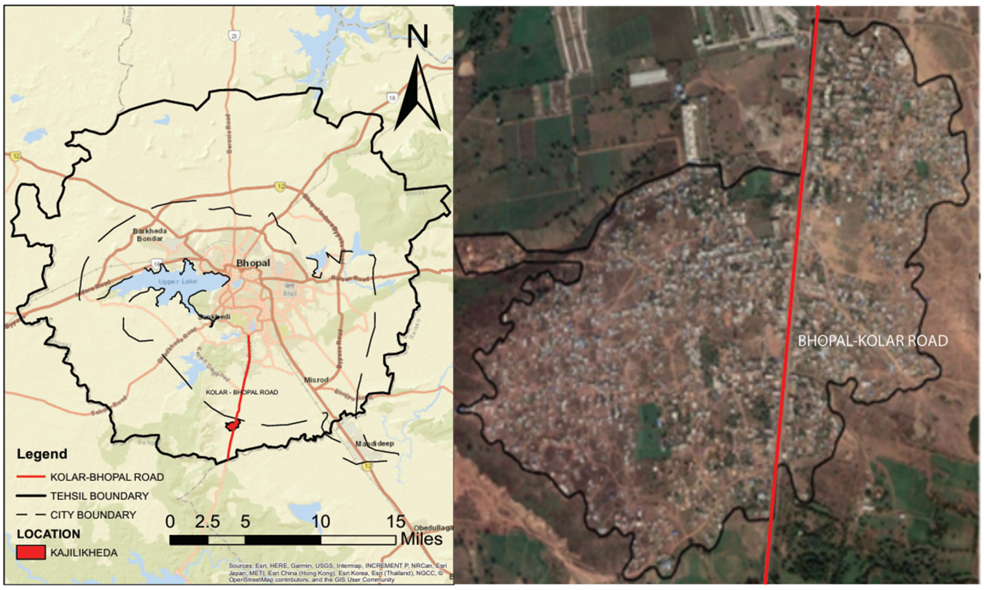
Integration is a key measure of space syntax and indicates how topologically "close" a street segment is to the other segments within the network. In accordance with the definition laid by Chen et al. (2015) and Lerman et al. (2014), integration is the mean directional change observed to reach a link from all other links in the network, whereas Lamíquiz & López-Domínguez (2015) substantiates the proximity of visual lines to all others in the system. It is the sum of turns required in moving from one segment to another. Less integrated street requires more turns to reach the segments while more integrated street segments required fewer turns (Koohsari et al., 2016a). Some researchers also have shown a positive correlation between pedestrian movement and high integration value, which means the street segment which essentially is a formal aspect of urban form could influence pedestrian movement (Hillier & Iida, 2005; Lerman et al., 2014; Penn et al., 1998).

Therefore, this paper uses the Space Syntax to measure the walkability of the suburban area in India. Measurement of walking conditions would be helpful in evaluating and prioritizing the needs of pedestrians. To trust the outcomes of the WSS, researchers suggested validation should be performed. For the validation, various transportation surveys, pedestrian counts, and visual surveys are applied.

2.4. Policies and guidelines for pedestrians in India

Urban travel in Indian cities principally happens through walking, cycling, and public transport, including Intermediate Public Transport (IPT) (IIHS, 2015; Kunhikrishnan & Srinivasan, 2018; Tiwari, 2002; Tiwari et al., 2016). However, the Indian urban environment is increasingly being overwhelmed by the automobile (Gopakumar, 2020; Pucher et al., 2004, 2005). With the fascination for capital-intensive rail-based projects, investments in pedestrian, bicycle, and road-based public transport infrastructure continue to be neglected. So, this section of the literature critically evaluates the existent legislation and policies of India regarding roadways from the perspective of the pedestrian. Starting with the Indian Penal Code, 1860 to the Motor Vehicle Act, 1988 (Agrawal, 2017), India has a rich variety of road legislations and policies. Despite the quantum of legislation, the rights of the pedestrian have always remained hazy. This is primarily because most of the legislation caters to motorized road users. The other legislation and policies like Road Regulation 1989, Equal opportunity, Protection of Rights, and Full Participation act 1995 recognize the pedestrian and his interest in a very fragmented and disjointed manner (Rahul et al., 2021). The Jawaharlal Nehru National Urban Renewal Mission (JNNURM),

Figure 2
Study area details



which was started in 2005, empowered cities to undertake large-scale infrastructure projects, especially those related to urban transportation (Ministry of Urban Employment and Poverty Alleviation & Ministry of Urban Development, 2005; PIB, 2016). The preparation of a thorough project report, which was necessary in order to acquire finance for a transportation project, necessitated the incorporation of pedestrians and cyclists into the transportation system (GoI, 2005).

Under the Prime Minister's National Action Plan on Climate Change, the National Mission for Sustainable Habitat in 2008 had established a subcommittee primarily focused on urban transportation (Press Information Bureau, 2021). The subcommittee outlined eight principles for sustainable urban mobility, the first two of which are "walk" and "cycle." When the 12th Five-Year Plan was being developed (2012–2017), a working committee was formed to provide suggestions on urban transportation. The development of dedicated funds to enhance, maintain, and upgrade existing walking and cycling infrastructure was one of the important suggestions made by this committee. Prior to 2006, both metropolitan and national strategies prioritized investment in heavy transportation infrastructure while ignoring the pedestrians and cyclists (GoI, 2014). The Nation Urban Transport Policy (NUTP), 2006, acknowledges that encroachment of footpaths affects pedestrian safety adversely and hence requires strict enforcement of laws 65 coupled with public participation (GoI, 2006). It states that the Central Government would give priority to the construction of cycle tracks and pedestrian paths in all cities under the JNNURM scheme, to enhance safety, and thereby enhance the use of non-motorized modes (HealthBridge, 1992). Moreover, the lack of comprehensive guidelines in the Indian context is revealed most of these provisions are not implemented. The failure in implementation, in turn, makes the provisions ineffective and redundant (Rahul et al., 2021).

3. Methodology

This research paper uses Walkability Space Syntax (WSS) (Garau et al., 2020; Koohsari et al., 2016a; van Nes, 2021; Zaleckis et al., 2022) to put forth an index measuring the walkability of suburb neighborhood of Indian cities. For the WSS measurement, this paper uses the axial street map of the selected area prepared in the AutoCAD®[1]. This street map is analyzed in the DepthmapX[2] software for calculating the street integration value. Then, this street integration value is correlated with the pedestrian choice to validate the results of WSS analysis. The pedestrian choice is the number of times a street is used when calculating the shortest paths between all the street paths. Evidently, according to Volchenkov & Blanchard (2007), the frequency of traveling shortest path via a link to the overall frequency of all shortest paths in an axial map is defined as choice; hence, Karthika et al. (2022) reinforce the fact that the more utilized a path or route is, the more choice it offers to a pedestrian A series of pedestrian counts were performed in a suburb neighborhood collected through TVC. Finally, the volume to capacity (V/C) ratio is calculated for the most preferred street by the pedestrians.

4. Investigation Area

Bhopal, the capital of Madhya Pradesh state in India, is taken as the study area. It is one of the fastest-growing cities in India that the urbanization in Bhopal has intensified from the city center and reached the periphery (Ghosh, 2019). "Kajlikheda" village situated on the outskirts of Bhopal Municipal Corporation is selected for the assessment of walkability as shown in Figure 2. The current population of Kajlikheda village is 4685 according to the 2011 census since the most recent data, i.e., 2021 is not available due to Covid-19. It is connected to the city center through the Kolar-Bhopal Road.

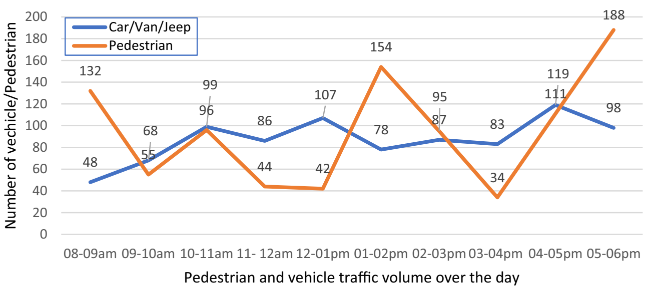
[1]AutoCAD is a commercial computer-aided design and drafting software application.
[2]DepthmapX is open-source and multi-platform spatial analysis software for spatial networks of different scales.

5. Survey Details

5.1. TVC

TVC survey has been conducted on the Kolar–Bhopal Road of Kajlikheda village as shown in Figure 3. The survey has considered the motorized and non-motorized mode of transport used by the neighborhood people in that area. 10% of the total 300 survey responses are taken here. The survey has explained the flow of traffic, mode, and volume of the vehicle on the Kolar–Bhopal.

Figure 3
Pedestrian and car bi-directional traffic flow



5.2. Reconnaissance survey

Reconnaissance survey of the study area was also done as shown in Figure 4 to understand the existing pedestrian facilities. From the figure, it is clear that the connection of the road from Kajlikheda to Bhopal is unpaved and underdeveloped. For the pedestrians, only the sufficient area has provided just next to the road of approximately 3 m at both sides for the footpath with the edges of the road blurred by the dirt and earth.

6. Analysis & Result

The study integrates two paradigms of research methods, namely the more computationally advanced Space Syntax apparatus and the traditional way of collecting traffic data from TVC and reconnaissance survey. Both approaches through their own theoretical backing support the research outcome, which significantly highlights lack of infrastructure. Depthmapx was utilized to understand and incorporate various attributes of space syntax, where only one of its kind software has been essentially developed by The Bartlett School of Architecture, University College London, London (Turner, 2004)

6.1. Walkability space syntax

Walkability Space Syntax, concerned with the topological aspects of the street network, has been used to measure the walkability of Kajlikheda. To calculate WSS, axial map of the street network is prepared as shown in Figure 5. This map represents axial lines of the street as nodes, each line connected to other line that it intersects.

Figure 5
Axial Map of Kajlikheda street network

This axial map is then analyzed in DepthmapX software to calculate how well "integrated" each street axial line was with respect to other lines. An interesting result was noted, which represents the level of integration for all the streets in the study area as shown in Figure 6.

The output depicts integration values in a color-coded scheme which ranges between blue (cold colors) to red (warm colors). Street with the lowest value of integration is depicted in blue and as the value increases the color changes to the warmest red. The integration value of main street (Kolar–Bhopal Road) is evaluated as 1.66162, highest among all street in the red color, i.e., this road requires fewer turns to reach the segment in comparison to others, thus is considered to be more accessible. It is then argued that more integrated street segments attract more pedestrians. To verify

Figure 4
View of Kolar-Bhopal Road in the study area

Figure 6
Level of integration for streets in the study area

this argument, pedestrian of choice or pedestrian count is correlated with the street of higher integration value as shown in Figure 7. The count is the number of times a road stretch is used by the pedestrians because of its shortest paths between all the street paths. For the correlation, pedestrian count is taken from the TVC survey and the value of higher integrated street is taken from integration map.

The correlated value between the street of higher integration and the number of pedestrian counts on it is evaluated as 0.742082. The result positively correlates street integration value with the number of pedestrians found to be walking along the axial line. Thus, it can be said that Kolar-Bhopal Road is the most used street by pedestrians in the study area.

6.2. Existing pedestrian services

This paper further identifies pedestrian Level of Services (LoS) in the Kolar-Bhopal Street. To identify the LoS for the off-street

Table 1
Volume to Capacity (V/C) Ratio

Mode	Capacity	Volume (peak hour)	V/C ratio
Automobile	900	200	0.2222222
Pedestrian	0	188	∞

pedestrian facility, V/C ratio is determined (Sahani, 2013). This ratio helps in relating traffic service quality to given pedestrian flow rate. Maximum volume (peak hour frequency) for the pedestrian is 188 while for the road is 119, identified through the bi-directional traffic volume survey analysis as shown in Table 1. In a similar manner, capacity of pedestrian pathway and road has been taken from Indian Road Congress (IRC) guidelines; according to the IRC guideline (IRC, 1990), the capacity of Kolar–Bhopal Road (two-lane, two-way collector road) should be 900 PCU/Hour/Lane while the capacity for the pedestrians has been derived as 0 (zero) because of the non-existence of pedestrian facilities.

From Table 1, V/C ratio evaluates out 0.223 for road and not defined for the pedestrian path because the pedestrian path does not exist in the location; this renders the pedestrian to travel on the main carriageway.

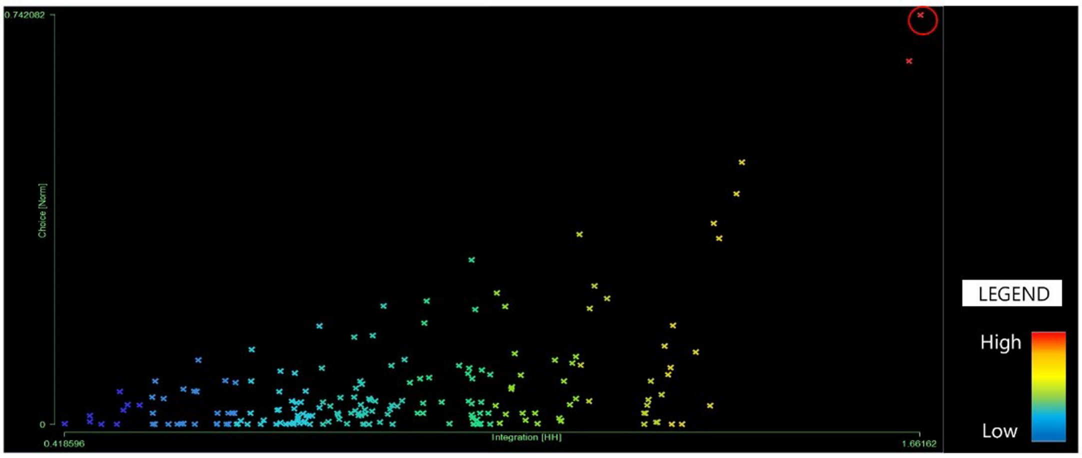
7. Conclusion

This paper highlights that the concept of WSS is very useful in measuring the walkability based on its relationship with the built environment. It helps in measuring connectivity not only for an area but also for a single street segment, i.e., identify the most used street by the pedestrians in the study area.

Based on the WSS analysis, it is found that Kolar–Bhopal Road is the most used street by pedestrians, but the road is made for vehicular movement only. In this street, large numbers of pedestrians walk for their basic need but still there is no footpath. Thus, the absence of a pedestrian pathway along this road makes the journey of pedestrians uncomfortable and leads to inconvenience in assessing jobs, public transport, and basic facilities. It also induces people to use the personal mode of transport.

From the literature study, it is found that there is no central level legislation or policy governing the pedestrian facilities. The NUTP

Figure 7
Correlation between street integration value and pedestrian choice



and a little other legislation have some provisions, but they do not talk exclusively about pedestrians. Our study suggests that the concept of Space Syntax can be used to measure the walkability of the neighborhood based on its relationship with the built environment. It helps in improving the pedestrian infrastructure in the most preferred street, determined by the WSS.

Although with the limitations like scarcity of data, methodological backing, and time and other resources, the study attempts to shade a vivid image of the contemporary scenario of pedestrian equity. The study furthers the direction of research into hitherto established techniques transcending into multiple dimensions which gives the analysis a holistic outlook with a generalizability toward other scenarios. This study also can be directed keeping economic, social, and geographical aspects in mind to align the studies in cognizance to applied geography.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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