Integrating Urban Space and Human Activity: A Study on Spatial Function Mixture in the Era of Information Technology

Ganesh kanadaje[1], Sabyasachi Mohapatra[2], Gauri Patil[3], Sanmesh Satpute[4]
[1, 2, 3, 4]Department of IT
[1, 2, 3, 4,]Sinhgad Institute Of Technology, Lonavala, India

Abstract- *Urban space management is a critical factor in sustainable city development, influencing human activities, spatial functionality, and technological integration. This study explores the relationship between urban spatial function mixture and individual activity spaces, emphasizing the impact of information technology on urban flows.Drawing from research on urban area structure mixing and human activity space, this study highlights the importance of urban structure blending in shaping citizen activity patterns and enhancing spatial utilization [1].*

The role of information technology in transforming urban space flows and connectivity further strengthens the analysis of modern urban planning approaches [2].

Additionally, insights into urban spatial function mixture and individual activity spaces contribute to understanding how functional integration in urban spaces affects resident mobility and accessibility [3].

By integrating spatial analysis and technological advancements, this study proposes innovative strategies for optimizing urban environments. The findings contribute to the discourse on smart city planning, fostering a balance between functionality, efficiency, and human-centric urban design.

MOTIVATION - *As cities continue to expand, effective urban space management has become increasingly important for ensuring sustainability, efficiency, and quality of life. Traditional planning methods often struggle to keep pace with rapid urbanization, shifting human activity patterns, and the growing impact of digital technology. The integration of spatial function mixtures with emerging technologies presents new opportunities to enhance urban accessibility, mobility, and social interaction. However, a lack of comprehensive research on how these elements interact limits the development of effective urban strategies. This study aims to bridge this gap by exploring the dynamic relationship between urban spaces, human activity, and technological advancements. By providing innovative insights, this research seeks to contribute to the creation of smarter, more adaptable, and people-centric urban environments that balance growth, sustainability, and functionality*

I. INTRODUCTION

Urban space management plays a crucial role in shaping modern cities, influencing spatial functionality, human mobility, and overall quality of life. As urbanization accelerates, the complexity of managing urban spaces effectively has increased, requiring innovative approaches that go beyond traditional planning methods. A critical aspect of urban management is the integration of spatial function mixtures, which contribute to dynamic and adaptable urban environments. Understanding how these mixed-use spaces impact human activities is essential for fostering accessibility, mobility, and social interaction [1].

Additionally, the transformative role of information technology in redefining urban spaces has gained significant attention, with studies focusing on how digital advancements enable real-time data analysis, smart mobility solutions, and more efficient land use [2]. Research has emphasized the relationship between urban structure and human activity, highlighting how spatial function mixing affects movement patterns and urban flow [3].

II .LITERATURE SURVEY

Aamudalapelli Anjali., et al. (2021) explores the impact of spatial function mixtures on urban space management, highlighting their role in improving accessibility, mobility, and social interactions. The study emphasizes the importance of integrating mixed-use spaces to enhance urban livability and economic activities. [1]

SHEN Lizhen., et al. (2011) examine the influence of information technology on urban flows, discussing how digital advancements such as real-time data analysis and smart mobility solutions contribute to efficient urban planning. Their findings suggest that technology-driven approaches can optimize land use and reduce congestion in growing cities. [2]

LINA LIU. et al. (2020) analyze the relationship between human activity and urban spatial organization. Their study argues that well-planned urban environments should accommodate diverse activity patterns, ensuring a balance between residential, commercial, and recreational spaces. The research highlights the benefits of mixed-function areas in fostering engagement and improving overall quality of life. [3]

III. METHODOLOGY

3.1 Data Acquisition and Preparation

The initial stage of studying urban spatial function and individual activity space involves acquiring and preparing the necessary data. This includes identifying relevant data sources, collecting the data, preprocessing it to ensure quality, and integrating it into a usable format. The quality and nature of the data significantly influence the subsequent analysis and findings.

Data Sources and Collection

The foundation of this research lies in collecting data from various sources that provide insights into urban activities and spatial characteristics. Foursquare check-in data is invaluable as it offers a detailed record of user activities and their location preferences, allowing researchers to understand where people go and what they do in the city . OpenStreetMap (OSM) data is another crucial resource, providing Points of Interest (POI) information that is essential for identifying functional units within the city, such as commercial areas, residential zones, and recreational facilities . Social media check-in data, in general, is beneficial as it can be used to examine how urban residents' activities and urban spaces influence each other, creating a feedback loop that shapes urban dynamics . ArcGIS software can be used to select relevant data points for further analysis, streamlining the data collection process and focusing the research on specific areas or activities of interest

Data Preprocessing and Cleaning

Once the data is collected, it needs to be preprocessed and cleaned to ensure its quality and suitability for analysis. Cleaning and filtering the check-in data to remove irrelevant or incomplete entries are essential steps to avoid skewed results and maintain data integrity . This process involves identifying and correcting errors, handling missing values, and removing duplicate entries. Geographic data is processed to map resident check-in records to specific spatial grids, enabling spatial analysis and the identification of activity hotspots . Dividing the study area into regular grids is essential for spatial analysis, providing a structured framework for examining activity patterns and functional distributions . The size of the grid needs to be set appropriately based on the scale of the study, with common sizes being 200m, 500m, or 1000m; the selection depends on the desired level of granularity and the size of the study area .

Data Integration and Formalization

The next step is to integrate the various data sources and formalize the data into a structured format suitable for quantitative analysis. Integrating POI data with check-in data creates a comprehensive dataset for analysis, combining information on user activities with the characteristics of the places they visit . Formalizing resident check-in points into a structured set facilitates quantitative analysis, allowing researchers to apply statistical methods and computational models to uncover patterns and relationships . The check-in data is formalized into a set of points including latitude, longitude, and position category label, which enables precise spatial mapping and analysis of activity distributions . POI data is integrated as a spatial anchor point for other data types, providing a geographic reference for linking activities to specific locations and understanding their functional context .

3.2 Functional Region Identification

Identifying functional regions within the urban environment is a crucial step in understanding how different areas contribute to the overall urban structure and how residents interact with these areas. This involves classifying activities, calculating activity ratios, and using information entropy to determine the degree of mixed-use in different areas.

Activity Category Classification

To simplify the analysis and derive meaningful insights, it is necessary to classify check-in location functions into broader categories . Detailed functional categories from check-in data are grouped into meaningful classes, such as "Home," "Work," and "Entertainment," which represent the primary activities that residents engage in . Classifying activity functions based on activity purpose helps in understanding urban dynamics, allowing researchers to examine how different activities are distributed across the city and how they contribute to the overall urban function . Careful classification is needed to account for the possibility of misclassification, such as a place marked as "entertainment" being the workplace for a resident; this requires a nuanced understanding of the data and the potential for multiple interpretations .

POI Activity Category Ratio (CR)

Calculating the POI activity category ratio (CR) is essential to identify the functional properties of each spatial unit . The CR is calculated using the number of POIs and the number of s-type activities in a spatial unit, providing a quantitative measure of the prevalence of different activities in each area . Using the POI activity category ratio (CR) helps to identify functional properties of each spatial unit . The function of the POIs determines the spatial units function, linking the physical characteristics of a place to the activities that occur there .

Information Entropy for Mixed-Use Degree

Applying information entropy is vital to evaluate the mixed-use of land functions in each spatial unit . Information entropy can be used to describe the quantity ratio mixed degree of land-use, providing a measure of the diversity and intensity of activities within a given area . Information entropy helps quantify the diversity and intensity of activities within a given area . This method allows for a quantitative analysis of the degree of mixed-use of urban functions, which is essential for understanding the complexity and vibrancy of urban spaces .

3.3 Topic Modeling with LDA

Topic modeling, particularly Latent Dirichlet Allocation (LDA), is a powerful technique for identifying underlying patterns and themes within large datasets. In the context of urban spatial analysis, LDA can be used to uncover mixed land-use patterns and understand the distribution of different activities within a spatial unit.

LDA Model Application

Introducing the Latent Dirichlet Allocation (LDA) topic model is key to identifying mixed land-use patterns . Using the LDA model helps to identify the mixed pattern of the function of the spatial unit . LDA helps in understanding the distribution of different activities within a spatial unit, allowing researchers to uncover the hidden themes and patterns that characterize urban spaces . The LDA model is used to generate a series of mixed land-use patterns, providing a comprehensive overview of the different functional combinations that exist within the city .

Determining Optimal Topic Size

Finding a decent number of potential topics is essential in the LDA model to ensure that the analysis captures the most relevant patterns without overfitting the data . Using perplexity helps to determine the optimal number of topics in the LDA model, providing a quantitative measure of the model's ability to predict the data . Perplexity is a standard performance measure of probabilistic models in machine learning, which can be used to assess the quality and reliability of the LDA model . The general solution is to use perplexity .

Topic Distribution Analysis

Analyzing the topic distribution of each spatial unit is crucial to understanding the mixed land-use patterns and how different activities are combined in various parts of the city . The LDA model is used to obtain the topic distribution of each spatial unit, providing a detailed profile of the functional characteristics of each area . The intensity of residential activities is used as the input of the model, allowing the analysis to focus on the most relevant and impactful activities within the urban environment . The LDA topic model realizes the mixed pattern of identifying the function of the spatial unit and the representation of subject ratio by using the function distribution of each specific spatial unit, providing a comprehensive and nuanced understanding of urban land-use .

3.4 Spatial Similarity Measurement

Measuring the similarity between different spatial units is essential for identifying regions with similar functional characteristics and understanding how activities are distributed across the urban landscape. This involves employing various statistical measures, such as JS divergence, Hellinger distance, and cosine similarity, to quantify the resemblance between different areas.

JS Divergence for Similarity Matrix

Employing Kullback-Leibler divergence (KL divergence) is important to evaluate the similarity of function distribution among units . Using the JS divergence of the spatial units similarity measure makes it easy to obtain the similarity matrix, which provides a comprehensive overview of the relationships between different areas . The JS divergence is used to compare whether two probability distributions are identical or divergent, providing a measure of the statistical difference between the functional profiles of different spatial units . The similarity matrix helps in identifying regions with similar functional characteristics, which can inform urban planning and development decisions .

Alternative Similarity Measures

Considering other probabilistic distance or similarity measures, such as Hellinger distance and cosine similarity, can provide additional insights and validate the findings obtained using JS divergence . The cosine distance is an arbitrary estimate of how close two vectors are, providing a simple and intuitive measure of similarity . The Hellinger distance quantifies the triangle inequality, which is a desirable property for distance measures and ensures that the relationships between spatial units are consistent and reliable . Selecting the most appropriate measure based on the specific characteristics of the data is crucial for obtaining accurate and meaningful results .

Spatial Unit Resemblance

Defining the JS divergence similarity matrix is essential to calculate the similarity between spatial units more intuitively The similarities in individual areas can be weighed when undertaking urban planning practices, allowing for a more nuanced and context-aware approach to urban development . Probabilistic distance or similarity can be assumed for certain kinds of spatial units . This allows for a comparison of the functional similarities between different spatial units, providing a basis for understanding how activities are distributed and how different areas contribute to the overall urban function .

3.5 Activity-Space Interaction Analysis

Analyzing the interaction between activity and space is crucial for understanding how individuals interact with their environment and how spatial functions influence activity patterns. This involves using distance decay functions, analyzing individual activity spaces, and considering the role of subjective decision-making.

Distance Decay Function

Fitting the Gauss distance decay function is important to analyze the variation of interaction intensity between individuals and space .The Gauss distance decay function is the best fit for the data, providing an accurate representation of how interaction intensity decreases with distance .The distance decay function illustrates how the intensity of interaction decreases as distance increases, which is a fundamental concept in spatial analysis and helps to understand how people navigate and interact with their environment . This analysis helps in understanding how spatial functions influence individual activity patterns, providing insights into the relationship between the built environment and human behavior .

Individual Activity Space

Analyzing the spatial distribution features of residents' activities around a core point is vital to understanding how individuals interact with their local environment . Clustering residents according to their check-in positions helps to understand activity distribution, providing a detailed view of how people move and interact within the city . The core point is taken as the focal point, and the spatial distribution features of residents activities are discussed, allowing researchers to examine the patterns and characteristics of activity spaces . This approach helps in understanding the interactive features between the core point and the spatial units, providing insights into the relationship between individual behavior and the built environment .

Subjective Decision-Making

Discussing the effects of spatial function on individual activity based on the distance feature in activity-space interaction is essential for understanding the human element in urban dynamics . Spatial function distribution similarity leads to the complementation and competition in the residents subjective decision-making, highlighting the role of individual preferences and choices in shaping activity patterns . The influence of subjective on activity-space interaction is to satisfy the functional requirements of the activity, emphasizing the importance of meeting individual needs and desires in urban planning and design . Subjective demand for activities is an essential factor in overcoming the distance limit, demonstrating that people are willing to travel further to access activities that are important to them .

3.6 Temporal Dynamics of Activity Space

Understanding the temporal dynamics of activity space is crucial for capturing the changing patterns of urban life and how people interact with their environment over time. This involves considering dynamic equilibrium, time-space constraints, and activity compression.

Dynamic Equilibrium

Under the two forces, the urban space will reach dynamic equilibrium, highlighting the constant adjustments and adaptations that occur within the urban environment . Individuals satisfaction on the activity space and the around situation will be the thrust of the spatial adjustment, emphasizing the role of individual preferences and choices in shaping urban dynamics . When adjusting the activity space will create surplus space, indicating that changes in activity patterns can lead to new opportunities and challenges for urban planning and development . This lagging supply will be the new space supply and become the pull to attract behavior adjustment, creating a feedback loop that shapes the evolution of urban spaces .

Time-Space Constraints

Since 1984 research has turned to the subjective initiative function under time-space constraints, highlighting the importance of considering individual agency and decision-making within the context of temporal and spatial limitations . Torsten Hagerstrand combined time and space at the micro-individual level and constructed a theoretical framework through spatial-temporal paths and spatial-temporal prisms, providing a foundation for understanding how people navigate and interact with their environment over time . The frame overemphasizes Euclidean distance constraints and absolute time and ignores the dynamics, indicating that traditional approaches may not fully capture the complexity and fluidity of urban life . The activity-based approach unifies daily activities in time and space through travel activities, providing a holistic perspective on how people integrate different aspects of their lives within the urban environment .

Activity Compression

With the development of the transportation industry and information communication technologies (ICTs), human movement is becoming more powerful, resulting in activity compression of time and space . Space distance is no longer a barrier to activities, making people's activities more fragmented, personalized, and sophisticated in time and space . Mobile phones and Global Positioning System (GPS) are essential tools for understanding activity patterns, providing detailed data on how people move and interact with their environment . This leads to a shift from single-function urban planning to mixed-use planning, as cities adapt to the changing needs and preferences of their residents .

IV.ANALYSIS AND RESULT

LDA Topic Model: Foundation

The study utilizes the LDA topic model to identify mixed land-use patterns based on resident activity data, offering quantitative insights into urban function mixing. The model categorizes urban areas by analyzing activity intensity and identifies 15 distinct mixed-use patterns, reflecting real-world spatial functions.

To determine the optimal number of topics, the study employs matrix creation from check-in data and perplexity testing. The document-word matrix organizes activity data for LDA input, while perplexity testing ensures an accurate topic number, ultimately selecting 15 for balance between model fit and interpretability.

The study further analyzes function hybrid patterns, revealing how urban functions mix across different topics. Some topics represent dominant functions, such as social services, eating, and transportation, while others highlight mixed-use areas with diverse activities, fostering urban vitality. The LDA model's topic distribution provides insights into urban spatial characteristics, showing that most .areas have a dominant function despite varying degrees of function mixing.

LDA Model Output

The LDA model provides a topic distribution, indicating the extent to which each spatial unit is associated with the identified topics . This distribution indicates the dominant topics within each area, revealing the primary functions and activities that characterize different urban spaces . Most units have a dominant topic, suggesting that while some areas may have mixed functions, one particular function tends to stand out as the primary activity .

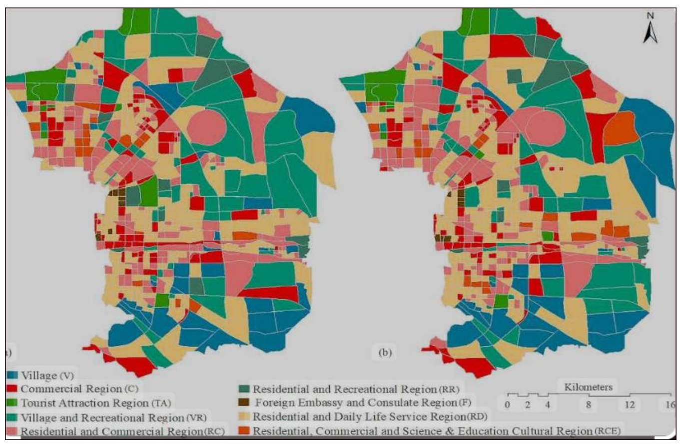

Fig.[1] Urban Functional Zones by Integrating LDA

Polynomial Distribution

Each unit is a polynomial distribution of a k-dimensional topic, representing the probability of each topic being present in that unit and capturing the functional diversity of the area . This represents the probability of each topic in that unit, providing a quantitative measure of the association between spatial units and different urban functions . The k-dimensional topic represents the central location of each resident's activities, indicating the spatial focus of individual behavior and the relationship between activity patterns and urban form .

Spatial Unit Similarity: Measurement

Spatial unit similarity is measured using the DJS metric, providing a quantitative assessment of the functional relationships between different urban areas. The DJS metric quantifies similarity, providing a numerical measure of the functional similarity between spatial units based on their topic distributions . It quantifies similarity in topic distribution between spatial units, enabling the identification of areas with similar functional profiles and activity patterns . It provides insights into the functional relationships, helping to understand how different urban functions complement or compete with each other and how this influences resident activity spaces .

Network Creation

Spatial unit Aij is recognized as a node, representing individual locations within the urban environment and enabling the analysis of their relationships . Each resident's activity is distributed in the grid graph, creating a network of interactions between residents and units that reflects the spatial patterns of urban life . This creates a network of interactions between residents and units, providing a framework for analyzing the complex relationships between individuals and their urban environment .

Fig.[2]. Green Open Space Network

Gaussian Fit

The gauss distance decay function provides the best fit, accurately capturing the relationship between distance and check-in activity, indicating that interaction intensity decreases with distance . Reveals the relationship between distance and check-in activity, demonstrating how spatial separation affects the frequency with which residents engage in different activities . The R-square values confirm the accurate representation, with the Gaussian function exhibiting a higher R-square value than other functions, indicating its superior ability to model the distance decay effect .

Urban Land Use

The research supports the combination of urban land use types, promoting mixed-use development and the integration of different functions within the same area to create more vibrant and accessible urban environments . Layout of facilities and guidance of activities are provided, suggesting that urban planning should focus on creating environments that offer a diverse range of functions and services that meet the needs of residents, and that urban planning can be used to guide resident activities . Functional complementarity weakens distance attenuation, indicating that mixed-use environments can reduce the impact of distance on activity patterns, and that urban planning should focus on creating environments that offer a diverse range of functions and services within a limited geographic area .

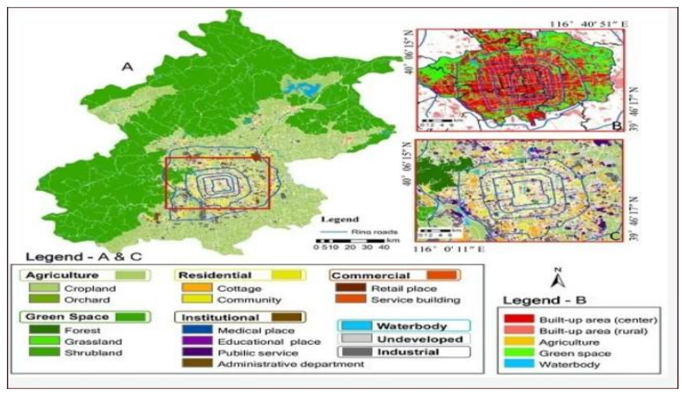

Fig.[2]. Urban Land use Mapping

Mixed-Use Development

Promoting mixed-use development, suggesting that urban planning should focus on creating environments that offer a diverse range of functions and services that meet the needs of residents, and that urban planning can be used to create more livable and sustainable cities . The inuence of subjective is to satisfy functional requirements, highlighting the importance of considering individual preferences and motivations when making urban planning decisions, and that urban areas should be designed to offer a variety of options and opportunities that cater to the diverse needs and interests of residents . The demand for A activity overcomes attenuation resistance, indicating that some residents are willing to travel longer distances to access specific functions or services, and that urban planning.

V. CONCLUSION

Effective urban space management is crucial for ensuring sustainable, accessible, and adaptive cities. This study has explored the integration of spatial function mixtures with technological advancements to enhance urban mobility, accessibility, and social interaction. By analyzing land-use patterns, human activity, and digital tools, the research highlights the benefits of mixed-function urban spaces in fostering economic growth, reducing congestion, and improving quality of life.

The findings suggest that integrating smart technologies, such as AI-driven spatial analysis and IoT-based urban monitoring, can significantly enhance urban planning. Digital tools help optimize land use, improve public space utilization, and support data-driven decision-making for sustainable city development. Furthermore, the study emphasizes the need for flexible urban policies that accommodate evolving human activity patterns and technological innovations.

Despite these advancements, challenges such as zoning constraints, data limitations, and stakeholder coordination remain. Addressing these issues requires collaborative efforts between urban planners, policymakers, and technology experts to develop holistic, people-centric urban strategies.

Future research should focus on further refining AI-based urban planning models, incorporating real-time data analytics, and exploring innovative governance frameworks for smart urban development. By embracing a multidisciplinary approach, cities can evolve into more resilient, efficient, and livable environments that balance growth, sustainability, and technological program.

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