Quantifying Street Properties as a Tool to Measure Urbanity: Insights from Velachery, Chennai, India

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Abstract

Improving accessibility is essential in smart city concepts and urban regeneration strategies. Vital urban regions characterize better urban accessibility. Streets are the people habitat's imperative spaces; Streets facilitate the networks for socio-economic activities that comprehend the vitality of any settlement. Improving design, street use mix, and movement intensity enhance accessibility.

This paper presents an analytical tool, a street modelling method. It utilizes the three distinct street properties combining the geometry of street networks, mixed-use index of streets (MXI), and traffic intensity to measure urbanity and understand its accessibility. The street network design influences land use and movement intensity; land use mix and movement intensity are mutually dependent. In the proposed method, Space syntax quantifies the topology of the street network, the diversity of street functions by MXI values, and the traffic movement intensity by the Gate Count method. The methodology of combining the parameters acts as a tool to understand urbanity implying urban accessibility. Velachery, a Neighbourhood of Chennai is subjected to the tool for quantifying the street properties, to understand the urbanity. Its findings revealed higher percentage of lower urbanity and vice versa.

Keywords: Urban Accessibility; Traffic Intensity; Landuse; Street Networks; Urbanity

Introduction

Urban accessibility is considered as the most critical principle in smart city concepts and urban regeneration strategies for development(Hansen, 2009). The ease of people accessing jobs, housing, shopping, and other goods and services in a city is defined as urban accessibility (*Improving Transport Planning for Accessible Cities*, 2020). Understanding the distinct components of urbanity and their relationships in a piece of the urban fabric and exploring ways to improve it to achieve holistic development ensures urban accessibility. Vital urbanity is essential to achieve by means of a high-density built environment accommodating a greater populace, a higher rate of diverse functions, and street activities facilitating transactions (Montgomery, 1998).

In order to achieve vital urbanity, as the first step, urbanity needs to be measured. In this context, the aim of this paper is to comprehend the street properties in terms of the topology of the street network, mixed-use function, and traffic intensity to measure urbanity and determine accessibility.

Its objectives are as follows.

1. Identify tools to quantify the street properties in terms efficiency of its network, mixed use index and traffic intensity.
2. Evaluating the properties of streets in terms of range from high to low.
3. Comprehensive assessment to measure urbanity of the neighbourhood by combining the properties.

This methodology of measuring the urbanity of the place shall be adopted by architects, urban designers, and planners at neighbourhood level to city level, based on the results the necessary interventions shall be planned to achieve vital urbanity.

Theoretical Basis

Urbanity

"Urbanity" refers to the quality or characteristics of urban areas, particularly cities or densely populated areas. It encompasses aspects such as the social, cultural, economic, and environmental aspects of urban life. Vital urbanity is the essential and critical aspects or characteristics that contribute to the health, vibrancy, and wellbeing of urban areas. It comprehends elements like efficient transportation systems, green spaces, access to amenities and services, vibrant social and cultural scenes, sustainable infrastructure, and a strong sense of community.

Street Properties

In this paper, the street properties are the functional characters of the streets in terms topology of its network, mixed use index and traffic intensity. The topology of street networks refers to the configuration of streets and roads in a urban area. It describes the spatial layout and connectivity of streets, intersections, and pathways that form the transportation infrastructure of the city. A mixed-use index is a measure that evaluates how well a street or street network contributes to promoting mixed land uses and creating a vibrant, multi-functional urban environment. This index considers factors such as the presence of diverse commercial establishments, access to public amenities, the density and mix of residential and commercial properties along the street, the ease of pedestrian movement. The traffic intensity of an urban street refers to the volume or flow of vehicles, pedestrians, or cyclists that pass through the street over a specific period, usually measured in terms of vehicles/pedestrians/cyclists per hour. It is a key metric used in transportation planning to assess the usage and capacity of urban streets and to determine potential congestion or safety issues.

Accessibility and Mobility

Ability of urban centers to operate their spaces efficiently depends on the design of the network of their streets. According to Yang, Yang and Tang (2012), street traffic is a form of spatial support system that directs land growth and extension in metropolitan areas. Street networks that facilitate mobility improve accessibility by faster reachability. By achieving a higher level of a functional mix of building typologies in the street, it is also possible to achieve greater accessibility with minimal mobility. Although accessibility and mobility are two distinct ideas, they are intertwined. Mobility is a measure of the vehicle involved in travel miles or person-miles, whereas accessibility is defined as the ability to connect activities. Lower accessibility leads to higher levels of mobility (Alba, 2003). For example, a neighborhood with all basic amenities within a shorter distance requires less mobility; the neighborhood is easily accessible. Accessibility is less dependent on mobility in this case. Suppose a neighborhood is mono-functional and the basic facilities are far from the region. In that case, the region relies on vehicle miles travelled to access the basic needs; accessibility is highly dependent on mobility (Susan and Handy, 2002).

Elements of Urban Morphology

Urban environment refers to the construction of masses, spaces, and patterns of connectivity between them in a heavily populated area. These patterns depend on several factors, including land use, density, and activities, which are the sources of movement and the creation of spatial organization for people use (Mahdi and Ibrahim, 2023). The morphological elements of urban structure, such as built environment density, built environment diversity, and street network design, influence accessibility related to travel demand (Cervero and Kockelman, 1997). The intensity of urban centers shall be measured by the characteristics of mixed land use, built environment density, and traffic support (Yang, Yang and Tang, 2012). Accessible urban Settlements characterize a high-density compact built environment with high mixed-use entities influenced by a topology of street networks that function as vital urbanity (Ye, 2014), and accessibility influences the land use pattern (Street and Hansen, 1976). Land use mix is influenced by built density and street network efficiency; a higher built environment density leads to a greater functional mix, which improves accessibility by providing a greater number of destinations within a shorter distance (Duranton and Guerra, 2016).

Diversity of local urban amenities influences pedestrian and vehicular mobility at the local level (Graells-Garrido *et al.*, 2021). In a broader context, traffic accessibility is a component that influences urbanization's development and plays a vibrant role in redefining land use (Liu *et al.*, 2019). The quality of accessibility dictates the development of multifunctional land use, which then influences the spatial distribution of activities (Straatemeier and Bertolini, 2020). Space syntax research has contributed to the theory of natural movement, concluding that the topology of street networks influences the movement and location of economic activities (Hillier *et al.*, 1993).

Topology of a street network and its efficiency in terms of integration values are considered significant factors in determining accessibility. Streets possessing a higher value of integration are considered highly efficient streets influencing mixed-use entities and have a higher potential for traffic movement.

Street network efficiency is a quantitative attribute measurable using integration values generated by using space syntax as a tool. Design of street networks inadvertently or directly influences growth and development. Evaluation of street network efficiency in terms of integration values by space syntax has been frequently employed in urban design and planning projects. As evaluated by integration values, the effectiveness of street networks is critical to urban spatial transformation.

Higher movement and a higher level of a functional mix of streets are influenced by higher integration values, just as higher built density influences a higher rate of the functional mix. The streets where people move frequently imply higher accessible streets of the overall street network and the connectivity of busy streets that creates diverse land-use types leading to a greater degree of mixed-use functions (Huang and Hsieh, 2014). A literature review reveals the interrelationships between the street network topology and its influences on movement intensity and mixed-use functions at the street level. It also reveals how mixed-use functions and movement intensity are mutually correlated.

Street design, which evolves organically or decided by a planning authority, exists for a long time. The building may also exist for a long time, but the function of a building changes frequently based on external factors. As already discussed, the street network topology is the prime factor deciding the mixed-use function and movement intensity.

Urban structure of a city is typically subject to transformation as a result of development processes by a variety of factors. They include continuous interactions between the physical parts and aspects of life that occur as a result of social, cultural, economic, technological, and ecological influences, as well as the response of contemporary urban developments (Abdullah and Basee, 2023).To assess the potentiality of streets and to transform them into vibrant streets or urbanity in the future, it is essential to understand the condition of their interrelationships by quantifying them at the neighborhood level.

Quantifying Tools for Measuring the Elements of Urban Morphology

Space syntax quantifies the property of streets in terms of integration value, and street traffic intensity is quantified by the gate count method in terms of measuring the traffic volume. MXI values quantifies the Mixed-use index of streets by categorizing them into multifunctional, bifunctional, and mono functional entities a practical methodology for identifying the properties of streets to understand the urban structure. The topology of the street network is a fixed parameter, measured as integration values considered an independent variable; the properties of the street are classified into high, medium, and low values of integration. Likewise, identifying and hierarchical classification of the traffic intensity and mixed-use index of the respective streets and comparing the values of all the three properties comprehend the urban structure.

Space Syntax

Space syntax is a phenomenon that uses integration values to determine the effectiveness of a street network, with integration value directly tied to accessibility. The most vibrant functional component is the topology of the street network, which is quantified in terms of integration values. It is built based on graph theory, with the alignment and network layout of the street as the only parameter. Many urban regeneration projects have used space syntax (Enström and Netzell, 2008). The depth map algorithm is used to generate the street network integration values.

Integration, also called accessibility (Szczepańska, 2011), is a syntactic measure that denotes how other streets relate to a street in its surroundings. A variable leads to understanding the relationships between people and the urban space (Dettlaff, 2014). It shall predict the potential of transactions in a space; the street network has a higher integration value, making it the most active functional area.

Integration is presumed to reflect the frequency of social interactions and retail activities, typically serving as a gauge of the anticipated number of people present in a specific area(Hillier, 1997). The more axial lines intersect, and the longer they are, the more they integrate.

In other words, the most integrated street segments require the fewest turns to reach all other segments in the system. The prediction of movement capacity shall be the integration measure. Integration value is a crucial space syntax metric that depicts a street segment's topological accessibility to all other street segments within a specific area. " Axial global integration refers to the integration values along axial lines at an infinite radius, which can be employed to illustrate the integration pattern at the largest scale possible.(Hillier, 1997). Axial local integration is characterized by the integration values along axial lines at a radius of 3 (comprising the root plus two topological steps from the root). This information can be harnessed to depict a focused, localized integration pattern.(Hillier, 1997).

Mixed Use Index

Quantification of land use by the mixed-use index (van den Hoek, 2009) expresses the degree of a functional mix of building types. MXI is calculated as the ratio of the development's total floor area against each building typology's total floor area. For example, if the area is a single function (residential), it is termed mono-functional. The functional distribution of two types at a ratio of 50:50% is termed bi-functional. Various typologies in an equally distributed configuration shall be termed multi-functional. Likewise, the streets shall also be categorized as mono-functional if the entire street possesses a single function such as amenities, housing, and working, bifunctional, in case of distribution of any combination of two varied functions in a single street, and multifunctional based on multiple destinations comprising amenities + working + housing in a single street.

Traffic Intensity

The Gate Count method is adopted to quantify the traffic volume or the movement intensity of streets. It measures the average traffic volume of streets for a specific duration at a specific location at equal time intervals. Multiple locations are to be chosen to conduct the survey. The survey shall be carried out by counting the number of pedestrians and vehicles crossing the imaginary line fixed by the observer (Othman, Yusoff and Salleh, 2020) and the average traffic volume of the particular street shall be obtained. The streets are categorized into high, medium, and low based on the values with a range of 3 equal divisions between maximum and minimum concerning traffic intensity.

Research Methodology

According to Ye (2014), the present methodology of "combining space syntax, space matrix and mixed-use index in a GIS framework" to quantify the urbanity of a place) is unreliable. Indeed, the quantification of the density of the built environment by space matrix have some inconsistency as the density is defined by massing and not by the population. Hence, a methodology is proposed that replaces the space matrix tool by Gate Count Method to measure traffic intensity, and to measure urbanity accurately by combining other parameters. Instead of combining the properties on the GIS platform, here, the values are transferred over the streets to understand the properties to conclude with the realistic data. Hence, the following tools are identified to measure the properties of the streets. They are: space syntax to quantify the street network design in term of integration values, mixed use index value of streets by analysing the mixed-use functional entities of the streets, measuring the traffic intensity by Gate Count method. It is argued that combining these tools and applying it on the street levels to understand their properties acts as a quantitative approach to measure the vitality of the streets leading to vital urbanity implying accessibility. The street character system combines and analyses three constituent parts of urban form in a street modeling method. A spatial classification system is used to expose the structure of various aspects of the metropolitan region in terms of street use mix, traffic intensity, and network efficiency. Combining street network integration, built mass density, and the degree of a functional mix of an urban area in a single framework reveals performance in terms of urbanity (van Nes and Ye, 2014); likewise, the quantification of street properties such as the design of the street network with its traffic intensity and functional mix aspects reveals the urbanity of the region.

Study Area - An overview

Chennai, a Southern part of India (South Asia), a coastal city that grew faster due to arbitrary development over a short period, faces several urban issues typical in many cities worldwide. The population of the Chennai Metropolitan Area (CMA) is expected to reach 12.6 million in 2026, resulting in 17.3 million daily vehicle journeys. According to the vehicle growth pattern, two-wheelers have grown from 0.4 million in 1991 to 2.16 lakhs today. With the current road conditions, the rapid development of vehicles has resulted in an average travel speed of 10 km in the central business district areas and 18 km in the rest. Travel demand has increased to 13 million trips from 7.45 million, showing a drastic increase in levels of motorization. Average automobiles per home have climbed from 0.25 to 1.26, suggesting a drastic increase in levels of motorization. The average number of automobiles per home has risen from 0.25 to 1.26, indicating a significant increase in motorization. The average traveling distance has increased to 9.6 kilometers from 7.8 kilometers. The statements described above conclude that Chennai's accessibility greatly depends on mobility (CMDA, 2010).

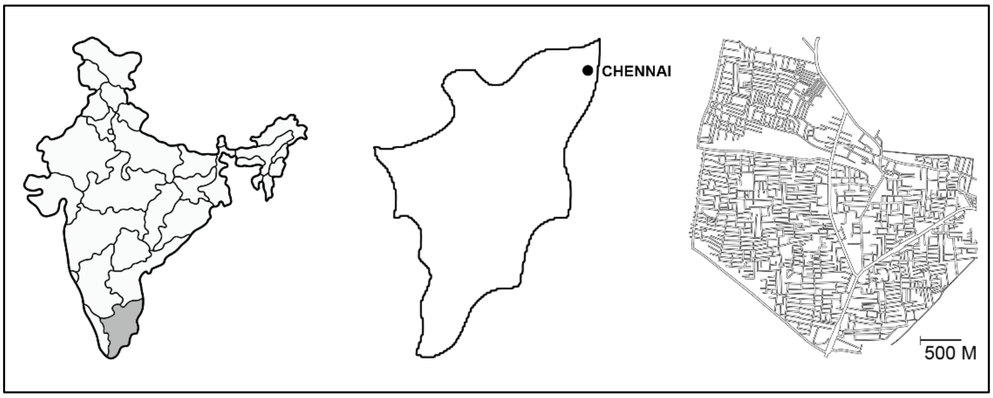

Fig. 1: Location map of Velachery

Velachery

One of the residential neighborhoods of the southern part of Chennai, Tamil Nadu, India is analyzed to understand urban accessibility by measuring the properties of streets by the topology of street networks, traffic volume, and mixed-use index. The study area is designated as a mix of residential, commercial, and institutional zones as per the Chennai Second Master Plan proposed for the year 2026. The rapid development comprises IT. parks, offices, subsidiaries, and residential facilities developed in a shorter period. The developmental patterns reveal no hierarchy in the street network organization, rapid development of multi-storied buildings, increased land values, and traffic congestion.

Findings

Case Study: Space Syntax Analysis - Integration Values

This study employed Space Syntax method to examine the case study: Velachery. Space Syntax method involves specific notions such as ‘Depthmapx’, and ‘integration values’. The street network map is subjected to the Depthmap program to simulate the integration values by Axial Map analysis; The integration values are generated according to the metric, topological, and Geometric Distance and connectivity. Axial integration analysis is performed to generate the integration values, where the entire street network is converted as a graph. Longest linear streets with a higher number of street connections with minor angular change paths and shortest street paths are considered higher integrated streets, which shall be considered potential streets with a vital urban feature. The simulated results are shown in the Table below, consisting of minimum and maximum integration values and categorizing them into high, medium, and low values. Figure 2 and Table 1 show the result of the program, and the properties are transferred to the map (Fig. 3) to suitably compare with the density value and the mixed-use index value of Streets.

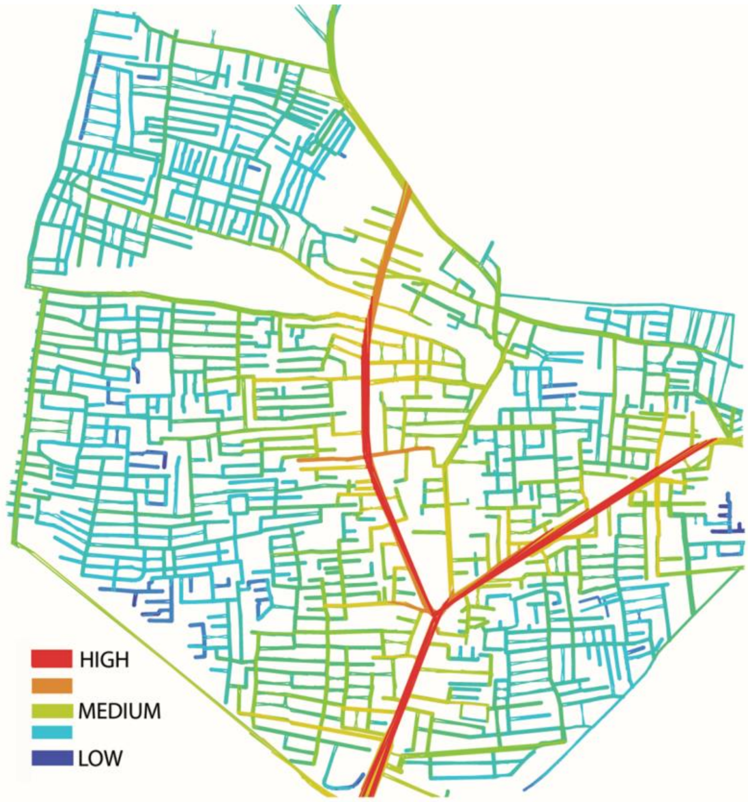

Fig. 2: Axial Map Analysis- Integration (Depth Map) of Velachery
Source: Author

Table 1: Categorized Integration Values (Depth map) of Velachery
Source: author

Description	Integration Value	Category
Average	1.1	
Minimum	0.67	
Maximum	1.88	
Standard Deviation	0.2	
Low	0.67 -0.78	Low values (1)
	0.79 -0.90	
	0.91- 1.02	
	1.03-1.14	Medium Values (2)
	1.15-1.26	
	1.27-1.38	
	1.39-1.50	
	1.51-1.62	High Values (3)
	1.63-1.74	
High	1.75-1.88	

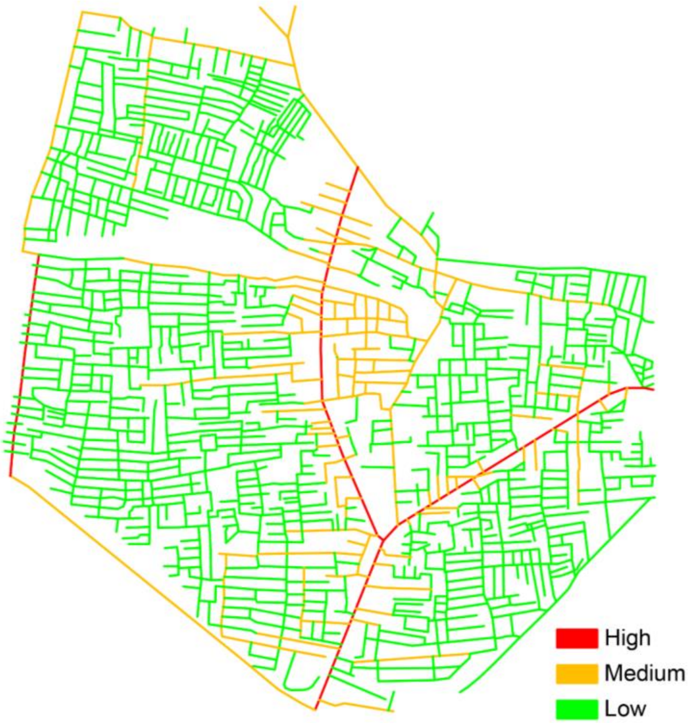

Fig. 3: Integration Value Map based on Categorisation in Velachery
Source: author

Mixed-Use Index of Streets

Streets in terms of mixed-use are classified based on the mix of existing establishments, and the purpose of travel. Streets providing access to multiple types of activities such as amenities, work, and housing are categorized as multi-functional. If a street is meant only to connect the houses or has only housing establishments, it shall be categorized as a mono-functional street. Streets providing access to any of the two types of housing, amenities, and work shall be categorized as bi-functional streets, as people find their destinations by accessing the basic errands within the streets.

In this research, the street network of the neighborhood of Velachery is carefully surveyed and categorized into monofunctional, bifunctional, and multifunctional streets based on their mixed-use functional structure. The neighborhood is surveyed to map the street establishments, and a land use plan (Fig. 4) is prepared to identify the mixed-use property of the streets. Finally, based on the land use map, the streets are further classified. (Fig. 5)

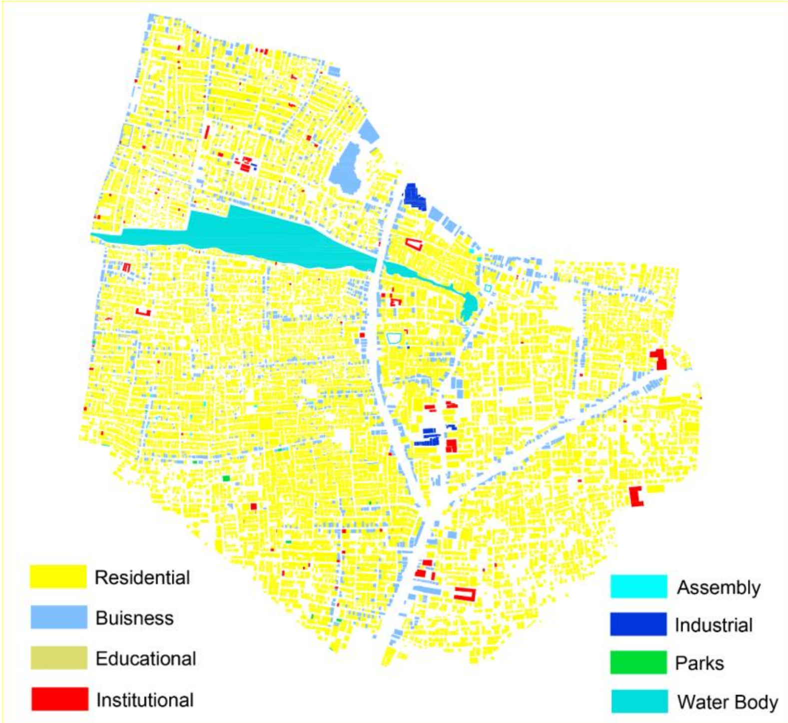

Fig.4*:* Land use map of 2022 - Velachery
Source: Author

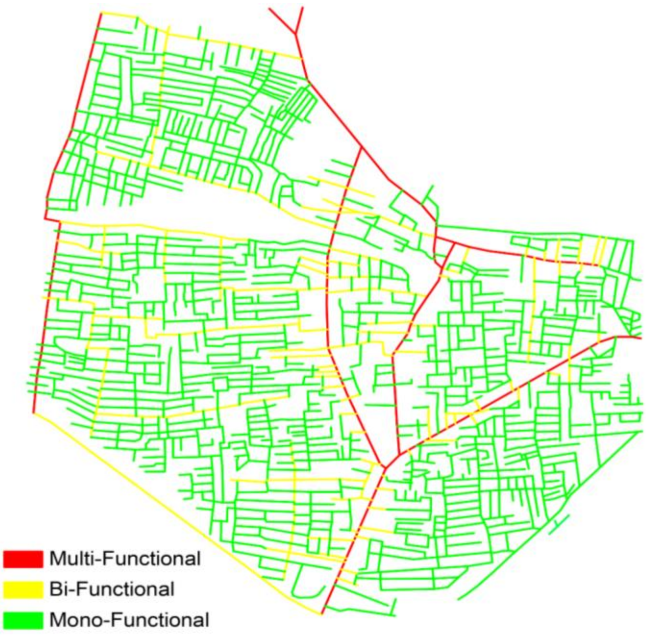

Fig 5: Streets classified based on the land use map 2022 - Velachery
Source: Author

Gate Count Method

The gate count method is employed to measure the traffic intensity of the street. The vehicular and pedestrian movements are carefully surveyed at regular intervals: typical traffic conditions are observed for a week in the month of March 2022, and the streets are categorized into high, medium, and low-intensity traffic. The gate count survey has been carried out on all the streets on weekdays and weekends four times a day for 15 min each in the morning, afternoon, evening, and night. Both pedestrian and vehicular movements were considered.

The arterial road (Velachery main road) produced the maximum average volume of 1243 counts, and the local street Dandeeswaram or the 7th main road produced the minimum value of 14 gate counts. The difference between the minimum and the maximum values is equally divided into three divisions. The gate counts of streets ranging between 1243- 832 fall in the first category as high intensity, 833-422 as medium intensity, and 423-14 are categorized as low intensity (Table 2). All the streets are mapped according to the number of gate counts and categorized into high, medium, and low intensity. (Fig. 6)

Table 2: Traffic Intensity Reference Values by Gate Counts - Velachery
Source: Author

S. No.	Gate Count Average Range (15 Minutes)	Traffic Intensity	Color Code
1	1243- 832	High	
2	833 - 422	Medium	
3	423-14	Low	

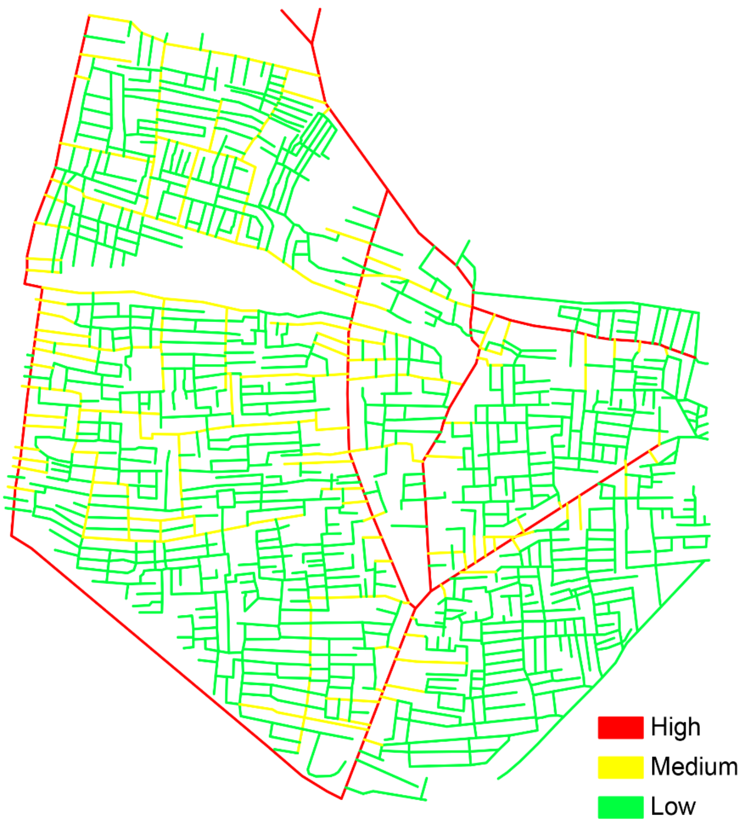

Fig 6*:* The streets classified based on traffic Intensity - Velachery
Source: Author

Evaluating urbanity based on three properties of street requires a comprehensive assessment to understand the overall urban environment. To evaluate urbanity, the individual values of street network efficiency, mixed use value, and traffic intensity are combined to generate an overall inference or urbanity score. The process may involve assigning weights to each property based on their relative importance in contributing to urbanity. The specific weights can vary depending on the context, the goals of the evaluation, and the preferences of decision-makers.

The property of all 717 streets of the neighbourhood is analyzed by categorizing them in terms of integration value, traffic intensity value, street use mix value, and inferred with urbanity. The inference with urbanity is concluded by comparing the values of three elements of urban morphology. Higher values of street network integration with higher mixed-use and greater traffic intensity imply higher urbanity and vice versa, and the other permutations and combinations of three properties with inference to the urbanity are listed below. (Table 3)

Table 3: Combinational property values inferring urbanity
Source: author

Street	Integration value	MIxed use value	Traffic intensity value	Level of urbanity
1	1 (Low)	(1) Low	1 (Low)	Low
2	1(Low)	1(Low)	2(Medium)	Low
3	2 (Medium)	2(Medium)	2(Medium)	Medium
4	1(Low)	1(Low)	3(High)	Medium
5	2 (Medium)	1(Low)	2 (Medium)	Medium
6	1(Low)	2(Medium)	3(High)	Medium
7	3(High)	3(High)	1(Low)	Medium
8	2(Medium)	2(Medium)	3(High)	Medium
9	3(High)	3(High)	3(High)	High
10	3 (High)	3(High)	2(Medium)	High

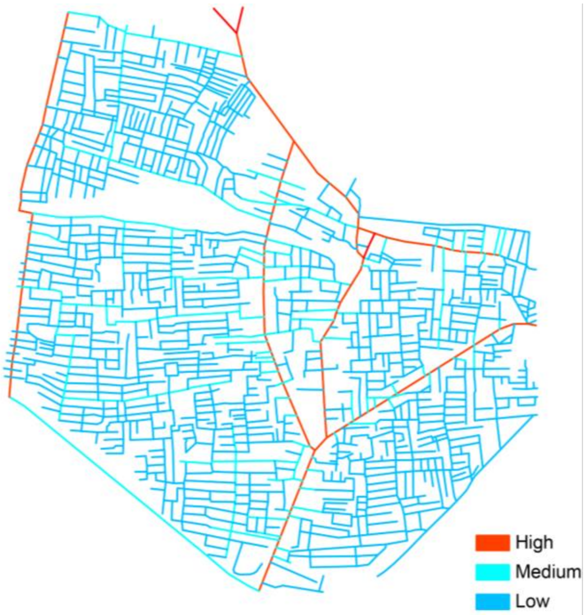

Fig 7*:* Urbanity values of streets in Velachery
Source: Author

The study area is quantified in terms of urbanity (Fig. 7); of the overall street network, 6.7 percent of the length of streets possess the property of high values in terms of integration value, traffic intensity, and mixed-use functions resulting in higher urbanity. This implies a greater socio-economic performing active streets and contribute to greater accessibility in terms of minimal mobility and walkability by the ease of reaching destinations; 14.8 percent of the length of the streets possess medium urbanity values, where a combination of vehicular dependency and restricted walkability in connecting the destinations and 78.5 percentage of lower accessibility by the higher rate of dependency over mobility.

The resulting overall urbanity score provides a holistic assessment of the urban environment, considering the three key properties of streets. A higher overall urbanity score would indicate a more vibrant, accessible, and well-connected urban area with a mix of activities, contributing to a higher quality of life for residents and visitors.

Conclusions

The quantitative analysis and results of the study area based on the methodology of identifying the street properties by space syntax, traffic intensity, and mixed-use index reveal that the study area characterizes a higher percentage of lower urbanity and a lower percentage of higher urbanity. The efficiency of a network configuration of a street is determined by its integration value; it dictates the ease of access. Land parcels adjacent to the streets with higher integration values have more potential for economic activities, whereas low-integrated streets possess low economic performance. It is possible to conclude that integrated streets characterize higher traffic intensity, whereas segregated streets the lower traffic.

The findings show multi-functional streets with a mix of commercial entities. Workplaces and amenities are located in adjacent streets with high integration values, whereas mono-functional residential entities are located in segregated spaces with vehicle-dependent accessibility. The analysis reveals a positive association between integrated spaces and the mixed-use index of streets; mono-functional non-housing type activities are found in medium-integrated streets. The relationship between the functional mix of streets and the traffic intensity of the study area results in positive relationships. This states that mono-functional streets possess less traffic intensity, where accessibility depends on mobility to meet daily errands, resulting in excessive no trips and vehicles. Traffic intensity value and the integrated value of streets are positively correlated. The results show that the developed residential neighborhood (study area- Velachery) follows the theory of economic processes, as integration values, mixed-use index, and traffic intensity are positively related.

Urbanity of the built environment is dependent on and adjusts based on street network patterns, according to the theory of natural urban transformation processes. A positive correlation between the variables insists on accessibility and more effortless mobility, whereas the negative constrains it. Accessibility can be improved by combining well-integrated street networks, a high degree of mixed land use, and higher traffic intensity, as all are interdependent. Necessary interventions are required to augment the street network to increase integration values and achieve a mixed-use of streets and traffic intensity, facilitating accessibility and mobility.

Housing areas that are both the origin and destination of trips are given the least attention in planning because they tend to develop in segregated zones and function as mono-functional areas in the form of decreased density, with low integration street values, causing lower urbanity. Housing regions outside the integrated system are more likely to rely on private transport, and mono-functional entities result in many journeys since destinations are far from their premises. As a result, effective street network planning, which influences appropriate density and a higher degree of the functional mix, is required to achieve vital urbanity. With the analysis, it can be concluded that the neighborhood- Velachery possesses a higher percentage of lower urbanity where accessibility depends on mobility. Identifying the streets' properties act as a tool to measure urbanity shall be applied to various city neighborhoods, and necessary policy decisions shall be implemented by enhancing urbanity at a greater level. One of the policy decisions shall be that even the local streets are to be equally distributed with mixed use functions as it makes it easy to reach the destinations enhancing accessibility. Current urban development practices are concentrated on widening the existing higher traffic intensity streets, where after widening, it invites more traffic, leading to a never-ending solution. Hence, concentrating on multiple local streets by introducing street connectivity and mixed-use functions shall solve the necessity of accessibility by lesser vehicle miles traveled and ease of access to pedestrians for daily errands enhancing accessibility. In summary, evaluating urbanity by combining the individual properties of streets provides a comprehensive approach to understand the overall urban environment's strengths and weaknesses. By considering the interactions between street network efficiency, mixed use value, and traffic intensity, urban planners can make informed decisions to shape cities into more vibrant and thriving spaces for their inhabitants.

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