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NEW CHALLENGES FOR XXI CENTURY CITIES

Global warming, ageing of population, reduction of energy consumption, immigration flows, optimization of land use, technological innovation

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TeMA Journal was established with the primary objective of fostering and strengthening the integration between urban transformation studies and those focused on mobility governance, in all their aspects, with a view to environmental sustainability. The three issues of the 2024 volume of TeMA Journal propose articles that deal the effects of global warming, the ageing of population, the reduction of energy consumption from fossil fuels, the immigration flows from disadvantaged regions, the technological innovation and the optimization of land use.

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Laboratory of Land Use, Mobility and Environment
DICEA - Department of Civil, Building and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples

www.serena.unina.it/index.php/tema
e-mail: redazione.tema@unina.it

The cover image shows heavy damage from floods in the Valencia, eastern Spain in October 2024
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ROCCO PAPA
DICEA - Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Italy
ORCID: https://orcid.org/0000-0003-3355-1418
e-mail: rpapa@unina.it

TeMA Journal was established with the primary objective of fostering and strengthening the integration between urban transformation studies and those focused on mobility governance in all their aspects, with a view to environmental sustainability. In other words, the mission of this initiative is to contribute to developing a novel theoretical and methodological framework that transcends the boundaries separating these research domains and develops innovative solutions for issues currently being addressed with methods and techniques rooted in the scientific culture of the last century.

The three issues of the 2024 volume of TeMA Journal propose articles that deal with the effects of global warming, the ageing of the population, the reduction of energy consumption from fossil fuels, the immigration flows from disadvantaged regions, technological innovation and the optimization of land use.

In this issue, the section "Focus" contains three researches. The first paper, titled "Building type classification using deep learning for transport planning" by Aniruddha Khatua, Arkopal K. Goswami, and Bharath H. Aithal (Indian Insitute of Technology Kharagpur in India), illustrates how outputs generated by a deep learning-based-approach can be effectively applied in land-use and transportation planning. By leveraging advanced deep learning techniques, this study aims to produce high-quality building classification data that has information about residential and non-residential structures.

The second contribution is "From smart city to artificial intelligence city. Envisaging the future of urban planning" by Romano Fistola, Rosa Anna La Rocca (University of Naples Federico II in Italy). The article highlights the urgent need to build a theoretical and disciplinary foundation that recognizes AI's creative capacity and effectively utilizes its capabilities to design sustainable future urban configurations in harmony with existing resources.

The last contribution of the section is "Measuring the walkability of areas around Addis Ababa LRT stations by integrating Analytic Hierarchal Process (AHP) and GIS" by Ashenafi Wondimu Tekolla, Abrham Gebre Tarekegn, Getu Segni Tulu (Addis Ababa University in Ethiopia). This research aims to find a spatial method to measure the existing circumstances that encourage walking around Addis Ababa LRT stations by integrating the Analytic Hierarchy Process (AHP) and Geographical Information System (GIS). The results clustered areas with similar levels of walkability in the group and represented them with different colours.

The section "LUME" (Land Use, Mobility and Environment) contains three articles. The first, "Exploring the use of active mobility in selected rural areas of Nigeria", by Marcela Juliana Cargnin, Cintia de Castro Marino, and Thaísa Leal da Silva (University of Johannesburg in South Africa) study employed a robust research design, collecting primary data through a multi-stage sampling method. Specifically, 50% of the wards in the rural areas of Ondo State, Nigeria, were randomly selected, and a total of 496 structured questionnaires were administered using a systematic sampling approach.

The second contribution is "Farmers decision on land use land cover change from agriculture to forest and factors affecting their decision: the case of Gurage Zone, Central Ethiopia" by Tesfanesh Ababu, Alemtsehaye Eyasu, Mister Abebe, Alemayehu N. Ayana, Asabeneh Alemayehu, Mulatu Mengist (Centeral Ethiopia Forestry Development Center in Ethiopia and University of Tuscia in Italy). This study investigates the direct and indirect drivers of the change, as well as factors affecting farmers' decisions regarding the conversion to provide necessary policy input. The data was collected from 311 households through household surveys, key informant interviews (KIIs), and focused group discussions (FGDs). Descriptive statistics and a binary logit model were used for analysis.

The third article, "Environmental factors affecting living comfort perception in different localities in Sri Lanka" by Mohamed Thariq Mohamed Gazzaly, Mohamed Mujithaba Mohamed Najim (South Eastern University of Sri Lanka in Sri Lanka and Sultan Sharif Ali Islamic University in Brunei Darussalam), investigates the factors influencing the living comfort perception in an urban and a non-urban locality in Sri Lanka. A pre-tested questionnaire was conducted to solicit the people's perceptions of identified environmental factors, randomly selecting fifty households from each locality.

The fourth article of the section, "Technological applications in sustainable urban logistics: a systematic review with bibliometric analysis", by Suzan Oguz and Mehmet Tanyas (Cag University and Maltepe University in Turkiye), aims to identify sustainable urban logistics and the role of technological applications in urban logistics. This research, designed as a systematic study based on the existing literature, examines the basic concepts, trends, researchers, and countries working in sustainable urban logistics using the bibliometric analysis method.

The Review Notes section proposes four insights on the themes of the TeMA Journal. The Urban planning practice section of Review Notes, "Energy transition and renewable energy policies in Italy", by Valerio Martinelli, discusses the importance of territorial governance plans and urban transformation tools in promoting the use of renewable energies and reducing emissions. Renewable Energy Communities (RECs) are identified as key instruments, thanks to the direct involvement of citizens and local energy autonomy. The second section, "Strategies and instruments for active mobility: a European overview", by Annunziata D'Amico, analyses the policies and actions taken in Italy to promote active mobility. Concrete examples of solutions implemented in some cities are presented, highlighting the commitment to promoting the transition from car-based mobility to a more sustainable and healthy one. The third contribution, "Global warming or global warning? A review of urban practices for adaptation to urban floods", by Stella Pennino, provides an overview of the challenges that global warming poses and the risks in terms of climate change that it generates for territories and cities, with a specific focus on the urban flooding phenomenon. The challenges that adaptation to urban flooding events commonly faces are outlined and a brief review of international case studies is carried out. Finally, the fourth section, "Exploring approaches and solutions for urban safety: a focus on the elderly", by Tonia Stiuso, provides a comprehensive overview of the challenges and solutions for creating safe and accessible cities for older people. Various scientific sources and practical resources are used to illustrate effective approaches and innovative strategies. In this final issue of 2024, I would like to express my sincere gratitude to all of TeMA Journal's editorial staff members who, with dedication and selflessness, undertake this challenging and demanding scientific endeavour without any financial compensation. A special thanks to Prof. Gerardo Carpentieri, who, for over a decade, has been instrumental in coordinating all activities necessary for the publication, promotion, and enhancement of the journal's scientific quality.

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Building type classification using deep learning for transport planning

Aniruddha Khatua [a], Arkopal K. Goswami [b], Bharath H. Aithal [c*]

[a] Ranbir and Chitra Gupta School of Infrastructure Design and Management
Indian Insitute of Technology Kharagpur, Kharagpur, West Bengal, India
e-mail: aaniruddha4@kgpian.iitkgp.ac.in
ORCID: https://orcid.org/0000-0002-4308-0595

[b] Ranbir and Chitra Gupta School of Infrastructure Design and Management
Indian Insitute of Technology Kharagpur, Kharagpur, West Bengal, India
e-mail: akgoswami@infra.iitkgp.ac.in
ORCID: https://orcid.org/0000-0003-1369-215X

[c] Ranbir and Chitra Gupta School of Infrastructure Design and Management
Indian Insitute of Technology Kharagpur, Kharagpur, West Bengal, India
e-mail: bharath@infra.iitkgp.ac.in
ORCID: https://orcid.org/0000-0002-4323-6254
* Corresponding author

Abstract

The transportation and land use sectors are closely interdependent, and real-life circumstances often exhibit substantial reciprocal influences. Currently, efforts are being made to enhance transportation and land use sustainably; hence to achieve sustainability, it is necessary to have well-optimized plans and implementations for the advancements, which consequently leads to an increased demand for vast amounts of data. Conducting manual surveys to collect data on various types of buildings is considerably costly, requires much labor, and is time-consuming. Remote sensing technology has demonstrated significant promise to encompass a greater extent in a reduced timeframe, as well as to engage in thorough data collection and effectively manage and analyze the acquired data. This work centers on constructing a classification system that categorizes buildings depending on their use, specifically distinguishing between residential and non-residential structures. The classification challenge is accomplished through instance segmentation using the state-of-the-art YOLOV8 model architecture and remotely sensed images. The main objective of this project is to create base maps for travel analysis zones (TAZs) using identified buildings. To properly align the output images generated by the model, geographical data is appended to the output images derived from the original input images.

Keywords

Image segmentation; Land use classification; Transportation planning; YOLOV8.

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1. Introduction

Over the years, Indian cities have grown substantially, prompting administrative bodies to institute various measures to contend with the challenges arising from this demographic surge (Aithal & Ramachandra, 2016). The ramifications of this population expansion are intricate, with urban development becoming a pivotal aspect of addressing the needs of the burgeoning populace. One crucial aspect of this development lies in the simultaneous growth of multiple industries within urban areas. A notable interdependence exists between land use and transportation sectors, implying that advancements in one sector invariably necessitate corresponding developments in the other. This interlinkage is particularly evident in the context of urban planning and development. For instance, envisioning the expansion of a business district requires not only an augmentation of physical space but also necessitates well-developed transportation amenities. The term "amenities" in this context encompasses a comprehensive spectrum, ranging from infrastructure like roads and public transit networks to considerations of accessibility and service quality. The quality and efficiency of transportation infrastructure play a crucial role in facilitating the smooth functioning of urban centers and supporting the growth of various industries.

In practical terms, this might involve establishing efficient road networks, implementing robust public transportation systems, and enhancing overall accessibility within the urban fabric. The relationship between land use and transportation is symbiotic; improved transportation facilitates the accessibility of different areas (Raju et al., 2020; Galderisi et al., 2021), decision-making (Tira, 2021; Gazzola et al., 2021), and influencing land-use patterns, while changes in land use necessitate adjustments and improvements in transportation systems. Therefore, understanding and managing this intricate interplay is vital for sustainable and well-planned urban development, ensuring that the needs of a growing population are met effectively.

The role of land use features in the realm of transportation planning is widely recognized for its significance. However, the traditional method of collecting information on buildings over expansive areas faces practical challenges such as a time-consuming process, reduced reliability, high costs, and substantial manpower requirements. In response to these challenges, remote sensing emerges as a powerful solution, demonstrating its efficacy in resource management by efficiently covering vast areas while minimizing labor and time demands (Ramachandra et al., 2012; Carpentieri & Favo, 2017; Zullo et al., 2015). The escalating demand for transportation often results in the need for urban expansion, leading to significant sprawls on the outskirts. Delhi, for instance, has witnessed a remarkable increase of over 800% in its built-up area within four decades (Ramachandra et al., 2015; Bharath et al., 2017). Conducting spatial studies encompassing diverse land use features necessitates using effective models for extracting information. Adopting machine learning or deep learning-based models is gaining traction in the geospatial domain and various research areas. Extracting features from satellite or aerial photography is integral to remote sensing and GIS, with building extraction standing out as a substantial task. Researchers have developed diverse methodologies, including training fully convolutional networks on multi-source datasets to exploit variations in targeted objects (Ji et al., 2018), detecting buildings from low-contrast images (Amir et al., 2018; Chen et al., 2018; Li & Cao, 2019), utilizing images of different scales (Yang et al., 2018; Chen et al., 2022), leveraging building shadows at different sun angles (Sirmacek & Unsalan, 2008), and incorporating spatial feature-based metrics (Pavlidis & Liow, 1989). Segmentation is the most efficient method for extracting buildings from remotely sensed images. Numerous deep learning architectures have been devised for this purpose, including U-Net with various modifications (Wang & Miao, 2022; Prakash et al., 2022; Madhumita et al., 2023), VGGNet (Simonyan & Zisserman, 2014), GoogleNet (Szegedy et al., 2015), ResNet (He et al., 2016), ImageNet (Krizhevsky et al., 2017), and Segnet (Badrinarayanan et al., 2017). The categorization of land use features operates at multiple levels, with building extraction falling under level-1 classification, involving the isolation of buildings from the total image. Beyond this, level-2 classification (Which means after classifying and extracting the buildings form the entire image, those buildings are againg classified into different classes) encompasses the categorization of building types based on utility, distinguishing between residential and non-residential structures. Achieving this classification level requires viewing buildings as entities with distinct architectural configurations, characteristics, dimensions, and scales. Object identification or instance segmentation becomes essential to surpass level-1 classification. Various model designs have emerged within the computer vision sector to harness substantial advancements. Notable models include Fast-CNN (Girshick, 2015), You Only Look Once (YOLO) (Redmon et al., 2016), SSD: Single Shot Multibox Detector (Liu et al., 2016), and Spatial Pyramid Pooling (He et al., 2015). These models showcase the evolving landscape of techniques and approaches in extracting and categorising land use features, playing a crucial role in integrating remote sensing and GIS into transportation planning and spatial studies. The allocation of land in urban areas has far-reaching implications for various aspects of transportation planning, exerting significant influence on key factors such as the identification of congestion zones, the evaluation of traffic flow dynamics, and the construction of origin-destination matrices. An integral component of transportation analyses involves considering land use issues, encompassing factors like land use mix and zoning, which offer valuable insights into the diverse activities occurring in different regions of an area throughout the day (Levine, 2010). Understanding the spatial layout becomes crucial in comprehending the current arrangement of streets (Zhang et al., 2019). The existence of densely populated commercial zones, for example, can have a profound impact on traffic flow and congestion levels (Waloejo, 2020; Yap et al., 2022). The geographical distribution of such commercial hubs directly influences the movement patterns of vehicles, contributing to the formulation of effective congestion mitigation strategies. Beyond commercial zones, residential areas also play a pivotal role in shaping transportation patterns. The significant increase in demand of urbanization due to rapidly increasing population asks for development of residential land uses (Mirzahossein et al., 2022). Suburban residential zones, characterized by lower population densities, often necessitate increased travel for work-related purposes, consequently elevating trip generation rates. This dynamic interaction between land use and travel behavior underscores the importance of accurately characterizing the types of buildings and land uses within an urban area. Moreover, land use intricately affects the accessibility and connectivity of different regions within an urban landscape. The densification of transport nodes orginating form various facilities comprising work, educational, recreational, etc are influenced by the transit oriented developments (TOD) (Agyemang et al., 2020). The configuration of roads, proximity of transportation hubs, and the distribution of various land uses collectively contribute to the overall traffic patterns and transportation network efficiency. Accurate and detailed classification of building types and their associated land uses becomes instrumental in conducting transportation analyses with added efficiency. It facilitates a more comprehensive understanding of the complex interplay between land use and transportation dynamics, enabling urban planners and policymakers to make informed decisions that contribute to optimising transportation systems and improving overall urban mobility. Travel Analysis Zones (TAZs) are fundamental transportation modeling and analysis building blocks. Their design significantly impacts the quality and accuracy of insights derived from such models. A common approach utilizes established Census geographies like blocks, block groups, and tracts as base units for TAZ delineation. This ensures data availability and compatibility with other sources (You et al., 1998; Moghaddam et al., 2022). Another method emphasizes accessibility to transportation infrastructure like roads, rail lines, and transit stations. TAZs are formed based on travel times, distance to key network elements (Ducruet & Lugo, 2013). TAZs can be generated focusing on the area's homogeneity in landuses and socioeconomic characteristics. This helps to understand the travel patterns associated with residential areas, commercial districts and industrial zones (Adams & Tiesdell, 2012). Factoring in multiple determinants like geography, networks, and landuse, a more nuanced representation of travel behaviour can be achieved (Yang et al., 2022). The primary goal of this study is to illustrate how outputs generated by a deep learning-based approach, as described here, can be effectively applied in land-use and transportation planning. By leveraging advanced deep learning techniques, this study aims to produce high-quality building classification data that has information about residential and non-residential structures.

Accurate building classification is crucial for informed decision-making in urban planning, as it provides valuable insights into the distribution and types of buildings within an area. This information can then support various applications, such as optimizing public transportation routes, identifying areas suitable for commercial development, managing zoning regulations, and planning infrastructure improvements. Using a deep learning-based model, the study seeks to offer a more efficient and automated way to generate detailed, up-to-date information, which is often challenging and time-consuming to collect using traditional methods.

2. Methodology

This study aims to generate high-quality building classification data capable of distinguishing between residential and non-residential structures. Accurate building classification is essential for urban planning and management, as it offers valuable insights into the spatial distribution and types of buildings in a given area. This detailed information plays a pivotal role in supporting various applications, such as optimizing public transportation routes, identifying areas suitable for commercial development, managing zoning regulations, and planning for infrastructure improvements. We aim to develop a more efficient and automated approach to produce up-to-date building utility data using a deep learning-based model. This method addresses the challenges of traditional data collection, which is often labor-intensive, time-consuming, and prone to inaccuracies. The deep learning model employed in this study processes satellite or aerial images of a given area to identify all buildings in the image. Once detected, the model classifies each identified building into residential or non-residential categories. The resulting output is a detailed image highlighting the buildings and their respective classifications. This provides a clear and easy-to-interpret representation of the area. This classified building data can then generate zone-specific maps and be helpful for more informed decision-making for urban planners, policymakers, and transportation authorities. Additionally, to provide a comprehensive understanding of the deep learning model used in this study, we have included a brief discussion of its architecture, working principles, performance metrics, and potential limitations. This insight offers a holistic view of how the model functions and the extent to which it can contribute to urban and transportation planning initiatives. The YOLOV8 (Jocher et al., 2023) model undergoes comprehensive training utilizing datasets sourced from SpaceNet-3 (Fig.2) and ISPRS Potsdam (Fig.3), the latter provided by BSF Swissphoto. This mixing of diverse datasets enriches the model's learning with a broader range of real-world scenarios and geospatial contexts. To facilitate the training process, the complete dataset is partitioned into three subsets: Train, Test, and Validation. Notably, modifications are systematically introduced to both the model architecture and the training dataset to optimize performance. These modifications aim to refine the model’s ability to accurately identify and categorize objects, particularly in the context of geospatial imagery. The iterative nature of the training process involves continuous evaluations using the Validation dataset after each epoch. This approach ensures that the model’s learning progresses controlled, allowing for adjusting parameters and fine-tuning to achieve optimal performance. The convergence of training and validation accuracy to predefined criteria is a crucial checkpoint. Once the model consistently meets the desired performance standards on both the training and validation sets, it undergoes a rigorous evaluation using previously unseen images from the Test dataset. This final assessment gauges the model's generalization capabilities and effectiveness in accurately detecting and classifying objects in real-world scenarios outside the training data. To showcase the model performance and the utilization of the model, two datasets are used such as, SpaceNet 3 Vegas and ISPRS Potsdam. As the model is trained on images from different sensors (both aerial and satellite sensors), the learning of the model becomes robust due to different scales, aspects, and pixel values. The SpaceNet 3 dataset (Fig.2), originally meant for extracting road networks from satellite images, contains a diverse range of buildings. This diversity is highlighted as an important feature for improving the training of deep learning models. The size of the images (1300x1300 pixels) and the high spatial resolution (30 cm per pixel) are provided, emphasizing the data quality for detailed analysis. The ISPRS Potsdam dataset

(Fig.3) is a widely recognized benchmark in remote sensing and aerial image analysis. This dataset provides high-resolution aerial imagery of the city of Potsdam, Germany. It is specifically designed to facilitate research in tasks such as semantic segmentation, object detection, and classification within urban environments. The dataset includes true orthophotos with a ground sampling distance (GSD) of 5 cm, allowing for the precise identification and analysis of objects. The diversity and high level of detail in the ISPRS Potsdam dataset can be a resource for researchers and practitioners to use in advanced image analysis algorithms for urban area mapping. In essence, the training and evaluation methodology outlined underscores a meticulous and iterative process involving diverse datasets and continuous assessments to ensure the YOLOV8 model is finely tuned and proficient in its geospatial object detection tasks. The utilization of separate Train, Test, and Validation sets, along with the adoption of performance criteria, establishes a robust framework for achieving and validating the desired level of accuracy and reliability in the model's predictions. The work demonstrated in this research is to execute a nuanced classification of building rooftops into two discrete categories: residential and non-residential. This classification is pivotal for the subsequent allocation of appropriate zones, a process contingent on the density of structures within a specific geographical area. The zoning strategy is straightforward: if a given region predominantly features residential structures, it is designated as a residential zone; conversely, areas not intended for residential purposes are classified accordingly. The designation of a mixed zone pertains to areas showcasing a relatively equitable distribution of various building types.

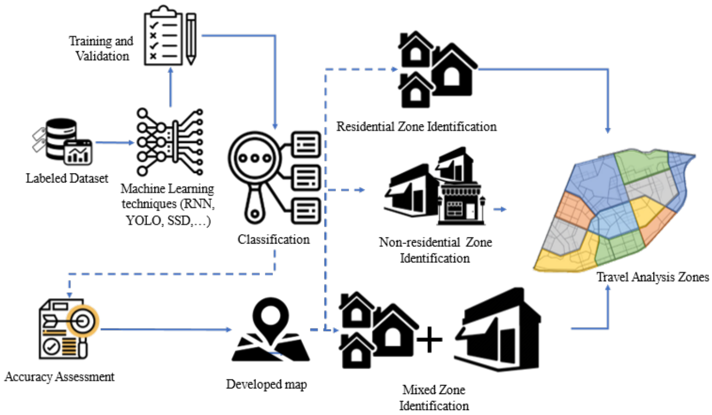

Fig.1 Methodology diagram

The utilization of zonal data forms the cornerstone for generating a foundational map of the targeted region, serving as a crucial resource for diverse transportation planning analyses. Fig.1 encapsulates the entire methodology, visually representing the comprehensive process. The validation accuracy, a crucial metric for assessing the model's performance, is presented in Tab.2, offering insights into the reliability and eff'ctiveness of the classification and segmentation techniques employed. Additionally, Figure 5 offers illustrative instances of the test findings, providing visual validation of the model's capabilities. The resultant images undergo a georeferencing step following the classification and segmentation processes. This georeferencing procedure aligns the images geographically, establishing the groundwork for the construction of Transportation Analysis Zones (TAZ) base-maps. Notably, all photos are standardized by downsizing them to square images with a resolution of 960 pixels, a preparatory step to enhance training efficiency and accuracy. The execution of the entire model pipeline, from classification to georeferencing, is conducted on the Python platform. This implementation is supported by an array of libraries, including but not limited to numpy, opencv-python, pytorch, CUDNN, and others. This technological framework ensures the seamless execution of the research methodology, leveraging advanced computational capabilities to achieve accurate and insightful results. In summary, the research encompasses a multifaceted approach, integrating image processing, geospatial analysis, and deep learning techniques, all executed on a robust computational platform to accomplish the study's overarching objective of refined building rooftop classification for transportation planning.

(a) (b)

Fig.2 (a) Examples of residential buildings (SpaceNet-3); (b) Examples of non-residential buildings (SpaceNet-3)

(a) (b)

Fig.3 (a) Examples of residential buildings (ISPRS); (b) Examples of non-residential buildings (ISPRS)

YOLOV8, as illustrated in Fig.4, inherits a foundational architecture akin to its precursor, YOLOV5, while introducing augmentations that contribute to the refinement of its training and prediction capabilities. Notably, a pivotal enhancement incorporated into this model is integrating a C2F module (Terven & Cordova-Esparza, 2023). The C2F module functions as a cross-stage partial bottleneck featuring two convolution modules. This architectural addition enables YOLOV8 to amalgamate high-level features containing critical information, thereby facilitating an augmentation in detection accuracy and a reduction in box loss.

One of the distinctive attributes of the model architecture lies in incorporating a dual decoupled head, coupled with the absence of anchors. This unique configuration empowers the model to autonomously handle diverse tasks, encompassing detection, classification, and regression. Eliminating anchors enhances the model's adaptability in addressing myriad scenarios, improving overall performance. Moreover, the architecture embraces various design branches, each assigned specific roles to improve overall correctness. A noteworthy aspect of YOLOV8 is its use of the sigmoid function to predict the probability of a bounding box surrounding a targeted object. Simultaneously, the softmax function is employed to compute the probability of a detected object belonging to a designated class. This dual-functionality approach enhances the model's precision and reliability in both localizing and categorizing objects within the given context. The meticulously crafted architecture, including these features, collectively positions YOLOV8 as an advanced and versatile model proficient in multifaceted object detection tasks.

The YOLOV8 model is highly adaptable and capable of training and making predictions on images or videos of any size. While it comes with a default frame size of 640x640 pixels for training and testing, users can adjust this frame size according to their specific requirements. Generally, high-resolution images involve larger frame sizes, which can enhance the accuracy and performance of the model during both the training and inference stages. However, this improvement comes at the cost of increased computational resource usage. The YOLOV8 model is available in multiple variants, ranging from YOLOV8n (nano) to YOLOv8x (extra-large), each with different numbers of parameters. These variants determine how complex and detailed the model's learning process is. Models with more parameters, such as YOLOv8x, tend to achieve better learning and produce more accurate results, but they also demand significantly more computational resources and longer training time. It's recommended to use a GPU-enabled environment for optimal performance, as this significantly speeds up the training and inference processes. Although the model can also run on CPUs, using a GPU accelerates the computations, making it more efficient, especially for larger datasets or higher-resolution images.

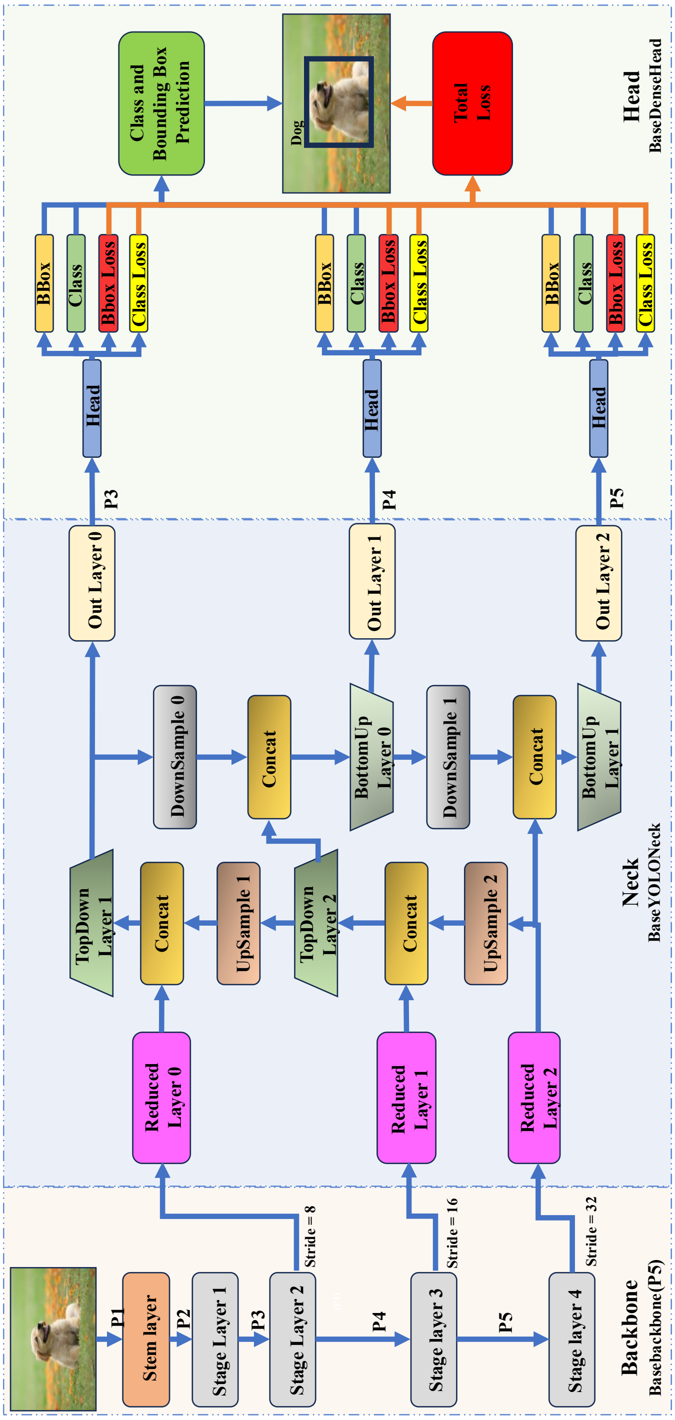

Fig.4 YOLOV8 Base architecture

SL No.	Metric	Formula
1	Mean Avearage Precision (mAP)	$mAP = \frac{1}{N}\sum_{i=1}^{N} AP_i$
2	Precision (P)	$\frac{TP}{TP+FP}$
3	Recall (R)	$\frac{TP}{TP+FN}$
4	Accuracy	$\frac{TP+TN}{TP+FN+TN+FN}$

Tab.1 Perfromance metrics details

3. Results and discussion

The YOLOV8 model architecture stands out for its versatility, demonstrating proficiency in a spectrum of computer vision tasks, including but not limited to segmentation, object identification, picture classification, object tracking, and posture estimation. This broad applicability has contributed significantly to the model's popularity, attributed to its simplistic design, user-friendly interface, and adaptability to various data input formats.

In the context of this study, the YOLOV8 model architecture is leveraged for the specific task of building classification. The dataset employed encompasses over 500 images, with approximately 300 sourced from the SpaceNet 3 dataset and the remaining images derived from the Potsdam dataset. In preparation for the training phase, all original images undergo a meticulous image augmentation process to enhance the model's training accuracy by introducing diverse variations to the dataset. The optimization process is facilitated by the implementation of Stochastic Gradient Descent (SGD) as the optimizer, with an initial learning rate set at 0.007. To ensure stability and effective convergence during training, the momentum is finely tuned to a value of 0.937. A judicious choice of hyperparameters is also made, with the weight decay parameter set at 0.0005. These optimization parameters collectively contribute to the model's ability to learn and generalize effectively from the training dataset. Tab.2 is enlisted to provide a comprehensive overview of the performance metrics achieved by the YOLOV8 model in the course of its application to the building classification task. This table serves as a valuable reference point for evaluating the efficacy and accuracy of the model in relation to the specific objectives outlined in the study.

Class	Precision	Recall	mAP(50)
Overall	0.944	0.892	0.945
CB	0.936	0.805	0.903
RB	0.953	0.979	0.986

Tab.2 Perfromance metrics. CB = Non-residential Building; RB = Residential Building

The primary objective of this study is the nuanced categorization of building rooftops into distinct classes, specifically differentiating between residential and non-residential structures. This categorization serves as a pivotal step in the subsequent assignment of appropriate zones based on the density of buildings within a given geographic area. The zoning process operates on the premise that areas predominantly characterized by residential structures are designated as residential zones, while those dominated by non-residential structures are categorized as non-residential zones. A mixed zone designation is applied to areas where the proportion of each building type is relatively balanced. This zoning methodology lays the foundation for the creation of a detailed and informative map of the targeted area. By systematically incorporating the zonal data into the mapping process, the resulting cartographic representation provides a comprehensive overview of the spatial distribution of residential and non-residential structures. This map, enriched with zonal insights, serves as a valuable tool for conducting various transportation planning studies. The utility of this approach extends

beyond mere categorization, as the zoning information encapsulates the socio-economic and land-use characteristics of the area. Such a detailed understanding of the spatial composition becomes instrumental in making informed decisions regarding transportation planning, urban development, and resource allocation. The methodological framework outlined in this study not only contributes to building classification but also facilitates a broader understanding of the built environment, thereby enhancing the applicability of the generated maps for strategic urban planning initiatives.
In order to create a zone-dispersed map, it is very essential to incorporate geographic information. This will enable the alignment of images with a spatial reference. In order to include spatial information in the resulting segmented image, the geographical information is extracted from the input images and used as a reference for each individual image. Fig.6 illustrates scenes derived from the categorized and segmented photos reflecting the datasets utilized in this investigation.

Fig.5 Examples of detection results (Cyan: Non-residential buildings; Yellow: Residential buildings)

Instance segmentation is used in this study as the desired objects are identified, classified, and segmented. Any instance segmentation model requires polygon annotations for training, and the polygons are made meticulously to produce better annotations, yield better training accuracy. Manual preparation of annotation in terms of the polygons is labour-intensive and time-consuming, hence automatic or semi-automatic mask generation algorithms are gaining popularity. Most of the instance segmentation models' work pace is also contingent on the hardware capabilities, so dealing with more pixel density calls for better computational power.
The model used in this study relies on pixel-based information, and to enhance the learning, size, shape, aspect, and scale of the targeted objects (here, rooftops of the buildings) are also considered. To confirm building types, every building from every image in the training dataset was checked by overlaying the images

on the Googe map. To ensure better learning and minimal occurrence of classification as well as segmentation error, image augmentations such as rotation (90˚), flip (both vertical and horizontal) are applied. While testing the model's performance, it was found that residential buildings with slender appearance are mostly misclassified as non-residential buildings; to mitigate that, reannotation of such buildings is done.

Fig.6 Examples of detection results and land use map preparation

The presented illustration (Fig.7) servs as a visual representation of the intricate process of generating pertinent cartographic information. The focal point of this process involves the careful selection of scenes from the SpaceNet 3 Vegas dataset. These chosen scenes are strategically employed to form a composite image of larger dimensions. This composite image, representative of a broader spatial context, is subsequently introduced into the model pipeline. Within the model pipeline, the composite image undergoes a series of computational steps and analyses, culminating in generation of output. This output, derived encapsulates valuable cartographic information with enhanced contextual insights. The resulting image, now enriched with the extracted data, is purposefully employed in delineating and categorizing distinct zones within the geographic are under consideration.

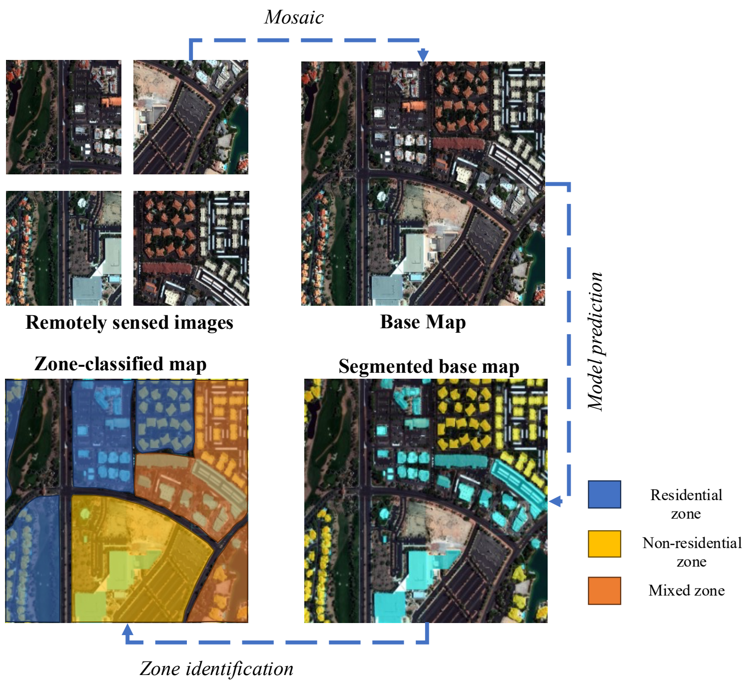

Fig.7 Insert here image description

The zones identified in the resulting image are further classified into residential, non-residential, and mixed zones. This classification process contributes to the creation of comprehensive cartographic representation, effectively conveying the spatial distribution characteristics of different structures.
The study's initial phase involved using georeferenced images from both datasets. The inherent georeferencing of these images facilitated a seamless alignment process, enabling the synthesis of accurate maps. Georeferencing is a crucial step in geospatial analysis, as it establishes the spatial location and positioning of features within an image in relation to real-world coordinates. It is imperative to note that standard instance segmentation models inherently lack the capability to transfer geospatial information from the input image to the output image. Recognizing this limitation, a subsequent step was introduced to address the geospatial integrity of the output. Consequently, all output images underwent an additional georeferencing process, aligning them with respect to the geospatial information present in the input images (Khatua et al., 2024). This meticulous georeferencing of the output images is paramount for maintaining spatial accuracy and ensuring that the generated maps faithfully represent the geographical features depicted in the input imagery. The alignment process contributes to the preservation of geospatial relationships, allowing for meaningful comparisons and analyses across different datasets and facilitating further geospatial operations with precision.
The YOLOV8 model’s segmentation effectiveness relies on its detection capability. This means the segmentation quality is affected by the detector models. It outlines three key challenges related to using bounding boxes: overlap, dataset size, and unnecessary pixels. Overlapping occurs when te objects and close together, leading to potential confusion during training. Narrow objects might results in bounding boxes containing many irrelevant pixels., which can interfere the model’s learning process by blending the target object with nearby pixels.
In summary, the entire workflow underscores the critical role of georeferencing in our study. The georeferenced images serve as the foundation for accurate mapping, and the subsequent alignment of output images ensures the preservation of geospatial context, enhancing the reliability and utility of the generated cartographic information.

4. Conclusion

The study delves into the intricate realm of instance segmentation, leveraging its capabilities for identifying, classifying, and segmenting desired objects, with a specific focus on rooftops in building structures. The process involves meticulous polygon annotations for model training, a traditionally labour-intensive and time-consuming task. To alleviate this, this study explores automatic or semi-automatic mask generation algorithms. The model adopted relies on pixel-based information, factoring in the targeted objects' size, shape, aspect and scale, and incorporates image augmentation for enhanced learning. However, challenges surface during testing, particularly in the misclassification of slender residential buildings as non-residential buildings, prompting the need for reannotation to mitigate errors.
Currently, this model has been tested only on planned urban environments where buildings exhibit distinct and easily recognizable features. These well-defined attributes make it easier for the model to learn and accurately detect objects, resulting in enhanced performance. However, the model's capabilities and additional limitations may become more apparent when applied to rural areas or urban settings characterized by organic and irregular development. In such environments, the architectural features are less structured, and buildings vary widely in shape, size, and arrangement, posing a greater challenge for accurate detection and segmentation. To thoroughly evaluate the model's adaptability and robustness in these complex scenarios, it will be necessary to train and test it on additional datasets that capture the diversity of rural and organically developed urban landscapes. Expanding this evaluation to include such datasets represents an important

direction for future research, as it will help identify potential shortcomings and guide further improvements in the model's performance across different geographic settings.

The study addresses the critical aspect of georeferencing, acknowledging the inherent limitation of instance segmentation models in transferring geospatial information. The georeferencing of images, both input and output, is meticulously executed to ensure accurate alignment, fostering meaningful comparisons and analyses. This process is pivotal for maintaining spatial accuracy, enhancing the reliability of the generated maps, and enabling effective geospatial operations.

In summary, this research contributes to the advancement of instance segmentation methodologies and showcases the integration of geospatial considerations in cartographic information generation. The proposed workflow emphasizes the synergy between advanced computer vision techniques, spatial analysis, and georeferencing for robust and accurate results in diverse applications, from object identification to cartographic mapping.

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Fig.2: Examples of residential buildings (SpaceNet-3) (b) Examples of non-residential buildings (SpaceNet-3). 2d semantic

labeling contest - potsdam. International Society for Photogrammetry and Remote Sensing.

Fig.3: Examples of residential buildings (ISPRS Potsdam) (b) Examples of non-residential buildings (ISPRS Potsdam)

Author's profile

Aniruddha Khatua

Research Scholar at Ranbir and Chitra Gupta School of Infrastructure Design and Management, Indian Institute of Technology Kharagpur. His research is mainly oriented towards feature extraction from remotely sensed images.

Arkopal Kishore Goswami

Professor at Ranbir and Chitra Gupta School of Infrastructure Design and Management, Indian Institute of Technology Kharagpur. Dr. Goswami is leading the Multimodal Urban Sustainable Transportation (MUST) research group at IIT Kharagpur. The primary research areas of the group include, Urban Transport Sustainability, Urban Travel Behavior, Seamless Integration of Urban Travel Modes, Active Transportation and Impact on Human Health, and Smart Management of Transport Infrastructure. His research program aims to develop the next generation of transport infrastructure professionals, who would be equipped with a holistic understanding of the impacts of transportation on liveability.

Bharath Haridas Aithal

Professor at Ranbir and Chitra Gupta School of Infrastructure Design and Management, Indian Institute of Technology Kharagpur. Dr. Aithal's method and theoretical research as well as a considerable portion of his applied work addresses Spatial and longitudinal data. An innovative contribution of his work is to show that agents that change the urban aspects of a urban social life are major players that have to be considered, while modelling in urban domain. This has established a new perspective to the analysis of urban spatial data and modelling. This perspective creates a new class of functional estimation procedures that non-parametrically account for the within-subject correlation in an intuitive and efficient manner. Thus providing a space for more efficient algorithmic modelling of urban developments and urban sociology.

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From smart city to artificial intelligence city. Envisaging the future of urban planning

Romano Fistola [a*], Rosa Anna La Rocca [b]

[a] Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: romano.fistola@unina.it
ORCID: https://orcid.org/0000-0001-6758-7510
* Corresponding author

[b] Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: larocca@unina.it
ORCID: https://orcid.org/0000-0003-2248-5152

Abstract
The paper emphasizes the need to advance both theoretical and methodological understandings to reflect the theoretical-methodological evolution of urban planning, considering the vast potential of Artificial Intelligence (AI). Specifically, the paper aims to chart an innovative path for the discipline of urban planning by adopting a systemic approach to studying urban phenomena and envisioning how the intentional integration of AI can lead to a completely new way of managing urban transformation. The study seeks to provide a fresh perspective on AI's potential impact, especially within fields overseeing urban and territorial changes. It begins with an analysis of the relationship between technological innovation and urban transformation, which is crucial today due to the opportunities AI presents. The paper particularly focuses on the relationships among urban sub-systems, which are essential for city survival. Historically, from the inception of urban planning to the rise of smart cities, the integration of technology and urban environments often lacked a cohesive theoretical framework to guide the deliberate adoption of technological innovations. The primary aim of the paper is to highlight the urgent need to build a theoretical and disciplinary foundation that recognizes AI's creative capacity and effectively utilizes its capabilities to design sustainable future urban configurations in harmony with existing resources.

Keywords
Artificial Intelligence; Urban Planning; Smart City; Complex Systems.

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1. Introduction

There is no doubt that we are witnessing one of the epochal transition moments among those that have thus far shaped the history and evolution of humanity. The relationship between humans and technology is undergoing an acceleration probably never observed in the past. The discovery of the possibility to extend the physical capabilities of human beings through the creation of technical tools - from flint, used to build axes and arrowheads, to silicon for the development of computer microchips (Giovannini, 1984) - now experiences an epochal turning point with the introduction, diffusion, and utilization of Artificial Intelligence (AI). We are likely facing an entropic watershed (Rifkin, 1980) that will determine new organizations and social structures on the planet and new ways of acting and interacting within human settlements where the future of humanity will be decided: the city.

This paper, agreeing on the need to develop theoretical and methodological insights, proposes an innovative interpretation of the role that AI can play, particularly in the disciplines managing urban and territorial transformations. In the past, from the birth of urban planning to the spread of smart cities, the relationship between technology and cities has generally involved the introduction of technologies, more or less advanced, into urban systems but outside a theoretical framework capable of guiding conscious processes of technological innovation adoption. Some scholars, always attentive to the modifications that new technologies often invisibly produce within the city (Balducci, 2023), have initiated interesting reflections on the current technological revolution and the impacts it will have on anthropic contexts. In this crucial condition, it is vital to surpass all previous interpretative models that indicated technology as the foundation of urban configurations; the smart city is giving way to the emergence of a new "system" of the city in which the network, and therefore the production and transmission of information, remain vital for new urban economies. It should also be noted that the term "smart city" has taken on different meanings depending on the various stakeholders involved in urban development processes (Papa et al., 2015). However, with the advent of AI, an innovative processing mode is spreading, whose speeds, potentials, and effects on the city are still unexplored. Starting from the analysis of the relationship between city and technology and adopting a renewed proposition of the holistic-systemic paradigm for interpreting urban and territorial transformations, this paper describes the possibility and necessity of constructing a new dimension of urban planning capable of consciously utilizing the enormous, yet not entirely known, potential of the new artificial reasoner. In particular, it emphasizes the AI's ability to analyze and formalize systemic connections and interactions rapidly. The point on which this contribution intends to prompt reflection within the community of scholars of urban phenomena, in this particular moment of "technological singularity", is the need to define a new dimension of urban planning using approaches well-known in the discipline, such as the systemic one.

2. City and technology: a diachronic literature review

Throughout its evolutionary history, humanity has consistently witnessed the development of technological changes that have impacted its evolution to varying degrees. However, as previously emphasized, we are now facing a groundbreaking shift in the relationship between cities and technology, unprecedented in history. Scientific literature is rich with reflections and in-depth analyses of the relationship between cities and technology, considering the systemic approach as an interpretative reference. The exploration of this theme dates back to the 1960s and 1970s with studies on the network city, initially rooted in a sociological approach (Barnes, 1972). However, applying algebraic analysis methods (Craven & Wellman, 1973) reflected the contemporaneous development of urban modelling and the systemic approach. In Italy, notable reflections on the systemic approach and its adoption for analyzing the relationship between technology and cities can be traced back to the studies of the Turin groups (Bertuglia et al., 1987) and the Neapolitan group led by Corrado Beguinot (1989). The 1990s witnessed an interesting evolution in the international debate, reflected in studies on the informational city (Castells, 1989), proposing a new approach for innovative analysis, methodologies, and research in economic innovation, urban development, and new media. Particularly noteworthy is the fundamental contribution of Graham and Marvin regarding the relationship between telecommunications and cities (Graham & Marvin, 1996). In Italy during the same period, scholars of urban phenomena produced an interesting collection of reflections in 1991 (Gasparini & Guidicini, 1990), emphasizing how a new urban order and structure can be considered the final stage of innovation produced by technology. A significant leap in the literature on the relationship between technological innovation and cities is represented by Bill Mitchell's book "City of Bits," which highlights how the city constructs its structure not based on the distribution and intensity of traditional urban functions but entrusts its survival to the ability to produce, process, and transfer information. Bits represent the new atoms of the urban organism and the basic elements of recombinant architecture (Mitchell, 1995). The 2000s were characterized by the construction of the concept of the smart city, primarily developed and disseminated by major global IT companies, proposing a model of a perfect city through the interconnection facilitated by the Internet of Things (IoT). According to a notable definition, a smart city is one that "makes optimal use of all the interconnected information available today to better understand and control its operations and optimize the use of limited resources" (IBM, n.d.). Despite generalist insights (Woetzel et al., 2018), urban planning theorization has been slow to mature in these years, proposing an effective definition of urban intelligence (Fistola, 2013). The exploration of the city as a complex system also finds a new dimension in the contributions of Michael Batty (Batty, 2009), who introduces reflections on big data, observing a significant shift in the nature of information available regarding events, locations, and timing within cities (Batty, 2013). Similar reflections are formulated in other interesting studies (McGreevy, 2017) and in the definition of the senseable city (Ratti, 2011), which, only a few years later, allows the development of studies on the digital twin as an environment for city management and planning (Ferré-Bigorra et al., 2022) and, more recently, on the city of AI. The relationship between smart cities and AI has been investigated in some interesting studies examining how AI could contribute in various fields of urban activities (Rjab & Mellouli, 2019). Recent studies on the Artificial Intelligent City (AIC) focus on the nature of this new urban structure, starting from the definition that considers the AIC: "a urban community that functions as a solid system of systems, and whose economic, social, environmental, and governmental activities are based on sustainable practices guided by AI technologies, helping us achieve social good and other desired outcomes and futures for all human and non-human beings" (Yigitcanlar et al., 2020). In extreme summary, carrying out a general examination of the literature it is highlighted that the topic has been of interest since 2010 with an explosion of contributions which from 2020 to date exceed 300 articles (Koumetio Tekouabou et al., 2023). What seems relevant to investigate further, and this paper attempts to do so, is the definition of a methodological background that starts from the systemic interpretation of the city. Even in the cited paper, a reference for many subsequent reflections, it is evident how the systemic interpretation is closely linked to the new technological structures of the city. In other terms, what remains to be completed, and this contribution moves in that direction, is an in-depth analysis of the role that AI can concretely play, if properly adopted, in urban planning processes, both in its interpretative role in the systemic approach and in the operational definition and construction of regulatory frameworks for city governance and management.

3. City as a complex system

As briefly mentioned previously, the development of the systemic approach to the study of urban phenomena began in the 1960s. The General System Theory by Ludwig Von Bertalanffy (1968) remains the reference text through which the theory of the urban system was developed. Given that cities are dynamically complex systems, they necessitate a theoretical model to comprehend their temporal evolution, model their complexity, and ascertain their components (Papa et al., 2021). In this way, the study by Sundstrom and Allen (2019) highlighted that complex systems can be dissected into structural and procedural elements across spatial and temporal scales. They proposed an adaptive cycle, based on Holling's (1986) phases: growth, conservation, release, and reorganization. During the growth phase, resources are utilized, while conservation leads to increased rigidity, potentially resulting in a loss of resilience.

The release phase involves the dissipation of accumulated energy, prompting the need for reorganization.

In the reorganization phase, the system may either maintain its original structure (predictable trajectory) or adopt a wholly different configuration (unpredictable trajectory).

In summary, it is possible to affirm that the systemic approach, also deepened in the study of urban complexity formalized through fractal functions (Batty, 2009), remains, to date, the most capable of explaining the transformation of the urban system and other systems in physical reality (Sanders et al., 1997), for which interactions among parts represent the key to understanding their behaviour (Parisi, 2021). This approach considers the territory as a complex system that evolves autonomously in space and time, and for which technology represents a dynamically powerful catalyst.

The "liquidity" of society (Bauman, 2011) finds in fluid and widespread technology its ideal context, its breeding ground, the most fertile territory for development.

4. City and technology: a new digital revolution

A notable statement by Schumpeter in 1942 reads: "In a free and capitalist society, innovation can impact certain sectors so intensely as to compel the societies within them to evolve, under penalty of extinction" (Schumpeter, 2001). The innovation of technique and technology has always been a determinant in the evolution of humanity. Among the determinants of urban change that characterize many dimensions of the contemporary city, technological change plays a fundamental role in understanding and envisioning future scenarios. The widespread adoption of new technologies in all fields of human activities is substantially influencing the behaviours and usage patterns of the city or its inhabitants. The phenomena of virtualization of activities settled in the territory are gradually altering the functional layout of cities, redefining models of location and distribution of functional weights. Technology has exerted its transformative power on human settlements by acting on production systems and social interactions.

Throughout history, humans have always interacted by exchanging symbolic forms or initiating communicative processes within a shared physical space. Digital technologies have progressively challenged this model, and the spread of multimedia systems has generated new forms of social interaction, gradually transforming the community's use of urban space, as a part of urban planning research foresaw about two decades ago (Fistola, 2003). New communication is slowly, invisibly but probably irreversibly, transforming the primary place of information processing and circulation: the city (Meier, 1962). Attempting an extreme synthesis of the relationship between technology and human activity, one can propose the paradigm of the three S's: Sustain, Support, and Substitution (Fig.1).

Technological advancement has undoubtedly played a decisive role in the progress of human activities. In the first phase, technological innovation sustained humans by opening new dimensions of activity. Subsequently, technological innovation has offered concrete and growing support in many human activities. Currently, also thanks to the advent of AI, human activities are almost entirely carried out by digital agents that tend to replace human action.

The advent of AI, currently declared for use in various human activities, has opened unimaginable scenarios until just a few years ago and is producing a significant acceleration between the S's of the paradigm. In other words, considering the most advanced research, AI facilitates the transition between the last two S's of the paradigm. In a short time, there will be a shift from supporting human activities to almost complete substitution. The comparison between AI and human intelligence, already proposed in interesting and detailed studies, will not be delved into here (Slaughter, 2024).

Fig.1 The three S's paradigm shows the relationship between technological innovation and human activity

AI is currently used in many fields of human activity. Its applications range from identifying new drugs and antibiotics capable of saving human lives (the case of Halicina is emblematic in this sense) to decoding the text of ancient scrolls in Pompeii and identifying dinosaur footprints by palaeontologists with 90% reliability, as happened at Lark Quarry. In the consideration of AI usage, we are currently in the support phase; in other words, humans use the artificial reasoner's rapid similarity consideration and analysis capacity for countless interactions. In general considerations, it is undoubtedly clear that AI's development promises rapid advancements for humanity in many fields, and medical-scientific research is undoubtedly the most interesting. Sequencing the human genome took ten years of research and a total expenditure of five billion dollars. Today, with AI support, it is possible to process a personalized anti-tumor vaccine for a patient in just two months. As in all previous cases of scientific-technological discoveries, the dilemma posed by Oppenheimer arises, stating that technology with enormous potential can be used for good or to support processes of destruction. In this sense, it should be considered that AI has quickly led to the discovery of antibiotics, such as Halicina, capable of resolving severe human conditions.

Through Google Deep Mind's Graph Network for Material Exploration (GNoME), 2.2 million new materials (inorganic crystals) were discovered, among which 380,000 are particularly stable and essential for advanced applications in energy, electronics, and mechanics (Merchant et al., 2023). Finally, thanks to Google Deep Mind and the use of imitative AI, students and professors at Stanford University have developed a robot known as Mobile Aloha, capable of assisting humans in all domestic activities (Zhao et al., 2023). Another interesting aspect of AI lies in its potential as a transformative agent of key systems of human organization (social, economic, etc.), as emphasized by relevant studies on the topic of Transformative Artificial Intelligence (Gruetzemacher & Whittlestone, 2021). On the other hand, it is known that AI has already been employed for military purposes and operations targeting the elimination of human agents and the destruction of infrastructure. It should also be considered that the extreme speed in the generative processes of AI could lead to a dimension of consciousness/sentience, as demonstrated by Google Synthesia's AI (built through LaMDA) and experienced by Lemoine, who subsequently resigned. In this sense, the experience of the AI software AlphaZero is significant. This software, designed to play chess, won in 2018 against the most advanced existing software, executing moves that were not previously recorded in its memory during the learning phase but were autonomously generated to achieve the goal of winning the game (Silver et al., 2018). A new form of partnership between humans and machines is emerging: humans first define a problem or goal for the machine, and then the machine, operating in a domain beyond human reach, identifies the optimal process.

5. AI and Urban System: a new interpretative paradigm

As underlined before, the advent of AI has transformed our perception and interaction with urban spaces, giving rise to the widely recognized concept of AI cities (AIC). These advanced urban settings harness AI technologies to enhance different facets of city living, such as transportation, energy consumption, public safety, and more. In this document, we will delve into a holistic view of AI cities, examining the diverse influence of AI on urban infrastructure, governance, and the overall urban environment. Through a thorough analysis of the intricacies and interconnections within AI city systems, our goal is to achieve a comprehensive understanding of how AI is redesigning the contemporary urban landscape. To understand the role that AI can play in defining a new urban and territorial planning, it is necessary to reconsider the specifics of the systemic approach, briefly outlined in the previous paragraph. The city is a complex system articulated into interacting subsystems. As already explored in other studies (Fistola, 1992), it is possible to schematize this interpretation by considering the elements that constitute the urban system and the active relationships among them (Fig.2).

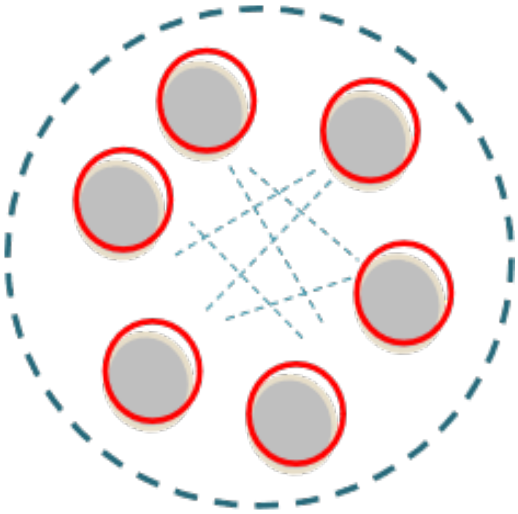

Fig.2 The system in its conceptual representation composed of elements in relation (interaction) with each other

Considering the properties of complex systems, it can be affirmed that the elements themselves constitute subsystems. To construct an effective model of the city, certain subsystems are considered useful for understanding and modelling the behaviour and functioning of the entire system (Fig.3).

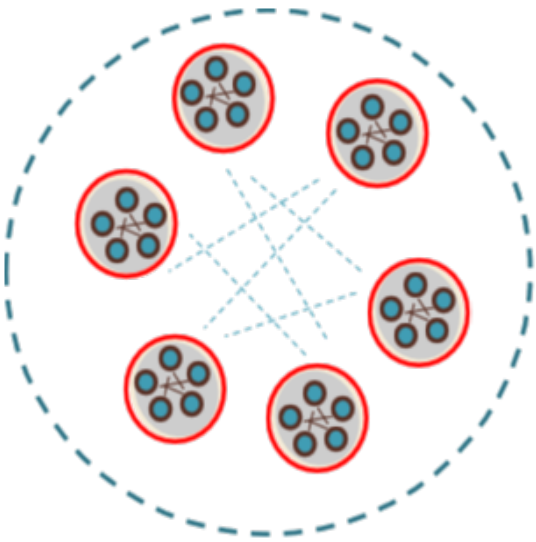

Fig.3 The system in its conceptual representation in which the parts represent subsystems in relation to each other. Each subsystem contains, in turn, other subsystems

In other words, thanks to the systemic approach, it is possible to identify a significant number of component subsystems: the geo-morphological subsystem (constituted by the physical substrate of the territory), the socio-anthropological subsystem (represented by the human component that adapts space and settles activities), the physical subsystem (directly represented by the urban artefact and the material component of the city), and the functional subsystem (consisting of functions performed within anthropic spaces). There is also another subsystem to consider among others, namely the psycho-perceptive subsystem, which considers the mental image that each citizen constructs within themselves through the perception of the space around them (Lynch, 1964). Moving from this approach, it is possible to affirm that the urban subsystem most impacted by IT is currently attributable to the social component of urban settlements. A further insight, which would further complete the reflection, could be formulated by distinguishing the material part of the city from the abstract component or the natural from the artificial. In this regard, interesting contributions have been made with arguments that, based on systemic complexity, come to ontologically distinguish the human artifact within the pre-existing natural environment (Cameli, 2020). The new technologies: widespread, pervasive, invisible, portable, wearable, and soon even "implantable," guide actions, dictate behaviours, direct movements, and characterize relationships. As highlighted by studies conducted by Giorgio Parisi, Nobel Prize winner in Physics 2021, in complex systems, what is crucial to study, formalize, and understand is the structure of relationships (Parisi, 2021). Relationships determine the autonomous and somewhat endogenous evolution of the system that proceeds in space and time. In the case of the urban system, they are fundamental to understanding its evolution and transition (Gargiulo & Papa, 2021).

Urban planning is a discipline of foresight (Carpentieri et al., 2023); it envisions the arrangement of human settlements in the future, seeking to understand how subsystems will evolve due to the relationships that activate among them. In this sense, AI can play a crucial role if it is possible to build an innovative theoretical-disciplinary layout that adopts and guides procedures and actions.

Through further exploration of urban complexity, one can envision an evolution of the proposed conceptual framework for the interpretation of modern metropolitan settlements. It is indeed possible to imagine that the systemic articulation does not lie on a single plane, but the multiplicity of urban subsystems suggests a multi-dimensional organization. In other words, in a preliminary hypothesis, one can think of a representation containing not a single systemic plane but a star of planes in space (Fig.4).

Each of the planes contains a system with its subsystems connected through the axis of the star. In this topological space, interactions between different systems take place.

Following this conceptual development and iterating the systemic planes n times, it is also possible to arrive at a deeper understanding.

This reflection is based on the following fundamental considerations:

- the star of "n" planes defines a three-dimensional topological space;
- this space with indefinite boundaries is of a fuzzy type, given that the city and the territory are open systems;
- the structure of interactions is articulated among all parts of the systems.

Remaining within a conceptual prefiguration, it is possible to imagine the existence of a "relational fluid" in which the different systemic elements are immersed (Fig.5) and that extends indefinitely.

This conceptualization allows us to recognize, as stated, the importance of inter-systemic relationships declared in the holistic-systemic approach with the formula: "The whole is not equal to the sum of the parts".

The limitation that has always characterized the systemic approach in all its fields of application (from neurology to particle physics to the study of the universe and beyond) is attributable to the difficulty of considering and classifying the relationships activated among the parts of the system.

Today, thanks to AI it's possible to understand the composition of the relational fluid by analyzing all the relationships inside it.

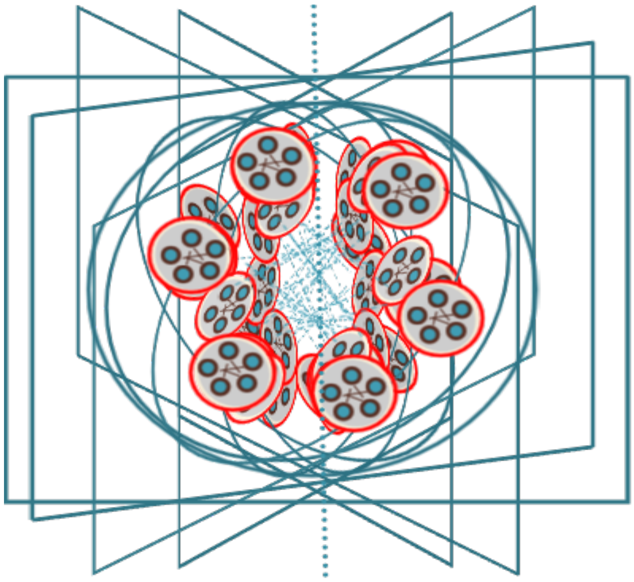

Fig.4 The star of systemic planes with the axis of connection for relationships

This is what has happened in all the cases mentioned earlier (the discovery of new antibiotics or protein structures, etc.) to analyze and classify, with very high speed, all relationships and their potential effects on systemic and sub-systemic components.

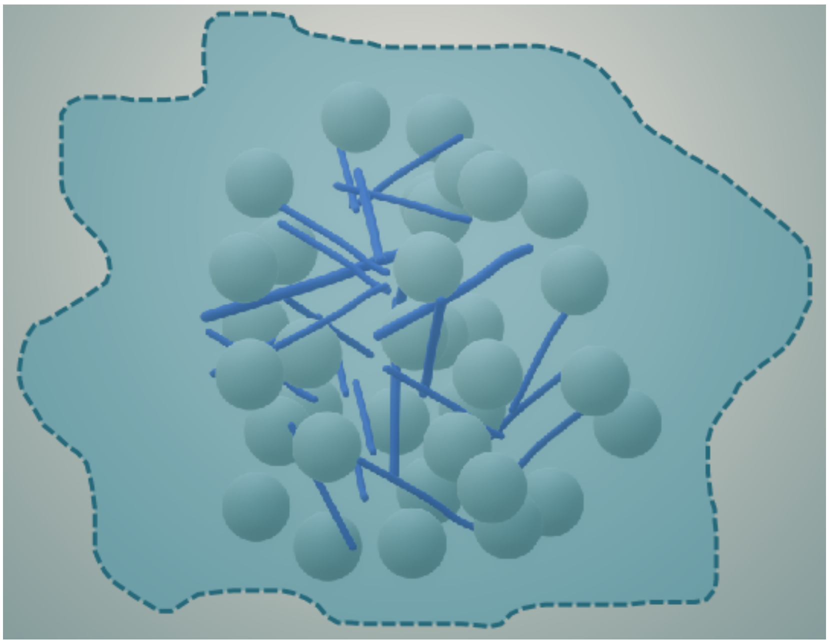

Fig.5 Conceptual image of the system and sub-systems immersed in the communicational fluid

This capability would allow for the rapid assessment of the best actions to activate in the urban system to properly govern its transformation. In an era of resource scarcity and necessary ecological transition, the preservation of natural resources and the appropriate consideration of ecosystem services (Fistola, 2023) become extremely relevant in the urban planning process, which must be innovated by consciously adopting technological innovation. In this sense, the overcoming of the smart city is configured, and a new urban smartness is envisioned characterized by effective collaboration between humans and machines.

6. Discussion and future developments

The proposal to consider the city as a dynamically complex system interpretable through the systemic approach (Fistola & La Rocca, 2013), which may seem outdated in its original formulation, can still hold scientific relevance given the potential offered by technological innovation, with AI being its most advanced expression today. This methodological proposal implies a redefinition of theories and approaches that have characterized urban and territorial transformation governance since the post-war period. It is no longer possible to ignore or simply add technology to the city, as seen in some cases of constructing smart cities. In particular, with smart cities, largely attributed to the desire of major IT companies to commercialize devices and systems capable of interacting in the IoT, urban theorists had to subsequently construct a disciplinary path that took into account the technology already widespread in the territory and society. In other words, scholars of urban phenomena have always had to chase technological advancements and try to construct, ex-post, a theoretical-disciplinary framework that encompasses their transformations. Focusing solely on the technological dimension, urban areas already have "urban control rooms" processing real-time data from sensors within the city and various IoT devices, constituting a sort of digital twin. Within such systems, AI algorithms can be implemented to manage and resolve anomalous or crises (Kissinger et al., 2023). An example of great interest in this regard is the Snap4City platform (www.snap4city.org) currently in use in many urban areas. These systems could represent elements of the transition from the smart city to the Artificial Intelligent City and need to be considered in defining new theoretical paths for governing urban and territorial transformations. Moving beyond the purely technological perspective, there is now a need to build a theoretical-disciplinary background that, considering the generative potential of AI, appropriately adopts its capabilities to envision sustainable future configurations of the urban system compatible with available resources (Sanjo, 2023). For smaller urban systems, a conceptual prefiguration could involve AI automatically proposing territorial zoning and regulatory frameworks based on information, data, and examples of cyber tools for territorial governance with similarities to the specific urban settlement. While such automatic propositions have the limits of imitative construction, they might offer a possible urban planning for the interest of local administrators who need territorial governance tools within their administrative period. This type of AI usage could lead to dangerous trends in urban and territorial transformations. However, this consideration deserves specific exploration, which is beyond the scope of this paper but certainly subject to future developments.

7. Conclusions

The debate on the role of AI in urban planning has already produced interesting insights (Sanchez et al., 2023). However, this paper emphasizes the need to change the perspective regarding the significant change that AI is producing in every aspect of human activity. In studying urban phenomena for developing actions in territorial transformation governance, it is necessary to adopt AI in interpreting the transformations of the city system. This is possible today thanks to the potential of AI to formalize the structure of systemic relationships and enable the prefiguration of future states of the urban system. We are currently witnessing a transformation in which entire sectors are incorporated into AI-assisted processes, making it sometimes difficult to distinguish between purely human decisions, purely artificial decisions, or the result of collaboration between humans and AI. Today, the digital revolution cannot be considered solely a "technical" revolution; it must be placed among the "ethical" revolutions capable of modifying the actions and interactions of individuals within anthropized contexts. This reflection has long been shared among scholars who believe that technological innovation represents an evolutionary determinant capable of "guiding" anthropic systems and their components (social, functional, economic, etc.) toward new evolutionary configurations. The transformation is no longer just the adoption of advanced technical tools for service production, but it is in the producers themselves modifying their behaviours due to the introduction of new technological dimensions capable of reconfiguring citizens' relational systems and, as mentioned, their way of acting and interacting in the city. As recently noted, the revolution is not only "digital" but probably "mental". AI, fueled by new algorithms and increasingly powerful and inexpensive computing power, is spreading almost everywhere. The advent of AI will change humanity's conception of reality and, therefore, of itself. We are moving towards great enterprises, but these enterprises should lead us to a more general philosophical reflection. This paper attempts to propose a different way of looking at technological innovation in the field of urban planning and to issue a warning to scholars and practitioners. With AI, we will not see what happened in the past when various technological devices were used to support planning actions, but we will be able to act to prefigure a new background panorama, the contours of which need to be outlined today. "What we need now [...] is a real push for demonstrating how AI can be used in urban analysis and city science, in urban planning and design. In this quest, we need a concerted effort to explore the limits of AI in our understanding of cities, in how we can invent new ways of automating functions within cities, and within the wider context of their urban planning" (Batty, 2018).

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Author's profile

Romano Fistola

Architect, Full Professor in Urban and Regional Planning at DICEA, University of Naples Federico II. His main research interests, developed over more than thirty years of scientific activity, are related to the study of the relationship between technological innovation and urban and territorial transformations, the interpretation of the city as a dynamically complex system, and the urban transformations induced by the climate crisis. In recent years, he has also focused on the possibility of envisioning urban transformation through the use of augmented and extended reality, as well as on the impacts of Artificial Intelligence on the functional and socio-anthropic systems of human settlements.

Rosa Anna La Rocca

Architect, Ph.D., Associate Professor in Urban and Regional Planning at DICEA, University of Naples Federico II. Her research activities refer to the analysis of phenomena that can change the urban organization and they are focused on the study of three main relationships: tourism and town planning; land use and mobility, innovation technologies and urban transformations.

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Measuring the walkability of areas around Addis Ababa LRT stations by integrating Analytic Hierarchal Process (AHP) and GIS

Ashenafi Wondimu Tekolla [a]*, Abrham Gebre Tarekegn [b], Getu Segni Tulu [c]

[a] African Railway Centre of Excellence (ARCE)
Addis Ababa University, Addis Ababa, Ethiopia
e-mail: ashenafi.wondimu@aait.edu.et
ORCID: https://orcid.org/0000-0002-3372-8933
* Corresponding author

[b] Civil and Environmental Engineering Department,
Addis Ababa Institute of Technology
Addis Ababa University, Addis Ababa, Ethiopia
e-mail: abrham.gebre@aait.edu.et
ORCID: https://orcid.org/0000-0003-0172-2905

[c] Civil and Environmental Engineering Department,
Addis Ababa Institute of Technology
Addis Ababa University, Addis Ababa, Ethiopia
e-mail: getusegne@yahoo.com
ORCID: https://orcid.org/0000-0001-8392-7466

Abstract

Creating suitable walking conditions is the primary objective of sustainable urban models such as Transit Oriented Development (TOD). Walkable built up area benefit cities economically, environmentally, socially and improving public health. This can be utilized by creating suitable streets that enable people to access their daily needs walking without relying on private cars. Therefore in planning TOD, the existing walkability of the areas around transit station should be investigated taking factors that encourage walking into consideration. The objective of this research is find spatial method to measure the existing circumstances that encourage walking around Addis Ababa LRT stations by integrating the Analytic Hierarchy Process (AHP) and Geographical Information System (GIS). The results clustered areas with similar levels of walkability in group and represent them with different colors. The finding the study revealed that the majority of the study areas (approximately 72.35%) were classified as fairly walkable, 19.47% of the study area clustered as not walkable and only 8.15% clustered as walkable. This result is expected to offer valuable insights for urban planners and decision-makers to pass calculated decision to enhance walkability of the areas. As this method continues to advance with technologies it will play crucial role in planning TOD focusing on shaping the future of urban walkability and creating sustainable cities.

Keywords: Addis Ababa; Analytic hierarchy process (AHP); Geographical information system (GIS); Transit oriented development (TOD); Walkability; Weighted overlay analysis.

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1. Introduction

Easy access of people to their daily needs by walk within a built-up environment is essential criteria of sustainable urban development (Distefano et al., 2023; Moayedi et al., 2013; Rafiemanzelat et al., 2017; Talen & Ellis, 2002) and it is the right of all walks of life including people with disabilities (Erçetin, 2024). In the research aims to highlight the potential of insight in terms of integrated approach towards urban mobility and accessibility through the adoption of user-centered paradigm (Costa & Delponte, 2024) stated contemporary individual needs certainly require to shape mobility in order to assure universal access to facilities and opportunities. Many researches such as (Fang et al., 2023; Lamour et al., 2019; Toralles, 2023) have stressed that creating walkable environments is essential components of Transit Oriented Development (TOD) that promote sustainable urban development. TOD emphasizes high density, diverse land use, and pedestrian-friendly design around transit stations (Berawi et al., 2020; Cervero & Kockelman, 1997; Distefano et al., 2023; Ganning & Miller, 2020; Kumar et al., 2020; Mirmoghtadaee, 2016). Despite walking being the most common, cost-effective, environmentally friendly, and healthy mode of transport (ITDP, 2017; Loukaitou-Sideris, 2020; Schmeidler, 2014), recent urbanization trend focusing on motorized transport than walking. To address this issue, several sustainable urban development models have been proposed, including neo-traditional development, compact city, smart city, eco-city, and TOD (Jabareen, 2006; Rossetti et al., 2020). In all these sustainable development models, creating pedestrian friendly, walkable environment is considered crucial criteria. However this can be achieved through well-connected streets design, ensuring safety, promoting diverse land use, and increasing the number of commercial facades (Lamour et al., 2019) street amenities such as sitting areas and street lights along the walking street.

Walkable conditions benefits a city in various ways such as reducing traffic congestion, reduction in traffic casualties, reducing greenhouse gas emissions, increasing economic vibrancy along the street and increasing social cohesion (Khare et al., 2021a; T. Litman, 2017; T. A. Litman, 2003). Moreover it benefits personal health since it encourages physical activity, thereby promoting fitness, combating chronic diseases, such as obesity (Baobeid et al., 2021; Boarnet et al., 2008; Ewing & Cervero, 2010; Hossein Pour et al., 2018; Zapata-Diomedi et al., 2019). In planning to implement TOD, the existing walkability of areas to access transit stations and other important destination need to be investigated. This requires rigorous assessment that considers multiple variables (Baobeid et al., 2021; Ha et al., 2015; Knapskog et al., 2019; Naharudin et al., 2020). Researchers have used different methods and considered different variables to measure the walkability of an area, depending on the objectives, availability of important data and local conditions (Knapskog et al., 2019; Lu et al., 2018; Pilgram & West, 2023). Some studies have attempted to measure walkability at various scales, including citywide (Jeong et al., 2023; Kim et al., 2019; Telega & Telega, 2021), neighborhood (Ensari et al., 2023; Kim & Kim, 2020), and small areas around transit stations (Jeffrey et al., 2019; Naharudin et al., 2020; Pilgram & West, 2023; Shaaban et al., 2018). Regarding the type of data, some use subjective data, such as pedestrians' perception (Naharudin et al., 2020), whereas others use objective data. Spatial methods of measuring walkability of areas can provide valuable insights for urban planners and policymakers to identify which areas are suitable for walking or not. It would also help identify and prioritize the places that need intervention to improve walkability level. Therefore, the objective of this research is to find suitable spatial method to assess the walkability of an area, within an 800-meter radius around the Addis Ababa LRT stations by integrating the Analytic Hierarchy Process (AHP) and Geographic Information System (GIS). AHP enables the analysis of multiple variables in a hierarchical manner, whereas GIS allows visualization and analysis of spatial data and produces a thematic map. The result displays areas with the same level of walkability in clusters and represented them in different colors. Therefore, this study is guided by three research questions:

1. What are the main variables (performance indicators) for walkability of area around transit stations in urban environment particularly Addis Ababa?

2. What is the significance of these performance indicators compared to each another?
3. How the walkability level of areas around of Addis Ababa LRT stations could be spatial evaluated?

To address these research questions, the study has the following specific objectives:

- Identify the main performance indicators (variables) of walkability in the context of Addis Ababa;
- Weight the significance of these variables among each other to impact walkability using the AHP;
- Find suitable way to integrate AHP and GIS to measure the walkability level of the area around four Addis Ababa LRT stations.

The remains of this paper are organized as follows: The next section provides a literature review on walkability, the main variables of walkability, methods used to measure walkability, and the integration of AHP with GIS. Section 3 describes the methodology employed in this research, focusing on weighting the significance of identified variables and the integration of AHP results in GIS through Weighted Overlay Analysis. Section 4 presents the results and finally section 5 summarizes the research, provides conclusions, and suggests future research areas.

2. Literature review

Walkable environment around transit station is the main prerequisite for TOD (Higgins & Kanaroglou, 2016; Jeffrey et al., 2019; Md. Kamruzzaman et al., 2014). In the research by (Pongprasert & Kubota, 2019) highlighted the significance of walkability by investigating the attitudes of TOD residents towards walking to transit stations. Measuring the walkability of the areas around transit stations is an important step (Khare et al., 2021a; Pilgram & West, 2023; Telega et al., 2021; van Nes, 2021) in advance of implementing TOD. Developing a method to measure walkability of urban areas for the purpose of improving its suitability to walk is utmost crucial (Hossein Pour et al., 2018).

2.1 The benefit of walkability in TOD

Walkable condition in TOD area reduce reliance on private cars, reduce traffic congestion, stimulate economic development, improve health outcomes, fostering a sense of community, and promoting environmental sustainability (Baobeid et al., 2021; Iamtrakul et al., 2021; Khare et al., 2021b; Wey & Chiu, 2013). Since benefits of walkability are multifaceted the focus of researchers varies based on perspectives and objectives the research. For example, a study by (Wey & Chiu, 2013) highlights the significance of pedestrian-friendly design in reducing automobile use, while (Lamour et al., 2019) focuses on the safety and security. Another study by (Lu et al., 2018) underscores the importance of walkability in sustainable planning strategies, and (Pongprasert & Kubota, 2019) emphasizes its benefits in terms of convenience, safety, and environmental concerns. Improving accessibility to important destinations and supporting strategic economic and sustainable urban development is considered by (Schlossberg & Brown, 2004). It also fosters social cohesion by encouraging interaction among individuals and encourages buying daily needs from local store, thereby support the local economy and strengthen the sense of community. Economically, walkability increases transit ridership, reduces transportation costs, facilitates business growth, and lowers infrastructure expenses and reduce housing problem (Gerardo et al., 2019). Environmentally, walkability yield positive outcomes in terms of low-carbon emissions, which is crucial for climate change adaptation (Baobeid et al., 2021; Ewing & Cervero, 2010). Generally, walkability is the core component of contemporary sustainable urban development models'.

2.2 Influencing variables (performance indicators) of walkability

In order for pedestrians to choose walking for their daily trips, certain encouraging conditions should be in place. Various studies have proposed different criteria for walkability based on objectives, perceptions, and the availability of important data for analysis. The most critical components of walkability are activities within the neighborhood, accessibility, structuring street network, safety, attractiveness and users density of streets (Batman et al., 2024). The Victoria Transport Planning Institute (VTPI, 2011) identifies pedestrian facilities, walkway condition, land use patterns, community support, security, and comfort as the main indicators (Rohana, 2015). The London Planning Advisory Committee takes a different approach and emphasizes connectivity, convenience, comfort, conviviality, and conspicuousness, calling them the '5C' features (Moura et al., 2017). Later on two more features such as coexistence and commitment, were added, making a total of '7C'. These seven features were measured using a set of 17 key indicators known as the Indicators of Accessibility and Attractiveness of Pedestrian Environment (IAAPE). In a research technique to quantitatively analyze walkability (Schlossberg, 2006) presented street network classification, pedestrian catchment areas and intersection density as the influencing variables. In the development of a conceptual framework to assess walkability in Malaysia, comfort, connectivity, convenience, conviviality, and conspicuousness were identified as the main indicators, endorsing the approach taken by Transport for London (Naharudin et al., 2020) . In another research by (Frank et al., 2005) identified building density, land use mix, and connectivity level. All the above literatures suggest different criteria that encourage walking within urban environment, however it is firm believer of the authors that it also depend on existing local condition of the city.

2.3 Methods of measuring walkability

There are numerous studies that have presented different methods for measuring the walkability of an area. The methods vary based on the objectives, perception, and scale of the study area. Additionally, the approaches used for analysis can differ depending on the type of data being used (subjective or objective). For measuring the walkability of an urban area (Telega et al., 2021), categorized the methods into four groups: (i) subjective methods based on surveys, interviews, and questionnaires; (ii) subjective methods using direct audit tools or stock-taking; (iii) objective methods utilizing GIS tools; and (iv) mixed methods. This approach they integrated open source spatial data and utilized the Kernel Density and Line Density tools in ArcGIS software to measure the walkability in Krakow, Poland. In measuring the walkability of a pedestrian street (Naharudin et al., 2020) combined ANP and GIS and integrated subjective and objective data. In a study conducted in Melbourne, Australia by (Cowie et al., 2016) , the walkability of areas around 230 train stations was measured using road density to identify "sweet-spots" (high walkability-low weighted road density) and "sour-spots" (low walkability-high weighted road density). A study in assessing the most suitable walkable path in Shiraz city, Iran (Schlossberg, 2006), integrated GIS, remote sensing, and multi-criteria evaluation (MCE). An objective walkability index was developed by (Frank et al., 2004) considering parameters related to people's health using GIS, which consisted of the sum of residential density, intersection density, and land use mix as indicators. In recent research aimed at promoting the environmental benefits of walkability (Jeong et al., 2023), combined a walkability index and transit accessibility index to create a walkable, transit-friendly metropolis. The potential of integrating AHP with GIS to measure walkability has been highlighted by studies such as (Gervasi et al., 2018; Lee et al., 2013; Rossetti et al., 2020; Schlossberg, 2006). AHP allows for assigning weights to each factor based on their relative importance, while the weighted overlay tool in GIS can calculate the walkability of areas. This index can then be used to identify areas with higher or lower walkability and prioritize interventions to improve walkability.

3. Methodology and data used

The methodology entails identifying key factors that contribute to a pedestrian-friendly environment, gathering data to analyze each variable, prioritizing the variables based on their influence, and evaluating the walkability of areas surrounding the stations. The research establishes six performance indicators, namely street network density, intersection density, land use diversity, business activities along the route, safety and security features, and comfort of street. AHP is then employed to determine the significance of these indicators. The walkability level of the areas around the four Addis Ababa LRT stations is finally measured by integrating the result of AHP into GIS using the weighted overlay tool. Spatial data for the areas around four selected stations is extracted from a geospatial database of the study areas. The vector layer is converted into a raster layer and reclassified to ensure easy integration into GIS. The weighted overlay analysis tool is utilized to combine the AHP results with the reclassified raster layer in the GIS software. Each indicator's percentage score from AHP is multiplied by the corresponding cell value in the reclassified raster layer. The sum of these results for each grid cell provides an overall value for the walkability level of the areas. The final outcome is then plotted on a spatial map. The methodology is illustrated in Fig.1.

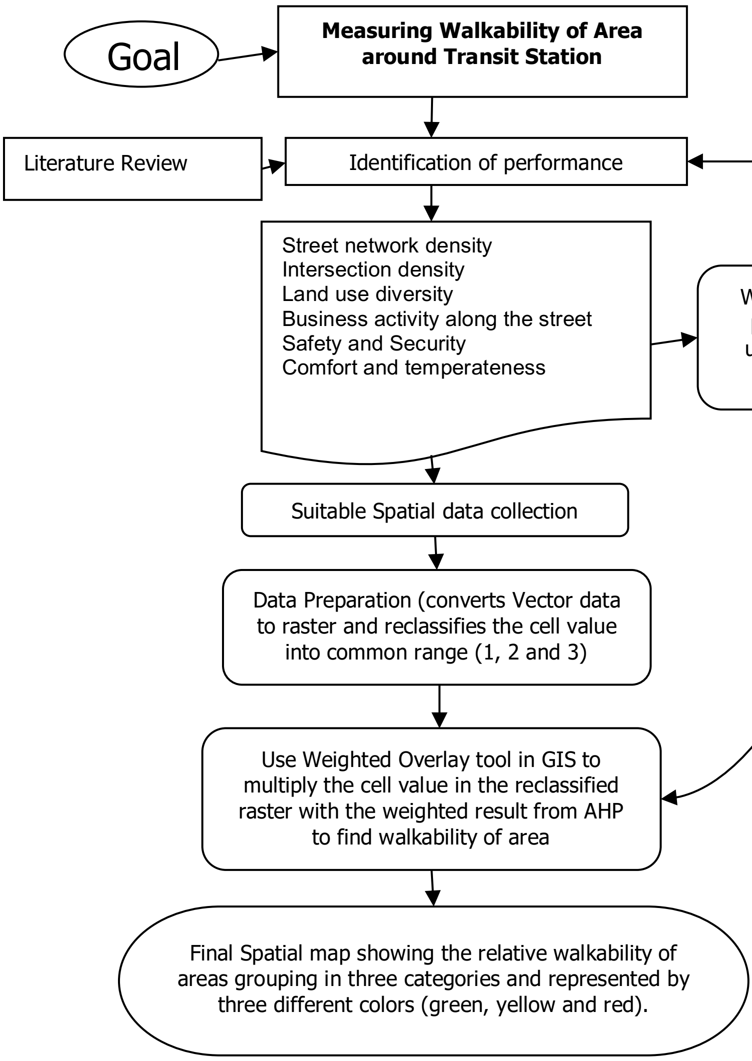

Fig.1 Schematic representation of methodology

3.1 Study area

Addis Ababa is the economic, political and diplomatic capital of Ethiopia with political boundary of 572 square kilometers and located at the central core of Ethiopia at an average elevation of 2,400 meters above mean sea level. The population and housing census which has been scheduled for 2017 delayed due to domestic security concern to 2020. The delayed 2020 census was rescheduled again in response to COVID-

19. Therefore according to 2007 population and housing census the population of Addis Ababa is more than 2.7 million with an annual growth rate of 3.8% per year.

The city has experienced unprecedented horizontal expansion and informal settlements that has caused political instability due to encroachment of surrounding farmland. It is also the main reason that has exacerbated the ousting of the central government from power in 2018. With the purpose to analyze the physical extent and proportion of population living in formal and informal settlements in Addis Ababa (Berhanu; et al., 2024) find out that informal area constituted 61% and 59% of the residential land use in 2011 and 2022, respectively.

To address long standing transportation problems in the city, the Federal Government, in collaboration with the Addis Ababa city administration, implemented the Light Rail Transit (LRT), connecting the four corners of the city to the central Business District (CBD). Ever since LRT's commencement in September 2015, is has played a significant role in easing transportation problems. However LRT itself faced has faced financial challenges that would jeopardize its sustainability. In addition, the LRT system intended to resolve mitigate traffic congestion, air pollution and GHG emission the system's impact on the environment is criticized due to lack of enough crossing points for cars to cross from one side to the other. TOD is considered as one of the remedial measures to address the financial shortage.

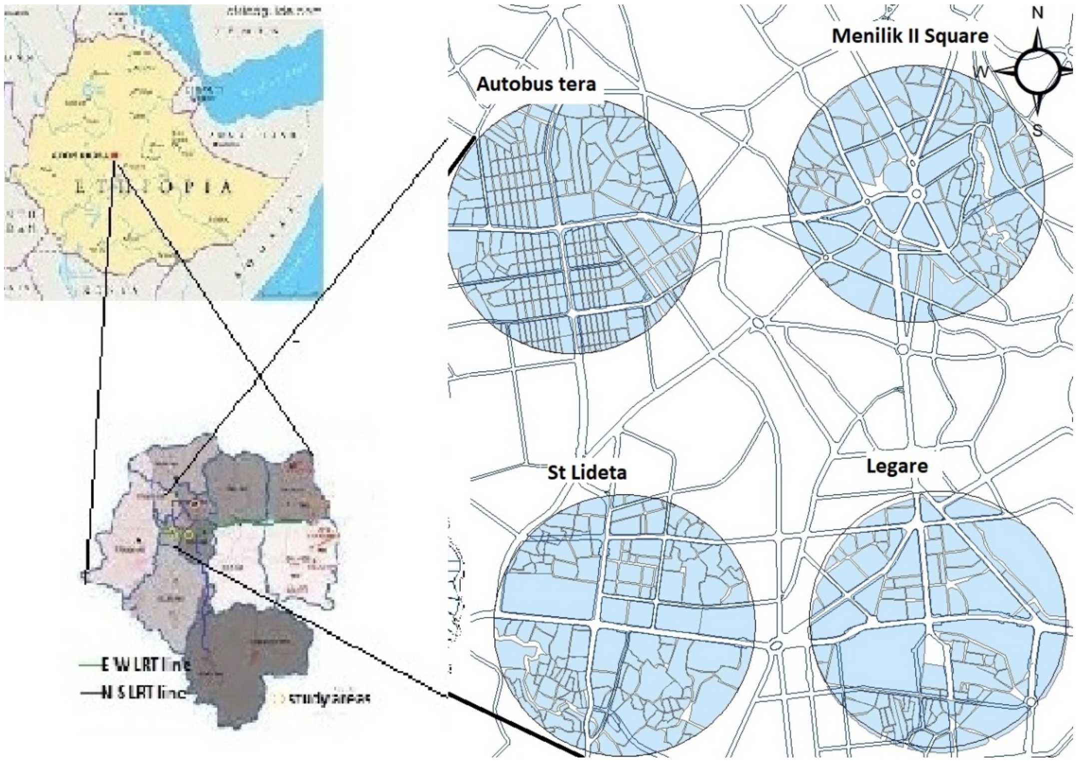

Fig.2 Detail map of the study area

Ethiopian Railways Corporation (ERC), in charge of LRT together with the Addis Ababa City Administration established a steering committee (Tekolla et al., 2021) to oversee the planning and implementation of TOD. The feasibility study has been conducted along the LRT route, focusing on 10 stations, and a detailed bankable feasibility study also been undertaken on four stations mainly located in the central Business District (CBD). These stations are Legare station, St. Lideta station, Autobus Tera station, and Menelik 2nd square station as shown in Fig.2. In order to understand if TOD would be a real solution for the problem, a rigorous investigations need to be performed. One of these investigations is measuring the existing walkability of built-up area around the transit station. Walkability is defined as a measure of how friendly an area is for walking (Westaby, 2019).

3.2 Identification of the indicators, data collection and preparation for the analysis

The variables of walkability identified in this research are street network density; intersection density; land use diversity; safety of walkways and crossings; business activity and vibrancy along the streets and comfort and temperateness of the street. To analyze the variables primary and secondary data used. The primary data have been collected interviewing experts in the relevant field to weight the significance of multiple influencing variables using AHP. Secondary data is a spatial data extracted from Geospatial Database of the study area. The vector layer converted to raster layer and reclassified to fit for the analysis as shown in Fig.3.

Street network density (SND)

Presence of enough street networks invites pedestrian to walk than taking private car. Thus street network density considered as an influencing factor in most research regarding the assessment of walkability (Frank et al., 2005; Schlossberg, 2006). The data used to analyze street density extracted from Geospatial data of the study area. Vector layer of road network was converted to a raster using the line density tool in GIS and reclassified to the common range of (3, 2, and 1) representing higher, moderate and low street density respectively as shown in Fig.3A.

Intersection density (ID)

Road crossing provides shortcuts for pedestrians to overcome network barriers. Higher intersection density increases connectivity, accessibility and interconnected street network. To analyze intersection density point data was extracted from the geospatial data of the study area. The vector layer was converted to a raster layer using the point density tool in GIS software and reclassified common range 3, 2 and 1 representing higher moderate and low intersection density respectively as shown in Fig.3B.

Land use diversity (LUD)

Land use diversity determines access to various important destinations such as retail shops, public services, and recreational areas (Suminar & Kusumaningrum, 2022). However the interaction of transport and land use are complex and not widely analyzed (Carpentieri et al., 2019) and suggested new governance tools to support territorial transformations for sustainable use of land resources. In this research to analyze land use diversity, data was extracted from the Geospatial data of the study area in vector format and then converted into a raster layer. The raster layer reclassified to a common range (3, 2, and 1), as shown in Fig.3C.

Safety and Security of the Streets

Safety and security play a significant role in the walkability of an area. The streets and crossings must provide encouraging environment for pedestrians, avoiding crime, robbery and traffic fatality (Jamal, 2017). For the analysis of safety and security, the study areas have been tessellated into a 400 by 400 meter vector map. Each cell has been filled with a value based on relative safety and security. If the area is believed to be safe and secure, the cell value is 3; if the area is fairly safe, the cell value would be 2; and if the area is not safe, the cell value would be 1. The vector file was converted to a raster with three cell values (3, 2, and 1) as shown in Fig.3D.

Business activity and vibrancy of the streets

The presence of business activity along the streets enhance walkability as it provides convenient access to a variety of retail shops (Knapskog et al., 2019; Batman et al., 2024). Walking in a city provides ample time to experience everything the ground floors have to offer (Singh, 2016). To evaluate the presence of business activity on the streets, the study area has been divided into 400 by 400 meters grid cells and assigned cell values of 3, 2, and 1 based on the relative number of business on the streets. If business activities good, assign a cell value of 3; if there is a fair amount of business activities, assign a cell value of 2; and if there are less business activities along the streets, assign a cell value of 1. The vector layer then converted to a raster layer to common range 3, 2, and 1, as shown in Fig.3E.

Comfort and temperateness of street

Pleasant and comfortable streets encourage people to walk for more than just commuting such as for recreation. Elements such as street furniture, plantings, overhead lighting, and improved landscaping enhance the appeal of walking (Jamal, 2017). To assess the comfort and suitability of the streets, we divided the study area into grid cells measuring 400 by 400 meters. Each cell was assigned with cell value of 3, 2 and 1 based on the comfort and temperateness of the cell. A value of 3 indicates a comfortable walking area, 2 indicate a fairly comfortable area, and 1 indicates an area that is not comfortable for walking. Then vector layer was converted to a raster layer with values (3, 2, and 1) as shown in Fig.3F.

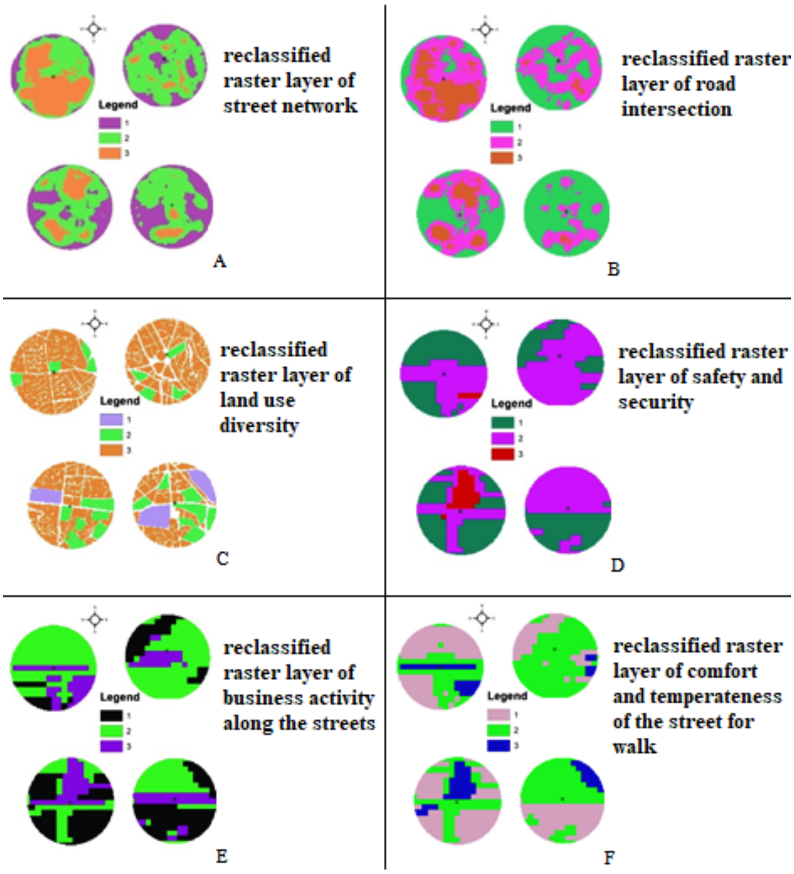

Fig.3 The reclassified data of the indicators

3.3 Weighting significance of walkability indicators

Analytic Hierarchy Process (AHP) technique has been utilized to weight the influence of variables according to their significance. A questionnaire survey was conducted among 30 experts in the relevant field. The experts are asked to rate the significance of the identified variables to influence walkability of areas. The expert judgments were then summarized into a single score, which was then used to create a pair-wise matrix.

The critical steps in AHP are building hierarchy, establishing comparative pair-wise matrix, calculate the significance, and finally check the consistence of judgments.

Step 1: Building hierarchy from the main goal to influencing variable: in the first step hierarchy is built from the intended goal to the main variables as shown in the Fig.4 below.

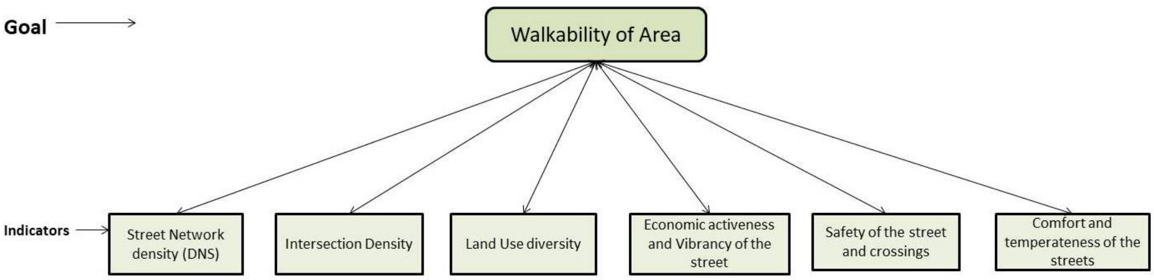

Fig.4 Hierarchal arrangement of goal and criteria

Step 2: By consulting 30 experts in relevant field, we established the comparative pair-wise matrix. Analytical Hierarchal process (AHP) adopts the 1 to 9 ranking methods.

	SND	AV	TC	SCA	ID	LUD
SND	1	1	2	2	3	1
AV	1	1	0.5	3	3	2
TC	0.5	2	1	1	1	1
SCA	0.5	0.33	1	1	1	1
ID	0.33	0.33	1	1	1	1
LUD	1	0.5	1	1	1	1

SND=street network density
AV= Economic Activity and vibrancy of street
TC= Comfort and temperateness of the street
SCA= Safety of street and crossing
ID= Intersection density
LUD=Land use diversity

Tab.1 Pair-wise matrix of indicators for walkability

Step 3: Calculate the significance of each indicator. Calculate Eigen value or Lambda

$$W = \frac{Egi}{\sum_{i=1}^{n} Egi} \tag{1}$$

Where

$$Egi = \sqrt[n]{(a11\ x\ a12\ x\ a13 \ldots \ldots ann)} \tag{2}$$

$$\lambda max = \sum_{j=1}^{n} [wj * \sum_{i=1}^{m} aij] \tag{3}$$

Step 4: Check the consistency of judgments.

To calculate the consistency index CI of judgment matrix (Eq.4), and get the consistency ratio CR using the following (Eq.5).

$$CI = \frac{(\lambda max - n)}{n-1} \tag{4}$$

Where λ_{max} is Eigen value or Lambda

n is the number of indicators

$$CR = \frac{CI}{RI} \tag{5}$$

Where CR is consistency ratio and RI is the random index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.46

Tab.2 Saaty's random ratio for different value of n

Eigen value (Lambda max) is calculated to be 6.42, consistency index equals to 0.07 and consistency ratio equals to 0.068 which is 6.8%. Since the consistency ratio is less than 10% threshold the pair wise comparison is consistent.

Indicators and Description	Symbol	Priority
Street Network Density	SND	0.24
Economic Activity and vibrancy of street	AV	0.23
Comfort and temperateness of the street	TC	0.16
Safety of street and crossing	SCA	0.12
Intersection density	ID	0.11
Land use diversity	LUD	0.14

Tab.3 The weight of indicators to alter walkability of area around transit station

3.4 Walkability using weighted overlay tool in GIS

Weighted overlay analysis technique integrates AHP with GIS to create a consolidated result displayed on spatial map. It involves combining the result of AHP with reclassified raster data of influencing variables such as street network density, intersection density, land use diversity, safety and security, business activity along the street, and comfort and temperateness of the street for walking.

Weighted overlay follows steps for the analysis:

- Find suitable data for each indicator to analyze;
- Vector layer have to be converted to raster layer and reclassified to suitable common scale;
- New raster layer is generated multiplying each raster layer cell's value with their corresponding weight resulted from AHP using *equation 6 and* totaling to derive walkability.

$$Walkability = \sum_{i-1}^{n} Wi * Xi \tag{6}$$

Where: Wi is weight assigned for each performance indicator, X_i is the cell value in raster file of spatial data. The spatial data used includes street network density, intersection density, land use diversity; safety and security of streets, business activities along the streets and comfort and temperateness of the streets. All spatial data extracted from Geospatial database of the study area, converted to raster data and reclassified to normalized common scale 3, 2 and 1.

GIS model builder enabled the automation of workflow, making the process quick and repeated with appropriate data for other area by only change location of data as shown in Fig.5.

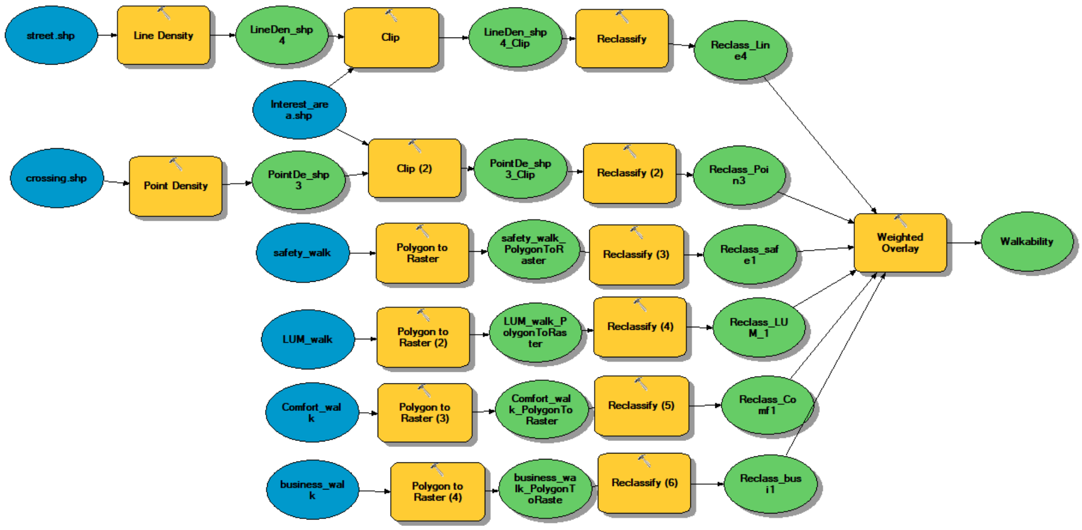

Fig.5 GIS model of the workflow of measuring walkability of area

4. Findings

The objective of this research was to find spatial method to measure the relative walkability level of areas around the Addis Ababa LRT stations by integrating the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS). This integration allowed benefiting from the multiple criteria analysis power of AHP and the power of GIS in spatial data analysis. This approach helped to come up with comprehensive results that can be illustrated on thematic map. The method involves three main steps: identifying main performance indicators, weighting the significance of the indicators based on their influence to create a walkable environment in context of Addis Ababa combine the AHP and GIS to measuring walkability. The identified indicators include road network density, intersection density, land-use mix, safety and security of the streets, business activity along the streets, and the comfort and appeal of the streets.

Since all performance indicators would not have equal impact, indicators were weighted according to their significance to influence the walkability of the area using AHP. The analysis results reveal that the road network density has the highest influence rate with 24%, Economic activity along the street ranked second with 23%, Comfort and temperateness of the street ranked third with 16%, Land use diversity ranked fourth with 14%, safety of street and crossing rated fifth 12% and Intersection density ranked last with 11% priority. The above result clearly displays the significance of street network density and business activity along the street in Addis Ababa Context taking up almost 47% priority compared to other four performance indicators. It also revealed that intersection density and safety of the street have less significance to encourage people to walk.

The third step involves integrating the results of AHP into GIS software using the Weighted Overlay Analysis tool to measure walkability. The result clusters areas with similar levels of walkability into the same categories representing them with different colors; Green Yellow and Red represent high, moderate, and low walkability, respectively. The results revealed that the majority (about 72.35%) of the study areas were classified as moderately walkable, followed by lower walkability areas, making up 19.47% of the total, while walkable areas constituted about 8.16%.

4.1 Walkable areas

As it is shown in Fig.6, the walkability level varied among different stations in the study area. For example, the area surrounding the Autobus Tera station had a higher concentration of walkable areas. The area around this station has a well-organized street network, resulting in a more regular urban layout.

Additionally, the presence of Merkato, the largest marketplace in Addis Ababa, further enhanced the walkability of this area, as shown in Fig.6. Business activities increase walkability and thereby increase property value like real-estate (Carpentieri et al., 2019). Another LRT station that exhibits a relatively higher walkability is the area around St. Lideta station mainly located at the immediate north of the station. The main reason duet to the recent redevelopment of the area with mixed residential and commercial complexes. This particular area is characterized as a well-connected street, active business activities, presence public service within the area contributed to higher level of walkability. The walkable areas are mainly known for active business and vibrant nature.

4.2 Lower walkable areas

On the other hand, areas with lower walkability levels were mainly found around St. Lideta and Legare stations. These areas are characterized by larger block sizes, unplanned settlements (slums), and lower business activity. These areas are primarily occupied by industrial zones, warehouses, and government institutes surrounded by fences. Walking in an area is extremely difficult because lack of appropriate side walkways, lower land use mix, lesser comfort, lesser business activity etc. Any intervention to improve walkability of area should focus on those variables.

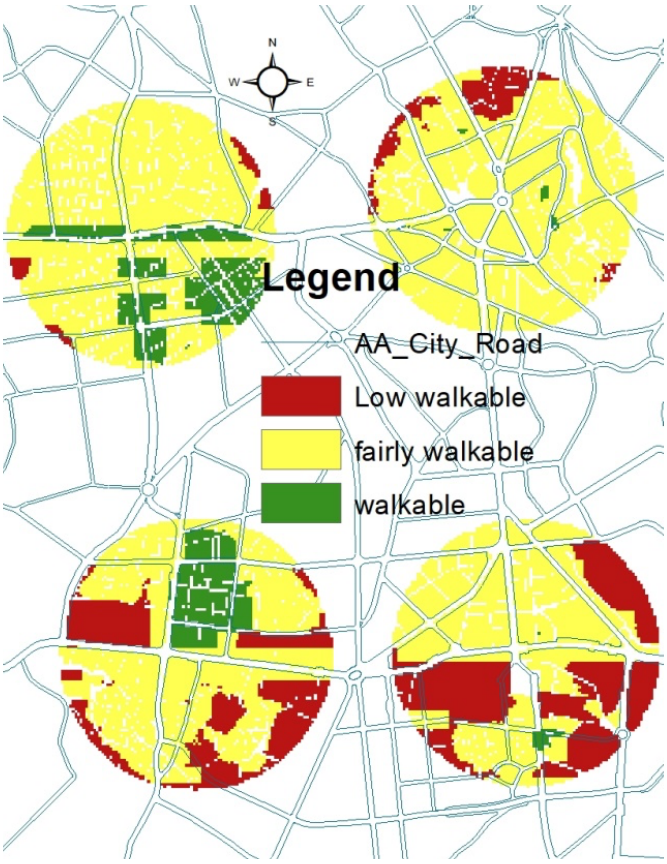

Fig.6 The areas with better walkability

5. Conclusion

Establishing walkable conditions around transit stations is crucial to the success of TOD projects. The process should also focus on the factors that would encourage people to choose walking over using private cars for short trips to access their daily needs. Measuring walkability of area is crucial steps in planning to implement TOD projects around transit nodes considering the entire factors that influence the suitability of the areas to walk. However, this is a complex and multi-dimensional process. It involves physical infrastructure, social concern, safety and security, environmental conditions, economic activity, and comfort. Thus, integrating AHP and GIS is a suitable method to analyze all in hierarchal manner. AHP allows the simultaneous analysis of multiple variables, whereas GIS enables the analysis and production of thematic maps that highlight walkable, fairly walkable, and non-walkable areas. The results revealed that the majority of the study areas (approximately 72.35%) fell under the fairly (moderately) walkable category (yellow), followed by non-walkable areas, accounting for 19.47% (red). The walkable area represents only 8.16% of the study area, represented in (green). As shown in Fig.6, walkable areas are concentrated at places where street networks are well connected, smaller block sizes, and vibrant business activities, such as the Autobus Tera station. On the contrary low walkable areas are concentrated at locations with bigger blocks size, less business activity, less safety, and uncomfortable walking conditions. This finding can assist urban planners and policymakers in locating walkable areas and identifying priority areas for intervention to improve walkability. The hybrid approach of integrating AHP and GIS enables the analysis of complex multi-criteria problems, resulting in a comprehensive result. As this method continues to advance and new data analysis methods emerge, the field of measuring walkability thereby planning successful TOD and shaping the future of urban mobility and creating more sustainable, vibrant, and resilient TOD cities.

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Image Sources

Fig.1: Authors' elaboration:

Fig.2: Authors' elaboration combines the city map and Google earth;

Fig.3: Authors' elaboration;

Fig.4: Authors' elaboration;

Fig.5: Authors' elaboration;

Fig.6: Authors' elaboration;

Author's profile

Ashenafi Wondimu Tekolla

He is PhD student in Addis Ababa University, African Railway Centre of Excellence (ARCE) in Railway Civil Infrastructures department. His thesis focuses on "How to Get the Best out of Transit Oriented Development around the Addis Ababa LRT stations". The research based on the recent interest of Addis Ababa City administration to implement TOD LRT station along the route and mainly stresses on what need to be done, what kind of research need to undertake in advance of investing time and many on TOD. He worked as a project manager of Addis Ababa LRT Transit Oriented Development project of three years. Currently he is also working as Team leader of Quality Management System division in Ethiopian Railway Corporation (ERC).

Abrham Gebre Tarekegn

He is Associate professor in Addis Ababa University, Addis Ababa institute of Technology and Head of Civil and Environmental Engineering Department.

Getu Segne Tulu

He is lecturer in Addis Ababa University, Civil and Environmental Engineering Department. His research focus is Road and Traffic Accident, Road Safety and Pollution and Traffic Management.

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Exploring the use of active mobility in selected rural areas of Nigeria

Oluwayemi-Oniya Aderibigbe [a]*, Trynos Gumbo [b]

[a] Sustainable and Smart Cities and Regions Research Group, Department of Urban and Regional Planning, Faculty of Engineering and Built Environment, University of Johannesburg, Corner Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa
e-mail: oboniya@uj.ac.za
ORCID: https://orcid.org/0000-0002-8914-323X
* Corresponding author

[b] Sustainable and Smart Cities and Regions Research Group, Department of Urban and Regional Planning, University of Johannesburg, Corner Siemert & Beit Streets, Doornfontein 0184 Johannesburg, South Africa
e-mail: tgumbo@uj.ac.za
ORCID: https://orcid.org/0000-0003-3617-4996

Abstract

Recently, an increasing number of road users are turning to active transportation (AT) modes such as walking and cycling, viewing them as not the only means of mobility, but also opportunities for enhancing physical activity and improving health. However, while AT holds numerous benefits, its adoption and efficacy are influenced by complex environmental and social factors, particularly in rural areas. To investigate these dynamics, this study employed a robust research design, collecting primary data through a multi-stage sampling method. Specifically, 50% of the wards in the rural areas of Ondo State, Nigeria were randomly selected, and a total of 496 structured questionnaires were administered using a systematic sampling approach. Findings from our study revealed that majority of respondents in the rural areas were aged between 70 years and above, and mostly relied on the use of active mobility for trip making. Factors influencing the use of active travel showed distance as the most influential factor. This has a relative index of 0.993 and it is closely followed by travel time with a relative index of 0.984. this study proposed that residents in the rural areas should be sensitized on the benefits associated with active mobility, especially in relation to their health as majority are not aware of its health benefits.

Keywords

Rural areas; Active travel; Accessibility; Sustainable planning; Non-motorised transport.

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1. Introduction

Effective rural road infrastructure is essential for enhancing accessibility and driving socio-economic growth. In developing countries, poor transport access in rural areas hampers economic and social progress, worsening poverty levels. Addressing this requires improved transport infrastructure and services, focusing on facility location, quality, and affordability. Njenga et al. (2015) and Akpan & Morimoto (2022) emphasize that strong transport networks empower rural communities, enabling agricultural transport, access to healthcare, and political participation. The rural transport sector supports 'Sustainable Development Goals' (SDGs), providing socio-economic benefits globally. The World Bank (2017) estimates that in sub-Saharan Africa, around 70% of rural people—over 450 million—have limited access due to inadequate roads. Many roads are impassable during the rainy season (Aderibigbe & Gumbo, 2022). This, combined with poor public transport and low infrastructure maintenance capacity, creates significant challenges. Despite this, rural inhabitants adapt their travel behaviors, using available transport options. Active modes like walking and cycling are increasingly used across sub-Saharan Africa (Olawole, 2017), showing resilience in transportation constraints.

Nigeria's transport system heavily relies on roads, but the infrastructure is strained. Rural areas predominantly use active travel, yet vulnerable road users like cyclists and pedestrians face rising fatalities. Paradoxically, these groups lack access to motorized transport. Walking, though widespread, is overlooked in highway planning, especially in rural areas. Kaiser and Barstow (2022) highlight the rural transport ecosystem, which, though catering to basic mobility, presents challenges for pedestrians and cyclists. While walking has been extensively studied in developed countries (Ding et al., 2017; Kamargianni & Polydoropoulou, 2013; Nelson et al., 2008), it is under-researched in developing nations like Nigeria. This study fills that gap by examining active travel, non-motorized transport, and public transportation in rural areas lacking infrastructure. It explores the links between infrastructure and socio-economic factors like economics, agriculture, health, policy, gender, education, and environmental issues like climate change.

The study examined how differences in socio-economic and travel characteristics affect active mobility. It also identified key factors influencing active travel and assessed their impact on mobility choices. Moreover, the paper explores practical implementation aspects of infrastructure projects, such as road and bridge construction and maintenance. By addressing these issues, the research contributes to a comprehensive understanding of Nigeria's transportation dynamics and informs policy to enhance rural mobility and well-being. Mobility is crucial for well-being, as it fosters better quality of life by facilitating interaction between people and the environment, underscoring this article's relevance to land use, mobility, and environmental relationships. The article is divided into three sections: an introduction and literature review on rural transport and active mobility, a section on methodology, and a final section discussing findings with policy recommendations.

2. Literature review

2.1 General overview of rural transport

This section reviews relevant literature addressing the main objectives of the study. It is divided into sections covering the general concept of rural transport, rural transport accessibility, and factors influencing active transport. This will provide context from previous studies on rural transport and active mobility. Settlements in Nigeria range from rural to urban, with many in-between. Rural Nigeria refers to areas with fewer than 20,000 residents or larger areas where at least half the population farms and lacks basic amenities. Jibowo (2000) notes stronger social cohesion among rural dwellers compared to urban ones. Rural areas tend to have older populations, as younger individuals migrate to cities for jobs, education, or training. Vertical social mobility is more prevalent in urban areas, where opportunities for job advancement, education, marriage, and relocation are more abundant. Urban centers also tend to be larger, with higher population densities. Recent research into rural transport planning in developing nations has shifted perceptions of rural transport's economic dynamics. Scholars such as Barwell (1996) and Oyeleye et al. (2013) stress that rural populations' primary deprivation is limited access to activities, thus, understanding this is vital for addressing rural transport Moseley (1979) proposed principles for assessing accessibility, offering solutions that include both transport and non-transport interventions. The framework of Moseley (1979), which includes mobility solutions and strategic service placement, serves as the cornerstone for contemporary efforts in rural accessibility planning across developing countries. It implies that mobility and the siting of services and infrastructure are key to defining rural accessibility. Moreover, studies by Carra et al. (2022), D'Amico (2023), and Stiuso (2024) emphasize the need for social inclusion and stakeholder participation as critical elements in promoting active mobility. Proper rural planning is essential to improve walkability and active living.

1.2 Concept of accessibility and rural transport

Accessibility encompasses individuals' perceptions of living conditions and ease of daily activities within a specific travel mode or lifestyle, often reliant on public transportation. Objective measures fail to account for contextual, climatic, and cultural factors or preferences for walking and cycling (Van Wee, 2016). Jamei et al. (2022) propose two perspectives for assessing accessibility: process indicators (travel opportunities) and outcome indicators (actual use and satisfaction). They argue that both aspects are essential for complete assessment. Scholars debate accessibility, focusing on time, cost, interaction opportunities, and travel modes (Dalvi & Martin, 1976; Curl et al., 2011). Curl et al. (2011) highlight the importance of perceived accessibility metrics in transportation planning, which reduce social exclusion and improve quality of life.

Morris et al. (1979) also considered process and outcome indicators, emphasizing their complementary roles in measuring accessibility. Dalvi and Martin (1976) stressed the importance of time and cost in activity access, while Hansen (1959) defined accessibility in terms of interaction opportunities. Jamei et al. (2022) noted the crucial role of perceived safety and service quality in public transport on daily travel accessibility, with social determinants revealing disparities among demographic groups, such as gender, age, income, occupation, and education. For instance, in Sweden, women perceive higher accessibility than men across certain travel modes (Lättman et al., 2018), although older women report lower perceived accessibility compared to men (Lättman et al., 2019).

Age is a key factor influencing perceived accessibility, but its impact is debated. Sundling et al. (2014) suggest older individuals with reduced mobility have lower perceived accessibility than younger counterparts. Aderibigbe et al. (2024) argued that built environments often hinder accessibility, especially for older populations. This reduced accessibility impacts their quality of life. However, retirees may perceive higher accessibility when urban services are available via public transportation. This is similar to active mobility in rural areas, where improved infrastructure for active travel would increase accessibility and mobility, improving rural dwellers' quality of life (Aderibigbe & Gumbo, 2022). Studies by Aboyeji & Aguda (2024), Roulet et al. (2024), and McHenry et al. (2023) attest to the positive impact of mobility on rural livelihoods through increased income and agricultural yield. Thus, there is a pressing need for transport services and infrastructure that enhance rural accessibility and quality of life.

1.3 Active / non-motorised travel in rural areas

Walking is the oldest, safest, and most accessible mode of transportation, requiring no technical expertise. Despite its advantages, many African countries lack adequate infrastructure for walking (Busari, 2019). Scholars such as Papa et al. (2018), Michel et al. (2024), Rainieri et al. (2024), and Mehriar et al. (2024) emphasize the environmental benefits of reducing car use and adopting active mobility, which releases little to no harmful emissions and promotes healthy living. Pedestrian trip distribution is significantly influenced by land use, with Busari et al. (2015) highlighting the role of urban morphology and pedestrian networks. Stradling (2002) also identified factors such as school journeys that affect pedestrian trips.

In developing countries, rural transport infrastructure—roads, tracks, footpaths, and bridges essential for accessing farms, markets, schools, and clinics—often remains in poor condition year-round. Transport services are frequently inadequate and too expensive for rural residents. Consequently, in many regions, particularly in Sub-Saharan Africa, rural transport still relies heavily on walking and cycling. Access to essential services is measured in terms of time, effort, and cost, and depends on infrastructure availability and affordability, such as roads, schools, hospitals, and markets. The poor rural population often endures significant time and effort to access basic necessities, underlining the importance of enhancing accessibility to alleviate poverty. Efficient rural transport requires suitable infrastructure—paths, roads, bridges—and their maintenance.

Wachira et al. (2022) found that factors such as rural living, lower parental education, and vehicle ownership play a significant role in limiting active mobility use. Location and other factors heavily influence mobility choices. Aderibigbe & Gumbo (2022) also found that rural households depend primarily on active travel, such as walking and public transport, but lack infrastructure to support these modes in developing countries like Nigeria. Sustainable mobility and road safety must be prioritized, ensuring inclusive mobility for all. Key factors that encourage active travel include pedestrian infrastructure, distance, travel time, and safety (Wangzom et al., 2023; Olojede et al., 2017; Mejia, 2019; Ding et al., 2017).

Distance to school significantly affects transportation mode choice, especially for children and adolescents. Wangzom et al. (2023) found perceived distance to be a major barrier to active school travel. Kamargianni & Polydoropoulou (2013) revealed that travel time and costs impact transport behavior similarly in adolescents and adults. Additionally, availability of infrastructure like bicycle paths influences the preference for walking and cycling. Mitra & Ratkim (2013) supported the association between the built environment and active commuting. Mendiate et al. (2022) asserted that factors such as travel speed and paved roads influence active mobility, highlighting the need for good transportation infrastructure. Age also affects willingness to walk or cycle, with younger and older commuters more inclined to choose these modes (Ding et al., 2017). Factors influencing active mobility vary across age groups and locations, necessitating careful planning of built environments to support sustainable travel modes. Thus, there is a need for policies that address rural transport needs, particularly those that support active mobility, the dominant mode of transport in rural areas.

3. Materials and methods

3.1 Study area

Established on October 1, 1996, Akure North Local Government Area (Rural) is situated in Ondo State, Nigeria, with its headquarters located in the town of Iju/Itaogbolu. Covering an area of 660 km^2 (250 sq mi), it had a population of 131,587 according to the 2006 census. The region boasts fertile land conducive to agriculture, with farming being the predominant occupation. This agricultural focus characterizes the area as rural, with the majority of its inhabitants engaged in agricultural pursuits. Despite accessibility by road, certain communities within Akure North, such as Ilado and Moferere, face challenges during the rainy season due to flooded footbridges, hindering transportation.

It was discovered that the local government has no conventional mass transit system such and the residents only access major activities through the use of unregulated private taxis, keke napep (tri-cycles), motorbikes popularly known as Okada. The town's deficient transport infrastructure fails to accommodate active travel, with a stark absence of cyclist lanes and walkways. Compounding the issue, a significant portion of the city's population lacks personal vehicles, exacerbating the vulnerability of pedestrians and cyclists to road accidents. Based on the above, this study explored the factors and barriers which respondents face in the use of active mobility.

3.2 Sampling procedure

This research employed primary data derived from a survey conducted through trained research assistants utilizing a structured questionnaire. Employing a probability sampling technique, a multi-stage sampling procedure was implemented as adopted from the studies of Aderibigbe & Gumbo (2022) and Olawole (2013). Initially, residential areas were stratified into zones (core, transition, and periphery), followed by the random selection of registered streets, constituting 20% of the streets in selected wards. Subsequently, 10% of the 4968 registered buildings in the chosen wards were systematically sampled, resulting in a total of 496 buildings for further investigation. Within each selected building, the household head was chosen for questionnaire administration, consistent with prior studies justifying the focus on household heads due to their representative nature. In cases where the intended respondent was unavailable, the subsequent building was sampled. The criteria for selection ensured that household heads, aged 18 years or older, residing on the first floor of each building were included, culminating in a total of 496 respondents, of which 402 questionnaires (81%) were deemed analyzable.

The questionnaire utilized in this study consisted of three primary sections. The first section gathered socio-economic data from respondents, encompassing variables such as gender, age, education, income, marital status, employment status, occupation, household size, and car ownership. The second section delved into the travel behaviors of participants, capturing information on trip frequency, trip purposes (e.g., work, shopping, health, recreation), transport modalities, and associated travel costs. The final section focused on identifying factors influencing the adoption of active travel within the study area, thereby providing comprehensive insights into the socio-economic and behavioral determinants of transportation choices in the surveyed population.

Variables	Data Types and Description
Gender	Male, Female
Age	Age in Years
Marital status	Are you married, single, divorced
Income	Monthly Income earned by respondent
Occupation	What is the nature of your Job e.g. Farming, Civil servant
Education	What is your highest level of education? Primary school, Secondary/High School/ or Tertiary education
Cars in the Household	How many cars do you have in your family/household
Trip Frequency	What is the average number of daily round trips (completed)
Transport Mode	What is your dominant mode of transport for making trips
Trip purpose	What trip do you make more often on a daily basis? E.g. shopping trips: trips to commercial activities such as grocery shopping etc, Work trips: Trips to office or job related trips, School Trips: Trip for educational activities, Religious trips: Trips to church or mosque, etc
Travel Cost	What is the average cost you spent on your trip (in Naira)
Factors influencing active mobility use	What are the major factors you consider in using active travel, e.g travel cost, age, income level, safety among others

Tab.1 Data types and variables description (Source: Author's Field work 2023)

2.3 Model specification

The research data was analyzed utilizing percentages and the Relative Importance Index (RII) to gauge the influence of various factors impacting the decision to walk or not. Based on the study of Olojede et al, (2017), the likert scale method has been identified as one of the formulas for ranking factors in order of their relative importance, hence, its adoption in this study. Participants were tasked with rating the importance of each factor using the Likert Scale, ranging from 1 to 5 in ascending order of significance, from Very Low to Very High. These ratings were then converted into RIIs for each factor, mathematically expressed as follows:

$$RII = \frac{\sum W}{A * N} \tag{1}$$

Where W is the weighting given to each factor by the respondents to the survey (i = 1-5), 5 being the highest weight and N is the total number of respondents. A higher value of RII indicated a greater importance of the factor in influencing the decision to use active mobility (walking/cycling) by the respondents. The identified factors were ranked using the RII. This ranking facilitated the determination of the relative importance of the factors as perceived by the respondents. The RII of each factor as perceived by the respondents was used to assess the rankings of the factors that influenced the respondents' decision to use active mobility or not. This represents the mean for the factor identified in the study.

Additionally, to validate the result of the Likert scale. This study further employed the use of the multiple regression analysis in identifying and modelling factors influencing the use of active travel in the study area. The multiple regression model has been identified by scholars such as Kyeremeh & Fiagborlo (2016) and Ogunsanya (2002) for generating predictive models, hence, its adoption. The study examined the relationship between active travel behavior, specifically walking/cycling, and various determinants identified in existing literature, validated through this research using Relative Importance Index (RII). Participants reported the frequency of their active travel on a 5-point Likert scale, with scores aggregated to form a composite measure. Subsequently, categorical responses were converted into interval data. Regression analysis was employed to construct a model aimed at empirically elucidating the factors influencing the choice to walk or cycle to major destinations within the study area.

In this model, the mode (walk/cycle) was set as the outcome variable, and the demographic and trip characteristics as well as behavioural factors were entered as predictors/independent variables. The independent variables or predictors included: age, income, travel time, travel cost, availability of pedestrian facilities, safety, travel distance, avoidance of traffic congestion, healthy living and the number of cars available for the household.

A stepwise regression analysis was adopted to determine the factors influencing respondent's decision to walk/cycle. The formula is given as:

$$Y = a + b_1 x_1 + b_2 x_2 + \dots\dots\dots + b_n x_n + e \tag{2}$$

Where Y represents the dependent variable. The dependent variables in this case represents Y= walking, x_1, x_2, x_3 .... x_n represent the independent variables (age, income, travel time, travel cost, availability of pedestrian facilities, safety, travel distance, avoidance of traffic congestion, healthy living and the number of cars available for the household).

a, b : constants/slope of the regression line

e : error term

This represents the relationship between the average number of times respondents walk to their respective activities and other independent variables (predictors) or other factors as x_1, x_2, ... x_n. However, the unstandardized coefficients was utilized in the model to explain the influence of each independent variables on the dependent variables.

3. Results

3.1 Socio-economic characteristics of respondents

The socio-economic profile of residents in Tab.2 is explained empirically using data obtained from the survey. This profile includes gender, age, marital status, educational attainment, income, occupation and number of cars in the household. The socio-economic characteristics of respondents revealed that the majority were not educated with 44.3% of the respondents in this category, while a greater proportion (46%) engaged in farming. Also, result on age distribution of respondents showed that majority (60.2%) of the aged who are 70 years and above resides in the rural areas of Nigeria. Research findings indicate that 44.5% of the participants reported earned below the federally approved minimum wage, indicating a prevalent low-income scenario among rural households. The proportion of government-employed respondents aligns with previous studies suggesting that individuals' educational attainment influences both their occupational choices and income levels (Ahn, 2001; Badiora, 2012; Stead & Marshall, 2001). Also, the retirement age of 60 years in Nigeria makes it impossible for the elderly to still be actively engage in government jobs/activities. The availability of cars for a household is a function of the income earned by the household. It is thus given that household with higher income will be able to afford cars to ease its movement. It is clearly evident from our study that more than half (55.7%) of the respondents do not own a car while 25.4% of them own one car. The mean age for this study is 68, while average income is 21,008.

Characteristics	Variable	Frequency	Percent
Gender	Male	176	43.8
	Female	226	56.2
Age	Less than 30 years	24	6.0
	30-39	22	5.5
	40-49	25	6.2
	50-59	33	8.2
	60-69	56	13.9
	70 years-above	242	60.2
Educational status	No formal Education	178	44.3
	Primary Education	113	28.1
	Secondary Education	50	12.4
	Tertiary Education	61	15.2
Marital status	Single	44	11.0
	Married	108	26.9
	Widowed	208	51.7
	Divorced	42	10.4
Occupation	Civil servant	68	17.0
	Farming	185	46.0
	Artisan/Self employed	57	14.2
	Unemployed/Retiree	92	22.8
Income of respondents (Naira)	<20,000	179	44.5
	20,000-39,999	67	16.7
	40,000-59,999	52	13.0
	60,000-79,999	45	11.2
	80,000-99,999	26	6.4
	100,000-above	33	8.2
Number of cars in the household	None	224	55.7
	1	102	25.4
	2	50	12.4
	3-above	26	6.5

Tab.2 Socio-economic characteristics of respondents (Source: Field Survey 2023)

3.2 Travel characteristics of respondents

Analysis of trip frequency of respondents in table 3 showed that 50.8% made an average of 2 round daily trips. Trips for agricultural related activities comprised the majority (31.3%) of trips while 19.4% of them made work trips. Overall, the trip purpose of respondents showed that majority of households 69.2% made more of discretionary trips against the 30.8% of their counterparts who made more of non-discretionary trips. The findings on the dominant transport mode of respondents revealed that walking and cycling were more phenomenon as 31% and 26.9% of the respondents respectively utilized this mode of transport. The travel cost of households revealed that trips to health facilities accounted for the largest expenditure, with respondents averaging 7,500 naira on this activity. They often travel outside their neighborhoods to specialist hospitals in neighboring towns such as Akure and Owo for quality healthcare services, as many rural health facilities are smaller centers with limited staffing. Following closely is the cost of trips to educational facilities, with an average spending of 4,800 naira. This is attributed to students attending schools outside their districts in pursuit of better education quality. Trips for recreation incurred the least expenditure, averaging 400 naira, as only a few residents visit recreational centers beyond their immediate neighborhoods.

Characteristics	Variable (in number)	Frequency	Percent
Average number of daily round trip	1	102	25.4
	2	178	44.3
	3	65	16.1
	4	34	8.5
	5-above	23	5.7
Dominant trip purpose	Work	78	19.4
	School	46	11.4
	Agricultural Activities	126	31.3
	Health/Medical	69	17.2
	Shopping	51	12.7
	Others (recreational, religious etc)	32	8
Dominant transport mode	Walking	125	31.0
	Cycling	108	26.9
	Public Transport	75	18.7
	Private Vehicle	39	9.7
	Others (Motorcycle, Keke)	55	13.7
Average cost of making trips to the following places (N)/week	Work	1,500	
	School	4,800	
	Agricultural Activities	800	
	Health/Medical	7,500	
	Shopping	700	
	Others (recreational, religious etc)	400	

Tab.3 Travel characteristics of respondents (Source: Field Survey 2023)

3.3 Analysis of factors influencing active travel in the study areas

In the final phase of the study, an examination was conducted to evaluate the determinants affecting mode selection (specifically, active travel) among participants. Utilizing both Likert scale ratings and stepwise multiple regression analysis, the study aimed to identify the impact of various factors, including individual and household attributes, as well as trip-specific characteristics, on the adoption of non-motorized transportation and active mobility. Mode preferences for the primary purpose of trips were assessed through stepwise regression modeling, allowing for a comprehensive analysis of influential factors in mode choice.

The findings of this study as presented in Tab.4 showed that distance was the most influential factor influencing the use of active travel in the study areas. This has a relative index of 0.993 and it is closely followed by travel time with a relative index of 0.984. Next to this are income level of respondents, travel cost, availability of pedestrian facilities, availability of private vehicle, age, and healthy living. Their relative index are 0.978, 0.933, 0.931, 0.878, 0.842 and 0.769 respectively. The least factors influencing respondent's decision to walk/cycle rather than use another mode with relative index of 0.724 and 0.706 respectively are safety and avoidance of traffic congestion. It was also revealed from this study that health benefits associated with walking has not been fully explored by the respondents as majority of them who walk are not fully aware of the benefits associated with active mobility, hence ranked 8. Likewise, safety and traffic congestion were not significant at influencing the decision of people to walk in the rural areas as they ranked 9 and 10 on the relative index list.

S/N	Factors	N	A*N	SW	RII	Rank
1	Travel cost	402	2010	1,876	0.933	4
2	Age	398	1,990	1,676	0.842	7
3	Income level	400	2,000	1,957	0.978	3
4	Healthy living	402	2,010	1,546	0.769	8
5	Safety	402	2,010	1,456	0.724	9
6	Travel time	402	2,010	1,978	0.984	2
7	Distance	402	2,010	1,997	0.993	1
8	Availability of pedestrian facilities	401	2,005	1,867	0.931	5
9	Private car availability	402	2,010	1,765	0.878	6
10	Avoidance of traffic congestion	396	1,980	1,399	0.706	10

Tab.4 RII index table for factors influencing the decision to use active mode (Source: Author's Field Survey)

3.4 Model predictors for active travel in the rural areas of Nigeria

The stepwise regression was used to enter the predictors and out of the 10 predictors determining walking/cycling in the study areas, six (6) variables were significant while the remaining four were excluded as they were found insignificant. The significant variables are: Age; Travel distance; Income of respondents; Travel cost; Number of cars in the household and Safety. As presented in Tab.5, age was found to be the strongest predictor of household and household to walk, with R and R^2 values of 0.692 and 0.515, respectively ($p < 0.005$). This implies that over 50% of the variability in walking could be explained by age. Further, the addition of travel distance and income increased the R^2 value to 0.578 and 0.612 respectively, implying that both travel distance and income explain about 57.8% and 61.2% of the total variation in the decision of the respondents to walk. In the same way, travel costs, number of cars in the household and safety increased the R^2 value to 67.9%, 70.1% and 74.2% respectively, Overall, the predictors retained in the model explained as much as 74.2% of the total variation in the decision of the respondents to walk rather than use any other mode of transport.

S/N	Factor	Beta	R	R^2	F Ratio	Sig
1	Age	-0.385	0.692	0.515	18.654	0.002
2	Travel Distance	-0.176	0.731	0.578	16.456	0.000
3	Income	0.247	0.786	0.612	12.356	0.010
4	Travel cost	0.412	0.809	0.679	10.412	0.003
5	Number of Cars	-0.256	0.823	0.701	9.764	0.012
6	Safety	0.192	0.892	0.742	5.987	0.007

Tab.5 Regression Coefficient for Factors Influencing the Use of Active Travel (Walking/Cycling) *Constant = 2.105 (Source: Author's field work)

The coefficients of the six predictors are -0.385, -0.176, 0.247, 0.412, -0.256 and 0.192 respectively, while the constant as obtained in the regression analysis was 2.105. Consequently, a regression equation/model was developed

y = 2.105 - 0.385 (age) - 0.176 (travel distance) +0.247 (income) + 0.412 (travel cost) - 0.256 (number of cars) + 0.192 (safety) + ε

where y = walking, x_1 = age, x_2 = travel distance, x_3 = income, x_4 = travel costs, x_5 = number of cars, x_6 safety and ε = error term. Highlight of the model is that a unit increase in age, travel distance and number of cars by 0.385, 0.176 and 0.256 respectively will reduce the propensity of an individual or a household to use active travel while a unit increase in income, travel cost and safety measures by 0.247, 0.412 and 0.192 respectively will increase the use of active mode by the respondents. The combined influence of the six significant variables at influencing the decision to use active travel in the rural area accounted for 74.2%, this implies that the coefficient of determination (R^2) is 74.2%.

4. Discussion

This paper explored the potential for rural dwellers in selected Nigerian villages to adopt active mobility. A key finding was that most respondents were senior citizens, aged 70 and above, which aligns with studies by Olawole (2015) and Wachira et al. (2022), indicating that the elderly predominantly reside in rural areas. This is due to younger populations moving to urban areas for job opportunities. Household income levels were also low, supporting claims by Odozi & Oyelere (2019) and Zhang et al. (2022) that poverty is prevalent in rural areas. Car ownership was low compared to urban centers, consistent with studies (Odozi et al., 2021; Giuliano, 2003; Aderibigbe & Gumbo, 2022) showing lower car ownership in rural, low-income households.

Regarding travel habits, most rural residents made discretionary trips, likely because many are retired, which aligns with Oyeleye (2013) that rural trips are often discretionary, particularly for agriculture. However, findings contradicted Pucher & Renne (2005), who suggested U.S. rural households rely more on private vehicles. This difference reflects disparities in socio-economic status and policy support between developed and developing countries.

The study also found that factors like distance, cost, income, and travel time influence the decision to walk, corroborating Emond & Handy (2011) and others. Safety and traffic concerns were ranked low as factors, as rural areas in Nigeria are generally secure with little traffic congestion. This contradicts Mejia (2019) and Potoglou et al. (2017), who emphasized safety in active travel, possibly due to cultural differences across countries. Overall, the study highlights the significant role of socio-economic and travel factors in influencing active mobility decisions. Similar to Ding et al. (2017), younger travelers, being healthier, are more likely to walk, whereas older individuals with frail health are less inclined to use active modes of transport. This aligns with studies by Mejia (2019), Harrison et al. (2007), and Mendes de Leon et al. (2009), which identified age, income, and distance as key influences.

5. Conclusion and recommendations

This study investigated the decision-making process and adoption of active mobility within rural areas of Nigeria, focusing particularly on Akure. The findings are timely, offering insights crucial for stakeholders aiming to implement policies enhancing active travel in rural regions. Identified influential factors affecting walking as a primary mode of active travel include age, income, travel expenses, distance, safety, car availability, health considerations, avoidance of traffic congestion, and travel duration. Notably, the study revealed a glaring lack of investment in transport infrastructure supporting active travel, with inadequate provision for amenities such as bicycle lanes and pedestrian walkways. Consequently, many individuals opt for private automobiles overactive modes of transportation. Despite awareness of the health benefits associated with active mobility, this knowledge does not significantly influence the decision to walk. Therefore, public awareness campaigns are essential to educate residents about the advantages of active travel, while government agencies must integrate active travel facilities into urban transport infrastructure.

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Author's profile

Oluwayemi-Oniya Aderibigbe

She is a Professional Planner and a Lecturer in the Department of Logistics and Transport Technology, Federal University of Technology Akure, Nigeria. She is also a Postdoctoral Fellow in the Department of Urban and Regional Planning within the Faculty of Engineering and the Built Environment in the University of Johannesburg (UJ). She holds a PhD in Transport Management Technology, Federal University of Technology, Akure Nigeria as well as a masters and bachelors degree in Urban and Regional Planning, Obafemi Awolowo University Ile ife Nigeria. Her research interests include urban transportation planning, travel behaviour studies, sustainable and smart cities, climate change, emerging technologies in urban planning and green economy. Her research interests leverage a combination of experimental and empirical approaches using both qualitative and quantitative data to study complex problems in the field of urban planning. She has published in reputable chapters, peer-reviewed journals and peer-reviewed conference proceedings.

Trynos Gumbo

He is a C2 NRF rated researcher and a SACPLAN Registered Professional Planner, who is currently working as a Full Professor and leader of the Sustainable and Smart Cities and Regions (SSCR) group within the Department of Urban and Regional Planning within the Faculty of Engineering and the Built Environment at the University of Johannesburg (UJ), South Africa. He holds a PhD from Stellenbosch University, South Africa, as well as master's and honours degrees from the University of Zimbabwe (UZ), Zimbabwe. He has previously worked in the Africa Institute of South Africa of the Human Sciences Research Council as a research specialist and Acting Head for the sustainable development programme. His research interests include urban transportation planning and management, sustain- able and smart cities development, housing and economic informality, green economy and renewable energy generation from waste, and innovative building technologies and materials.

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Farmers decision on land use land cover change from agriculture to forest and factors affecting their decision: the case of Gurage Zone, Central Ethiopia

Tesfanesh Ababu [a*], Alemtsehaye Eyasu [b], Mister Abebe [c], Alemayehu N. Ayana [d], Asabeneh Alemayehu [e], Mulatu Mengist [f]

[a] Central Ethiopia Forestry Development Center, Addis Ababa, Ethiopia
e-mail: tababu03@gmail.com
ORCID: https://orcid.org/0000-0001-5699-9771
*Corresponding author

[b] Central Ethiopia Forestry Development Center, Addis Ababa, Ethiopia
email: kalabe_alem@yahoo.com
ORCID: https://orcid.org/0009-0009-0086-5964

[c] Central Ethiopia Forestry Development Center, Addis Ababa, Ethiopia
email: misterabebe777@yahoo.com
ORCID: https://orcid.org/0000-0003-4210-6308

[d] Central Forestry Development Center, Addis Ababa, Ethiopia
e-mail: alemayehunayana@gmail.com
ORCID: https://orcid.org/0009-0009-3442-9300

[e] Bahirdar Ethiopian Forestry Development Center, Bahirdar, Ethiopia.
e-mail: alemayehuasabeneh@yahoo.com
ORCID: https://orcid.org/0000-0002-7752-4836

[f] University of Tuscia, Italy
e-mail: mulatm21@gmail.com
ORCID: https://orcid.org/0000-0002-0590-3255

Abstract

Land use and land cover change determined by numerous situation specific factors at different locations and times. In Ethiopia inappropriate land uses land cover changes become pressing challenges. Similarly, in the Gurage zone, there is a significant change from agriculture to *Eucalyptus* plantations. Therefore, this study investigates the direct and indirect drivers of the change, as well as factors affecting farmers' decisions regarding the conversion to provide important policy input. The data collected from 311 households through household surveys, key informant interviews (KIIs), and focused group discussions (FGDs). Descriptive statistics and a binary logit model used for analysis. The result indicated that the direct driver for this land conversion included the ability to generate high income from forest, soil infertility, and increasing demand for forest products. On the other hand, the allelopathic effect of neighboring plantations, lack of adequate agricultural technology and increased accessibility to forest products market were the top indirect drivers. The binary logit results show that farmers' decision to convert agricultural lands to forestland is significantly influenced by land size, forest income, education level, and years lived in the area. The findings suggest creating awareness about appropriate land use techniques to sustain the development.

Keywords

Land use dynamics; Drivers; Impact; Forest land; Cropland.

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1. Introduction

The factors influencing land use land cover change are complex and dynamic and vary from one place to another (Li et al., 2018). These changes are primarily driven by natural and human-induced factors (Kleemann et al., 2017; Zengin et al., 2018, Poudel et al., 2023). Globally, the identified reasons for land use conversion are specific to each case and differ across regions due to the unique socioeconomic and biophysical influences present in each area. Munthali et al. (2019) and Kariuki et al. (2020), stated that the main underlying causes of global land cover change are people's responses to economic opportunities influenced by institutional factors, emphasizing that the drivers of land cover change and land use change are specific to each time.

Similarly, the different landforms, agro-ecologies, socio-economic, cultural, and related settings of Ethiopia contribute to a diversified and complex land use land cover change (Kassa et al., 2017; Belayneh et al., 2020; Mengistu, 2024). Most Ethiopians live in rural and marginalized areas and rely entirely on natural resources for subsistence and household income. Ethiopia's land use system has undergone rapid and extensive changes in recent decades due to significant transformations caused by human and environmental interactions (Fasika et al., 2019). Previous studies in Ethiopia mainly focused on land use and land cover change from forest land to agricultural land (Ariti et al., 2015; Tolessa et al., 2020). However, after the expansion of plantations especially rapid Eucalyptus plantation practices, there has been a change from agricultural land to forest land via smallholder and forest enterprises (Jenbere et al., 2012; Kassa et al., 2017).

Among the different parts of Ethiopia that have experienced land use land cover change the Gurage zone is notable for containing 20% of natural forest land in 1930 (Zerga et al., 2021). However, this forest cover has been steadily declining. Since the 1960s, households in the area have been planting *Eucalyptus* trees at a rapid rate due to their fast growth, high economic benefits, and value as a source of forage for bees (honey production) under poor management (Kerbo et al., 2024; Sahle et al, 2018).

Formerly, farmers grew trees on lands not fertile for crop production, along farm borders, and in their home gardens (Desta et al., 2023). However, the conversion of fertile croplands to *Eucalyptus* has become common in various regions of Ethiopia especially in the Gurage zone (Alemayehu et al., 2022; Jenbere et al., 2012; Tefera & Kassa, 2017). This shift is because *Eucalyptus* provides better income for farmers than other alternative livelihoods such as annual agricultural production, livestock raising and other non-agricultural activities (Desta et al, 2023; Kaur & Monga, 2021; Kassie et al., 2017; Tesfaw et al., 2022). It is evident that farmers allocate their land use based on the potential benefits and costs they can derive from it. Although farmlands are crucial for food security throughout the country, many farmers have converted their fertile farms to *Eucalyptus* to diversify their income (Debie, 2024; Kassie et al., 2017; Stratton et al., 2021). Therefore, land use planning and policy development are essential for managing land allocation of different land use types to ensure sustainable development (Briassoulis, 2019; Liu et al., 2018; Salata & Yiannakou, 2016; Xie et al., 2020; Zucaro & Morosini, 2018). Comprehensive research on the drivers of land use dynamics is crucial for understanding the inter-relationships between societies and natural resources in Ethiopia (Ayele et al., 2016; Kamwi et al., 2015; Reid et al., 2000).

The concept of the drivers is focused on economic, technological, policy, and social factors. This classification explains how communities with locally available resources can respond differently to the interaction of variables, manifested as changes in land use. Community responses are not only limited by local resources but are also influenced by external factors that influence economic growth, the state of natural resources, and human well-being in that area.

Therefore, this study aims to:

1) assess direct and indirect drivers of land use land cover change from agriculture to the forest;
2) examine the pressure, state, impacts, and responses of the land use change from agriculture to the forest;
3) explore the factors affecting the decision of farmers to convert their land use from agriculture to the forest.

The results of this study will be fundamental in forming a solid understanding of the land use changes, helping planners, environmentalists, policymakers, and other stakeholders to develop strategies and sound land use management practices to conserve and sustainably use natural resources in Ethiopia.

2. Materials and methods

2.1 Study area

The study area is located in *Gurage* zone which is found in the Southern Nation Nationalities and People Regional State of Ethiopia. It lies between 7^{0}40' and 8^{0}30' North and 37^{0}30' and 38^{0}40' East with area coverage of 5,932 km^2. It is bordered by the Oromia Region in the west, north, and east; *Yem* Special District in the southwest; and *Hadiya* zone in the south. *Gumer* and *Cheha* are the districts among thirteen districts of the *Gurage* zone (Fig.1). The area lies at altitudes between 1000 and 3638m above sea level**.** Afro-Alpine (*Wurch*), Temperate (*Dega*), Sub-tropical (*Woina-Dega*), and Tropical (*Kolla*) agroecological zones are found in the Zone. However, *Woina Dega* dominates.

The average temperature varies between 3 °C and 28 °C. The annual range of rainfall varies between 600 and ,1900 mm. *Cheha* and *Gumer* districts were selected for our study due to their dense populations and high coverage of *Eucalyptus* under expansion. Though there have been reported increases in *Eucalyptus* plantations, land use in the Gurage Zone is primarily oriented toward subsistence agriculture, grains and crops like chat (Zerga et al., 2021). The Gurage people are perhaps best known for their heavy dependence on *enset* (*Ensete ventricosum*). Population levels within the Gurage zone reached approximately 1.3 million people according to 2007 Population Census Commission.

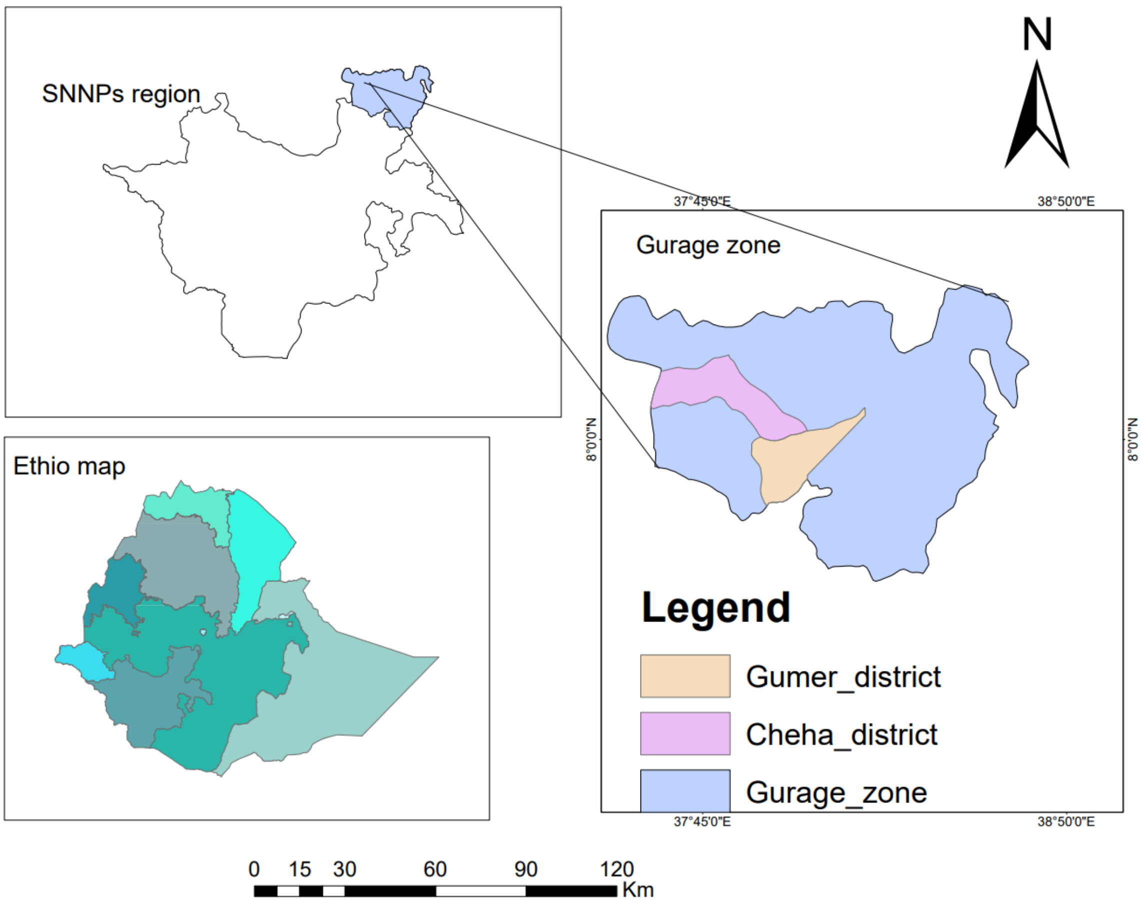

Fig.1 Study area map

2.2 Sampling methods and sample size determination

This study used a multi-stage sampling method. First, two potential districts (*Cheha* and *Gumer*) were selected from the *Gurage* zone based on plantation potential with the consultation of Zonal and *Woreda* (district) agricultural and natural resource offices. In the second stage, two potential *kebeles*[1] were purposively selected per sample district, taking into account the extent of land use change from agriculture to forest. *Degag* and *Worerber* were picked from *Cheha* district and *Bercher* and *Arekitsheleko* were selected from the *Gumer* district. Then, sample farmers were chosen from selected *kebeles* using a simple random sampling technique. The sample size of the two selected districts was determined using the sample size determination formula of Cochran at a 5% precision level cited by Wikidan & Tafesse (2023).

$$n = \frac{N * Z^2 p * q}{e^2(N-1) + Z^2 * p * q} \quad (1)$$

$$n = \frac{1640 * (1.96)^2 0.5 * 0.5}{0.05^2(1640-1) + (1.96)^2 * 0.5 * 0.5} \quad n = 311$$

Where: n = Sample size of household heads; P = 0.5, the maximum level of variability taken when previous population variability is unknown; q = 1-0.5. i.e., 0.5; e is the precision level and N=Total population size of the selected villages, obtained from an administrative office of the selected district. The total number of households in the study area was 1640. Therefore, the sample size is 311 households.

2.3 Data collection methods

Semi-structured questionnaires were used to gather information from sampled households in the study area. The questionnaires were administered to respondents 20 years of age and older who had lived in the area for at least 10 years and were the implicit decision-makers in the household. The questionnaires included questions aimed at assessing general information about the respondents, farmers, and the land cover history of the household parcels. Additionally, the farmers' opinions on the drivers, pressures, conditions, impacts, and responses to changes in land cover were requested. Focus groups were also organized using a checklist of questions to guide discussion. The discussion included different groups from the administrative part, community and women. A total of 2 focus group discussions were carried out for each of the selected districts with each focus group consisting of 10 people. Key informant interviews (KIIs) were also conducted to gain an in-depth and detailed understanding of the local people's perceptions of the land use changes that had taken place in the study area and the associated underlying causes perceived to contribute to the changes. The key informants were agricultural and natural resource officers as well as district managers of the study area.

2.4 Data analysis

Before conducting data analysis, data management, data transformation, and diagnostic tests such as multicollinearity and correlation were performed. Both descriptive and econometric models are applied for the analysis of qualitative data. The questionnaire results were complemented with qualitative results gained in FGDs and KIIs. The socioeconomic data derived from the questionnaire were entered, processed, coded in

[1] Kebele is the smallest administration unit in Ethiopia

SPSS, and analyzed using STATA version 17. Descriptive statistical analysis was used to describe the socio-economic variables of the households, summarize the responses and rank drivers of land use change.
The DPSIR model is used to integrate household perceptions of the drivers of land use change. In addition, the ranking of drivers of land use change perceived by the respondents was computed using the principle of weighted average using the ranking index adopted by Solomon et al. (2017).

$$Index = \frac{R_nC_1 + R_{n-1}C_2 \ldots\ldots\ldots + R_nC_1}{\sum R_nC_1 + R_{n-1}C_2 \ldots\ldots\ldots + R_1C_n} \quad (2)$$

Where R_n = value given for the least-ranked level (for example, if the least rank is the 10^{th}, then R_n = 10, R_n-1 = 9, R_1 = 1; C_n = counts of the least ranked level (in the above example, the count of the 10^{th} rank = C_n, and the count of the 1^{st} rank = C_1).
The binary logit model is used to examine the factors affecting farmers' decisions to change their land use from agriculture to forestland. The dependent variable, land use change from agriculture to a forest, is a dummy variable and is given 1 for those households that have changed and 0 otherwise. Various demographic and socioeconomic variables were used as independent variables and are summarized in Table 1.
According to Gujarati (2004), the functional form of the logit model is presented as follows:

$$\text{Li} = \ln \left(\frac{pi}{1-pi} = \text{Zi} = \beta0 + \beta1x1 + \beta2x2 + \beta3x3 + \beta4x4 \ldots \beta nxn\right) \quad (3)$$

Were; *pi* = probability of farmer's land conversion ranges from 0 to 1.
L= the natural log of the odds ratio or logit.

$$\text{Zi} = \beta0 + \beta1x1 + \beta2x2 + \beta3x3 + \beta4x4 \ldots \beta nxn \quad (4)$$

β0 = the intercept. It is the value of the log odds ratio $(\frac{pi}{1-pi})$ when X is zero.
β = β1+ β2+ β3+ β4… +βn the slope, measures the change in L for a unit change in X; Thus, if the stochastic disturbance term (Ui) is taken into consideration the logit model becomes

$$\text{Li} = \beta0 + \beta1\,\text{Xi} + \text{Ui}.$$

To analyze factors influencing land use change decisions, target farmers were classified into two groups. The first group includes smallholder farmers who have converted their land use from agriculture to forest and others who have not converted their land. Households that change 0.25 hectares or more are considered to change land use and those below 0.25 hectares do not change.

3. Results

3.1 Socio-economic characteristics of households

Among the respondent households, 87% were headed by males and 13% were headed by females. The vast majority (93%) of the respondents were married with only 7% being single. The age of the respondents ranged from 20 to 65 years, with a mean age of 47 years. The average family size of the respondents was 5, with the maximum and minimum family sizes being 11 and 1, respectively. The education status showed that the majority (66.9%) of respondents were illiterate, while only 33.1% were educated. The average number of years that households had lived in their current location was 47.18 years. Respondents owned land with a maximum size of 1.41 hectares and had an average of 2.26 TLU. The maximum forest income gained by the households was 11,000 Ethiopian Birr (ETB) per year. The average distance from the nearest town to their place of residence was about 3.09 km, while the average distance from the nearest forest to their place of residence was 7.03km. The primary income-generating activity in the study area was agricultural production, with an average family income of ETB 39,212.11 per year (Tab.1).

				Number of observations (N=311)			
Variable	Measurement	Description	Expected sign	Mean	Std. dev.	Min	Max
Sex (1=Male)	Categorical	1 if the respondent is male, 0 if female	+	0.87	0.34	0	1
Age	Continuous	Respondent age in years	-	50.58	13.86	20	65
Family size	Continuous	Number of persons in the household	-	5.00	2.05	1	11
Education	Categorical	Respondent’s educational status	+	0.33	0.47	0	1
Marital status(1=married)	Categorical	1 if the respondent is married, 0 otherwise	–	0.93	0.26	0	1
Years lived in the area	Continuous	Number of years the respondent lived in the area	+	47.18	16.02	10	60
Total land holding size	Continuous	Landholding size in hectares	+	1.41	0.96	0.09	10
TLU	Continuous	Livestock holding in tropical livestock unit (TLU)	-	2.26	1.71	0	10.5
Forest related income	Continuous	Amount of income in birr	+	1,071.70	2,099.58	0	11,000
Distance to town	Continuous	Distance traveled to a town in km.	-	3.09	6.72	0	30
	Continuous	Distance traveled to the forest in km.	+				
Distance to the nearest forest	Continuous	Total crop value in birr	-	7.03	10.10	0.05	75
Total crop value	Categorical	1 if the respondent is male, 0 if female	+	39,212.11	59,080.16	0	412,500

Tab.1 Summary statistics of socioeconomic variables and hypothesis

For the first analysis of the relationship between dependent Variables (decisions to change land use land cover) and socioeconomic Variables (sex, educational status, holding size, educational status, years lived in the area, TLU and forest related income) correlation analysis was applied before modeling continued. Those major socioeconomic variables were analyzed to determine the relationship with decision to land use land cover change or not. According to Belete et al. (2023) before conducting modeling analysis, Pearson correlation analysis can be used to explain the correlation between the dependent variable and the independent variables. Similarly, the Pearson correlation coefficient indicates positive and negative correlations. A positive correlation indicates that the dependent variable increases with the value of the independent socioeconomic variable, while a negative correlation indicates that the dependent variable increases with the value of the independent socioeconomic variable decreases as the value increases the values of socioeconomic independent variables that are the main causes which push for land use land cover change decision. Independents variables (i.e., Sex, Educational status, Total land holding size, Forest related income) have positive Pearson correlations with the drivers of land use land cover change; this means that when these independent variables increase, the decision to change land use and land cover from agriculture to forest also increase. However, when the independent variable of education status is negatively correlated with Livestock holding (TLU) and the number of educated population increases, the land use land cover change decision increase, while the status of livestock holding increases, the driving forces of land use and land use dynamics decline. Number one (1) correlation shows that the value of one variable can be accurately determined by knowing the value of the other variable, which is a perfect correlation (Tab.2).

		ISRSEVdlulcc	**Sex**	**Educational status**	**years lived in the study area**	**TLU**	**land holding size**	**Forest related income**
Is there a relationship between Sev and decisions in land use land cover change	Pearson correlation	1.000						
Sex	Pearson correlation	0.069	1.000					
Educational status	Pearson correlation	0.191	0.0569	1.000				
Years lived in the area	Pearson correlation	-0.170	0.0897	-0.3185	1.000			
TLU	Pearson correlation	-0.081	0.033*	-0.006**	0.111	1.000		
Total land holding size	Pearson correlation	0.310	0.086	0.053	-0.012**	0.0913	1.000	
Forest related income	Pearson correlation	0.177	-0.042*	-0.0484	0.247	0.232	0.1387	1.000

*Correlation is significant at the 0.05 level **Correlation is significant at the 0.01 level.ISRSEVdlulcc =is there a relationship between socioeconomic variables and decisions in land use land cover change. Sev =socioeconomic variables

Tab.2 Correlation coefficient values between socioeconomic variables and decisions in land use land cover change

More than half (74.6%) of respondents own the land through inheritance from their parents. Another 11.9% received it from local leaders. However, 8.68% of them own land as a gift, while the remaining 3.2% of respondents acquired the land through other means, such as being given by the local government, buying and donating, both inheriting and being given by the government, or both buying and inheriting (see Tab.3).

Ways of land acquisition	**Frequency**	**Percent**
Bought	5	1.61
Inherited	232	74.60
Donation	27	8.68
Given by the local leader	37	11.90
Others	10	3.2
Total	311	100.00

Tab.3 Means of land acquisition in the study area

The main crops in the study area are barley, wheat, *enset* (*Ensete ventricosum*), and maize (Zea mays), as confirmed by the respondents. The mean annual income obtained from barely is 11,090.84 ETB and 1,1024.76, 8,070.09, and 2,384.44 birr per year, respectively (Tab.4).

Crop type	**Number of observations (N= 311)**	
	Mean value in birr	**Std. dev.**
Maize	2,384.44	7,510.34
Wheat	11,024.76	35,094.55
Barley	11,090.84	13,658.42
Enset	8,070.09	14,929.56
Potato	1,901.22	3,416.13
Bean	2,543.01	6,467.02
Apple	3,426.05	17,082.34

Tab.4 Total crop production and its value the households received per year

Households in the study area also derived income from alternative sources other than crop production. These sources included full-time employment in the public sector, selling forest products, selling charcoal, remittances, and harvesting edible wild fruits. Remittances were the main alternative source of income for households, with a mean of ETB 5,630 per year, followed by non-farm businesses' income mean of 4,228.33 birrs (Tab.5).

Types of alternative income sources	**Number of observations (N=311)**	
	Mean	**Std. Deviation**
Full time government employment	2,856.71	1,965.17
Selling forest product	2,800.96	2,356.19
Charcoal	3,871.43	3,745.98
Non-Farm business	4,228.33	3,331.38
Remittance in Birr	5,630.00	3,604.33
Wild edible fruit	618.52	591.43

Tab.5 Annual income derived from alternative income sources of households in the study area

3.2 Perception of households for the status of crop production and forest cover change in the study area

According to the majority (75.3%) of respondents, crop yields have decreased over the past 10 years. More than half (64.21%) of households confirmed the decline in land allocation for crop production due to the loss of soil fertility, which is mainly affected by the allelopathic effect of neighboring plantations. Regarding the status of forest cover change, KIIs indicated that the forest cover change had increased over the past 10 years in the study area. Furthermore, the majority (89.47%) of respondent households perceived an increasing rate of afforestation in the area (Fig.2).

The perceptions of households in the study area indicate that the primary reason for the decline in crop yields was unreliable rainfall (35.4%), followed by repeated cultivation due to limited area, soil infertility, high cost of agricultural inputs and the emergence of new pest diseases 26.4 %, 15.2%, 11.9% and 10.8% respectively (Tab.6). The cost of fertilizers has become too high and the arable land cannot receive enough of it, leading to decreased yields in the study area.

The farmland in the study area was increasingly becoming unsuitable for crop production, a concern identified by key informants, discussants, and households. In response to this issue, farmers attempted various actions to meet their subsistence needs and increase their cash income. The majority of respondents (36.6%) reported trying to enhance fertility to boost crop yields, followed by fallowing (34.5%), seeking additional land (17.2%), and transitioning to plantation farming (8%) in the study area (Fig.3).

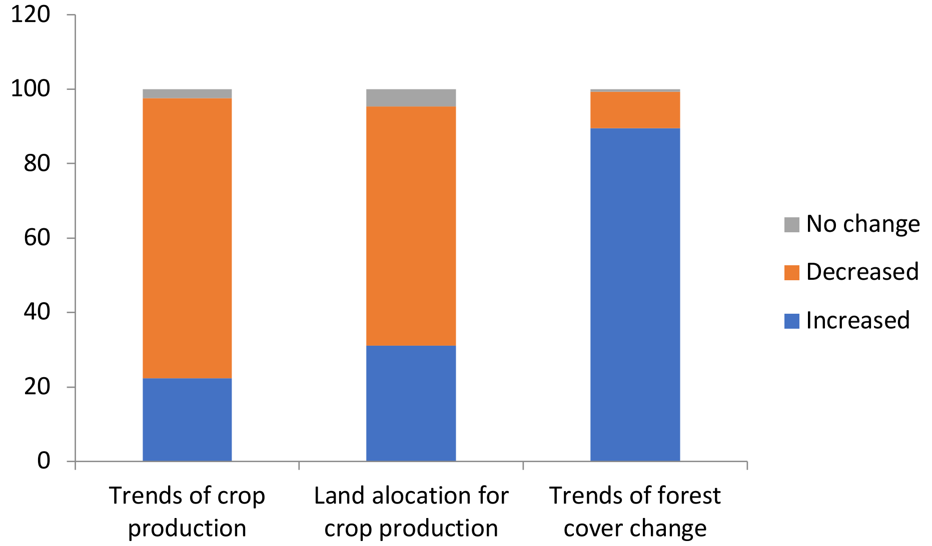

Fig.2 Trends of crop production, land allocation for crop production, and trends of forest cover change

Cause of crop production change	Frequency	%	Proportion (%)
Unreliable rainfall	98	28.0	35.4
Repeated farming due to limited land	73	20.9	26.4
Soil infertility	42	12.0	15.2
High cost of agricultural input	33	9.4	11.9
Occurrence of new pests and disease	30	8.6	10.8
Shortage of agricultural input	27	7.7	9.7
Lack of knowledge	22	6.3	7.9
Lack of improved seed quality	17	4.9	6.1
Inadequate labor	8	2.3	2.9

Tab.6 Cause of crop yield reduction as households' perception in the study area

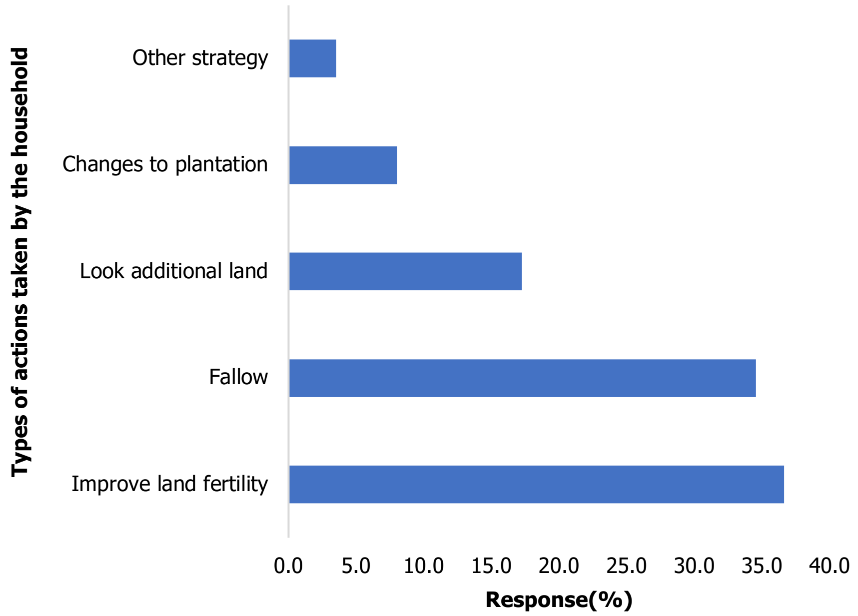

Fig.3 Households' action in response to crop yield reduction

3.3 Drivers of land use land cover change from agriculture to forest

The drivers of land cover change from farmland to forestland were ranked and presented in Tab.7. According to the respondents' responses, the top five causes of cropland changing to forest land were identified as income-generating activities from trees, declining soil fertility, increasing demand for forest products, extreme weather events, and the absence of natural forests in the area (Tab.7).

Key informants and participants in the focus group discussions also noted that the increasing demand for wood products, both for wood fuel and construction materials, has led to a rise in prices. This has motivated farmers to convert their productive agricultural plots to *Eucalyptus.*

Variables	**Weighted frequency**					**Index**	**Rank**
	1	**2**	**3**	**4**	**5**		
Use of the tree for income generation	191	55	28	4	11	0.13	1
Decline soil fertility	156	49	30	29	18	0.12	2
Increasing demand for forest products	156	59	18	17	37	0.12	3
Extreme weather events	118	51	29	15	44	0.10	4
No natural forest	93	41	42	31	55	0.09	5
Education and Awareness	76	55	39	46	56	0.09	6
Fragmentation of farmland	77	37	53	42	42	0.09	7
Expected future return	68	50	46	30	56	0.08	8
Biological property of species	64	51	53	20	48	0.08	9
Labor intensity	76	30	35	32	66	0.08	10
Others	24	7	4	29	29	0.03	11

Tab.7 Proximate causes of land use land cover change from agriculture to the forest

Furthermore, the increasing price of wood-based products, high agricultural input costs, the allelopathic effect of neighboring farmer plantations, lack of motivation for other agricultural practices, lack of adequate technology to improve agricultural practices, increased market accessibility, and unemployment were the top-ranked underlying causes for the conversion from agriculture to the forest (Tab.8).

Indirect drivers	**Weighted frequency**					**Index**	**Rank**
	1	**2**	**3**	**4**	**5**		
The increasing price of wood-based products	147	52	26	14	14	0.13	1
High cost of agricultural input	143	49	24	16	33	0.12	2
Externality	90	42	71	29	37	0.11	3
Lack of motivation to agriculture practice	85	73	37	23	49	0.11	4
Lack of adequate technology for agriculture	109	40	33	36	34	0.11	5
Increased accessibility of the market	90	50	50	17	40	0.10	6
Unemployment	129	18	10	31	63	0.10	7
Presence of soil and land degradation	70	52	51	21	76	0.10	8
Social demographic change	83	47	40	17	39	0.09	9
Others	27	11	5	27	7	0.03	10

Tab.8 Indirect drivers of land use land cover change from agriculture to forest

3.4 Pressures exerted, states, impacts, and response due to land cover change from agriculture to the forest in the study area

Pressures resulting from the change in land cover from agriculture to forest included decreased crop production (82.7%), a lack of crop residue for livestock feed (65.1%), over-grazing of land (64.2%), food insecurity (63.3%), and changes in soil moisture (59.4%) as reported by household farmers (Fig.4). The study by Meshesha et al. (2014) found that the conversion of cropland to forest leads to overgrazing due to scarcity of crop residues for livestock fodder.

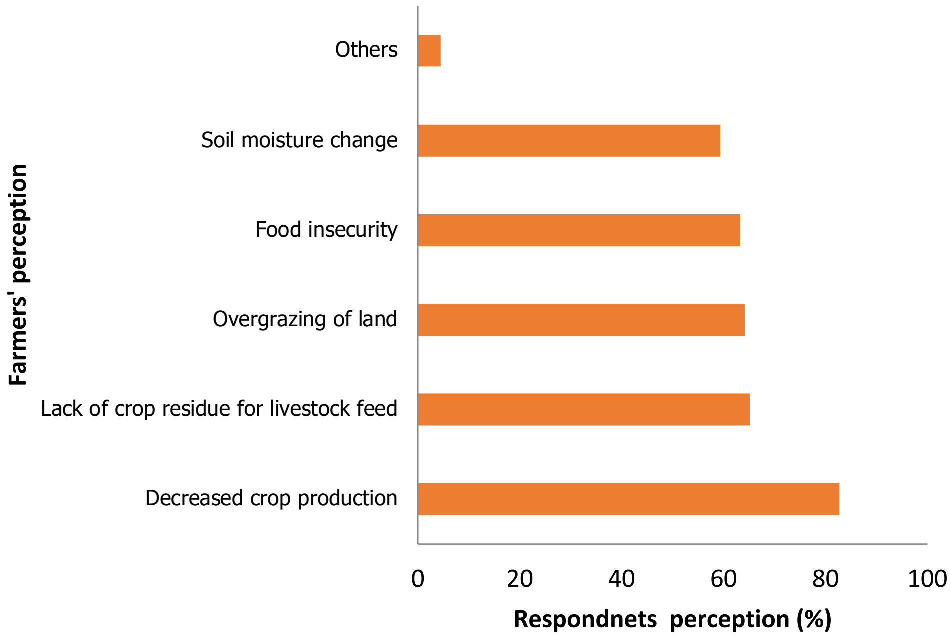

Fig.4 Farmers' perception of pressures exerted due to land cover change from agriculture to forest

In the study area, current observations show that land cover change from agriculture to forest by household farmers has led to increased land fragmentation as confirmed by the majority of respondents (70.1%). This change has also resulted in reduction of grazing land (64.5%), reducing land for agriculture (63.3%), improving biodiversity (53.4%), change of landscape (49.6%), improved soil fertility (42.4%), and (31.3%) of them reported as water quality improvement in case of plantation expansion (Tab.9).

State	Frequency	Proportion (%)
Reduced land for agriculture or increased forest cover	213	63.0
Increased land fragmentation	235	70.1
Reduced land for grazing	216	64.5
Soil fertility improved	142	42.4
Biodiversity improved	129	53.4
Water quality improved	105	31.3
Change of landscape	166	49.6
Other	11	3.3

Tab.9 State/ conditions existed due to land cover change from agriculture to forest farmers' perceptions. The total number of cases was 311 due to multiple-response questions multiple counts are possible

In the study area, the main impacts reported by household farmers were a reduction of fodder for animals (75.5%), scarcity of land for agriculture (73.4%), an increase of rural to urban migration (69.3%), a reduction of crop production (68.7%) and (58.2%) of respondents perceived that difficulty to revert plantation land to agricultural land were the major impacts of land conversion from agriculture to the forest (Fig.5).

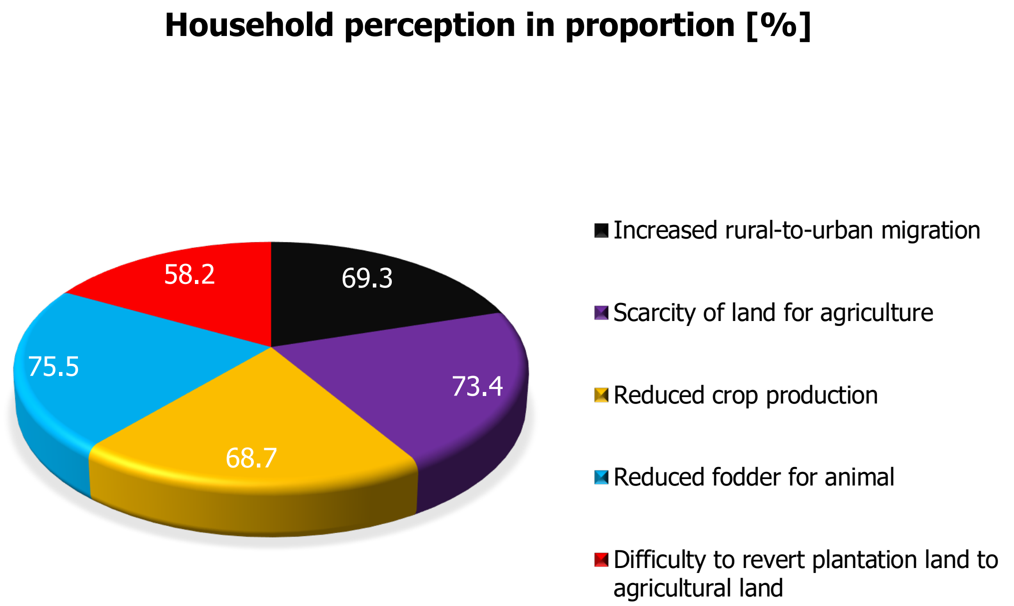

Fig.5 Impacts of land cover change from agriculture to the forest in the study area

The actions taken by households and stakeholders in response to the impacts of land cover changes were as follows; planting multipurpose trees (71%), implementing appropriate land use planning (69.3%), raising farmers' awareness of sustainable land management (66.9%), promoting sustainable agricultural intensification (64.8%), developing specific policies (60%), enforcing existing forest laws and regulations (56.7%), diversifying livelihood activities (47.8%) and utilizing renewable energies (43.3%) (Tab.10).

Responses	**Frequency**	**Proportion (%)**[2]
Planting multipurpose trees	238	71.0
Implementing appropriate land use planning	232	69.3
Raising awareness of farmers in land management	224	66.9
Diversification of livelihood activities	160	47.8
Sustainable agricultural intensification	217	64.8
Developing specific policies	203	60.6
Enforcement of the existing forest laws and regulations	190	56.7
Use of renewable energy	145	43.3
Others	33	9.9

Tab.10 Perception of farmers towards land use land cover change from agriculture to forest

Based on households' responses on their perception of various factors related to the conversion of agricultural land to forest land, the DSPIR model was developed. All the responses received from household farmers during

[2] The total number of cases was 311 and due to a multiple-response question, multiple counts are possible

household surveys and also the idea mentioned by the focus group discussants and key informants were included (Fig.6).

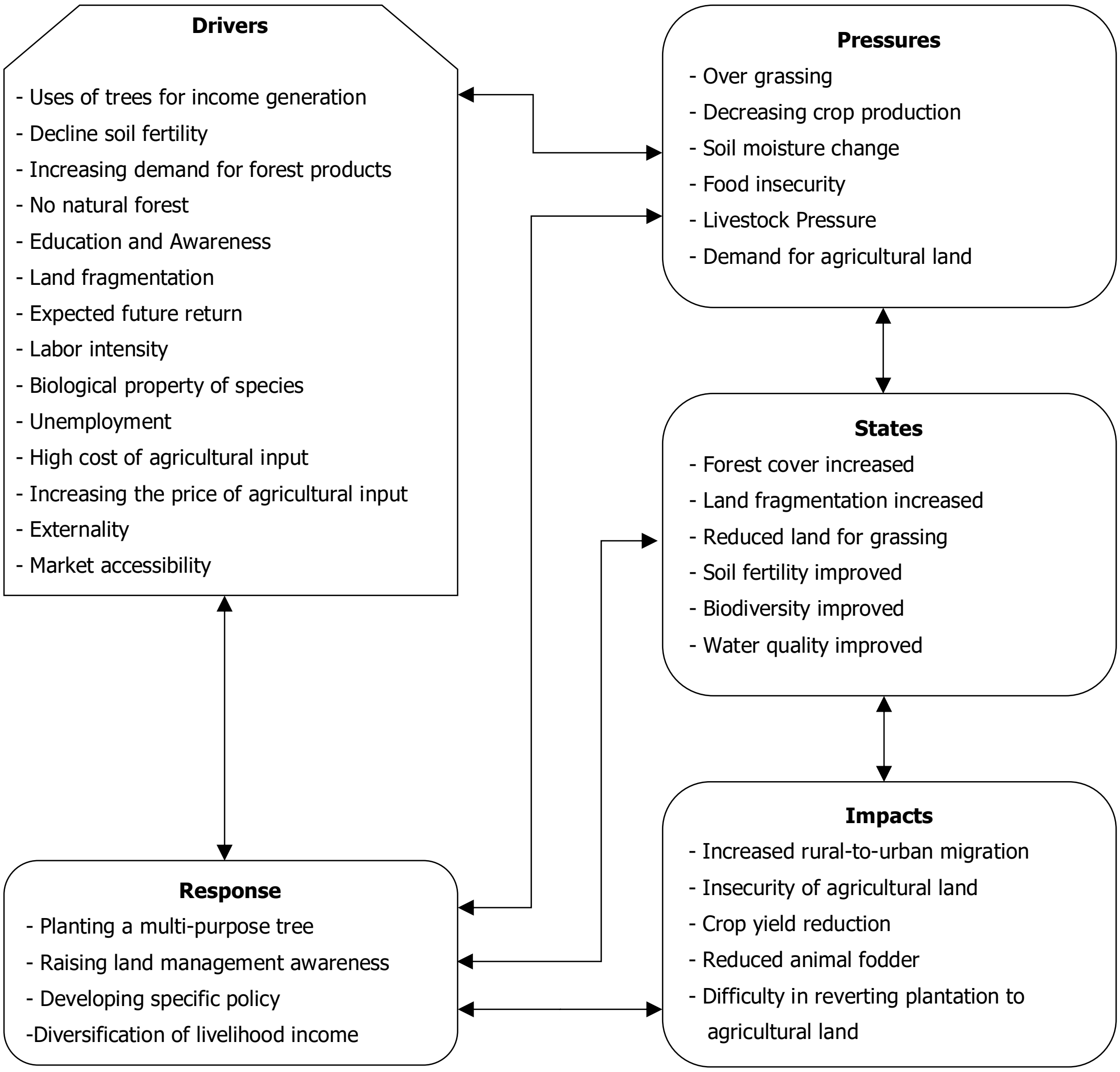

Fig.6 Driver, state, pressure, impact and response model

4.5 Factors affecting farmers' decisions to convert agricultural land to forest

The results of the logistic regression analysis regarding factors influencing farmers' decisions to convert their agricultural lands to forest land are presented in Tab.11. The total land holding size of farmers and their forest-related income have a significant and positive effect on their decision at a 1% level of significance. The number of years lived in the area and the tropical livestock unit (TLU) had a negative and significant influence on households' decisions to convert their farmland to forest land at a 5% level of significance. Furthermore, educational status and livestock holding had a significant and positive effect on farmers' decisions to convert their agricultural lands to forestland at a 5% level of significance. The result suggests that with each additional year of educated farmers, the likelihood of cropland being converted to forest land increases by 1.9%, assuming all other factors remain constant.

The positive and significant effect of farmers' land holding size on the conversion of cropland to forest indicates that land size is crucial in allocating land for different functions.

Number of obs = 311
LR chi2(12) = 67.00
Prob > chi2 = 0.0000
Pseudo R2 = 0.174
Log-likelihood = -158.34358

Parameters	**Coefficient**	**Std. err.**	**Z**	**P>z**	**Marginal effect**
Sex	0.608	0.464	1.31	0.190	0.107
Age	0.010	0.020	0.52	0.604	0.002
Family size	-0.070	0.075	-0.94	0.347	-0.014
Education status	0..632	0.322	1.90	0.057**	0.13
Marital status	-0.265	0.562	-0.47	0.637	-0.055
Years lived in the area	-0.034	0.017	-2.01	0.044**	-0.007
Total landholding size	0.686	0.168	4.08	0.000***	0.135
TLU	-0.195	0.091	-2.14	0.032**	-0.038
Forest related income	0.000	0.000	3.76	0.000***	0.000
Distance residence town	0.013	0.022	0.56	0.575	0.002
Distance nearest forest	0.006	0.014	0.45	0.653	0.001
Total crop value	0.000	0.000	0.43	0.666	0.000
_Cons	-1.116	0.903	-1.24	0.216	-

*** and ** indicates 1% and 5% levels of significance, respectively

Tab.11 Factors influencing farmers' decisions to convert agricultural land to forest

The result also showed that forest-related income correlated positively and significantly with farmers' decision to convert cropland to forest. This implies that if farmers gained more income from forests, the probability of their decision to convert agricultural land to forest increased to optimize their economy and cover their livelihood expenditures as well. The tropical livestock unit has a negative relation with the conversion of cropland to forest and shows a significant association.

4. Discussions

4.1 Perception of households for the status of crop production and forest cover change

The qualitative findings revealed that the trends of land allocation for crop production declined over the past 10 years in the study area. The households perceived that the crop yield had a declining trend. The major reasons for the decline in crop yields were unreliable rainfall, repeated cultivation due to limited land, soil infertility, high cost of agricultural inputs, and the emergence of new pest diseases. The cost of fertilizers has become too high and the arable land cannot receive enough of it, leading to decreased yields in the study area (Alebachew et al., 2015; Bizimana & Hategekimana, 2024). Similar results from a study by Ngoune and Mutengwa (2019) showed that the main constraints on agricultural yields are inadequate rainfall, declining soil fertility (Liliane et al., 2020), and biotic factors such as diseases and pests. Therefore, there is a declined land allocation for crop production in the study area. A similar study by Molla et al. (2023) and Worku et al. (2021) revealed that crop yields declined over time due to soil degradation. On the other hand, the forest cover became increased over time due to a rapid expansion of *Eucalyptus* plantations. The probable reason behind this is the households' ability to drive maximum income from forest products, they are going to convert the crop land to forest. This result is in line with Molla et al. (2023), which indicate a dramatic increase in plantation forests, especially *Eucalyptus* plantations, at the expense of fertile land due to farmers' anticipation of a better income source, and the manageable cost of production. A similar result was also revealed in the study by Phimmavong et al. (2019), indicating an increasing trend of forest cover associated with the rapid expansion of *Eucalyptus* plantations. Another study in Gozamin district of Ethioia (Gedefaw et al., 2020) shown that households are planting eucalyptus trees around homestead and farmland to get cash income.

4.2 Drivers of land use land cover change from agriculture to forest

The result of the study indicated that the to five direct drivers of cropland changing to forest land were the ability to generate maximum income from trees, declining soil fertility, increasing demand for forest products, extreme weather events, and the absence of natural forests in the area. This result aligns with the studies by Derbe et al. (2018), Worku et al. (2021), and Desta et al. (2023) which emphasized the economic potential of converting cropland to plantation forest for better return. Similarly, a study by Molla et al. (2023) in the northwestern highlands of Ethiopia found that the higher price of forest products compared to crops was the main factor driving farmers to plantations for increased income. This is also supported by a study in the *Tigray* region of Ethiopia, which highlighted that households chose to plant *Eucalyptus* trees due to its their low-cost requirements and ability to yield high returns when planted on croplands (Jagger & Pender, 2003). Furthermore, the farmers were motivated to convert their productive cropland to *Eucalyptus* plantations due to the increasing prices and the increasing demand for wood products, both for wood fuel and construction materials (Biziman et al., 2024). A similar finding was reported by Tefera & Kassa (2017) and Derbe et al. (2018).

Moreover, the increasing price of wood-based products, high agricultural input costs, the allelopathic effect of neighboring farmer plantations, lack of motivation for other agricultural practices, lack of adequate technology to improve agricultural practices, and increased market accessibility were the top-ranked indirect drivers for the conversion from agriculture to the forest based on the respondents' perceptions. This finding was consistent with the finding of Alebachew et al. (2015), Kidanu et al. (2005) and Worku et al. (2021), who found that the farmers converted to forests due to the rising prices of forest products and their income-generating potential. This result is also supported by the study of Tadesse et al. (2019) which showed that farmers convert their farmland to plantations when the land becomes unproductive for crop production and fertilizer prices increase.

4.3 Pressures exerted, states, impacts, and response due to land cover change from agriculture to the forest in the study area

The study findings revealed that the pressures, states, and impacts existed due to the land use land cover change from agriculture to forest. Based on the respondents' perception the pressure resulting from this land use change included decreased crop production, a lack of crop residue for livestock feed, over-grazing of land, food insecurity, and changes in soil moisture. The study by Meshesha et al. (2014) found a similar result that the conversion of cropland to forest leads to overgrazing due to scarcity of crop residues for livestock fodder. This conversion also leads to different states observed in the area like land fragmentation, reduction of grazing land, improving biodiversity, reduction of land for agriculture, change of landscape, and improved soil fertility (Liang & Zhang, 2024; Woldegebriel & Girma, 2023). Furthermore, the study findings of Lai et al. (2021) stated that forest areas are associated with low flood and landslide hazard which contributes for enhanced soil fertility. Likewise, the main impacts reported by household farmers were a reduction of fodder for animals, scarcity of land for agriculture, an increase of rural to urban migration, and a reduction of crop production, difficulty in reverting plantation land to agricultural land as respondents' perceptions. A similar result was revealed in a study by Gedefaw et.al., (2020) which indicated the high conversion of agricultural land to forest land in the *Gozamin* district, and identified that rural-to-urban migration, a decline in the fertility of land, and food insecurity were the major consequences of converting agricultural land use. Furthermore, the informants confirmed that land use land cover changes affected local communities' economic activities. Similarly, its social impact including changes in employment and agricultural production, equity, relocations of populations were reported by Francini et al. (2021).

According to the residents' perception, responses to revert and mitigate those impacts as well as the actions that should be taken by the government bodies and respected stakeholders were planting multipurpose trees, implementing appropriate land use planning, raising farmers' awareness of sustainable land management, promoting sustainable agricultural intensification, developing specific policies, enforcing existing forest laws and regulations, and diversifying livelihood activities.

4.4 Factors affecting farmers' decisions to convert agricultural land to forest

The farmers decide to convert their agricultural land to forest due to different socioeconomic factors as shown in the results of the logistic regression analysis. The total land holding size of farmers and their forest-related income had a highly significant and positive effect on their decision, which means when their land size and income from forest increased they made a strong decision to convert. This finding contradicts the study by Mulu et al. (2022) which revealed that total land holding size was significantly and negatively correlated with farmers' decisions on land use for plantations in *Guna Begemidir* District. This discrepancy is likely because decision-making regarding land use change is highly context-dependent. The number of years lived in the area and the tropical livestock unit (TLU) had a negative and significant influence on households' decisions to convert their farmland to forest land.

Furthermore, educational status and livestock holding had a significant and positive effect on farmers' decisions to convert their agricultural lands to forestland. Similarly, studies by Bekere et al. (2023) and Hailu et al. (2020) have shown that education plays a significant role in land use and land cover change. The educated individual has the opportunity to work in sectors beyond agriculture, leading them often to convert their agricultural lands into forest land. This is why education status has a positive effect on farmers' decision-making. This finding aligns with previous studies (Tsani et al., 2018) which found that a farmer's education is linked to the conversion of agricultural land to forest land. The result suggests that with each additional year of education of farmers, the likelihood of cropland being converted to forest land increases by 1.9%, assuming all other factors remain constant.

The positive and significant effect of farmers' land holding size on the conversion of cropland to forest indicates that land size is crucial in allocating land for different functions (Fei et al., 2021). However, this conclusion contradicts the findings of Tsani et al. (2018), who found that land-holding size does not influence the decision regarding agricultural land to forest conversion. The results show that farmers have an opportunity to convert some cropland into forest to meet their cash income needs (Zhang et al., 2018). Therefore, if their land size increases by one hectare, the probability of converting agricultural land to forest increases by 13.5%. On the contrary, the number of years lived in the area is negatively and significantly associated with the decision of farmers to convert their land from agriculture to forest. This indicated that as farmer lives in the area for an additional year, the probability of converting their land from agriculture to forest decreases by 0.7%. The probable reason for this could be farmers live more years in the area, they become more stable in their land tenure and therefore prefer to produce crops rather than convert to forest.

The result also showed that forest-related income correlated positively and significantly with farmers' decision to convert cropland to forest. This implies that if farmers gained more income from forests, the probability of their decision to convert agricultural land to forest increased to optimize their economy and cover their livelihood expenditures as well. The tropical livestock unit has a negative relation with the conversion of cropland to forest and shows a significant association. This means that if there is an increasing number of livestock in households their decision may be influenced to remain low due to the demand for fodder for their livestock (Hettig & Sipangule, 2016). This pushes them to prefer crop production as they can obtain more crop residuals for their livestock feed.

5. Conclusions

The *Gumer* and *Cheha* districts of the *Gurage* zone have been experiencing land use conversion for various reasons. The main finding of this study revealed that the use of trees for generating income was identified as a key direct driver of land cover change from agriculture to forest. Declining soil fertility, increasing demand for forest products, extreme weather events, and the absence of natural forests in the area were also identified as the top major causes for cropland changing to forest land. Similarly, the results show that the increasing price of wood-based products, high cost of agricultural inputs, allopathic effect, lack of motivation to other agricultural practices, lack of adequate technology to improve agricultural practices, lack of adequate technology for agriculture, increased accessibility to markets and unemployment were the top-ranked underlying causes of land conversion. The current major issues that exist due to land conversion from agriculture to the forest were an increase in land fragmentation followed by reduced land for grazing, reduced land for agriculture, and improved biodiversity as identified by respondent households.

The results further indicated that changes in land use land cover change affected households' livelihoods by reducing animal fodder, causing a scarcity of land for agriculture, increasing rural-to-urban migration, reducing crop production, and making it difficult to convert plantation land to back agricultural land. Farmers have implemented various remedies to mitigate the impact of land use land cover changes such as planting multipurpose trees, implementing appropriate land use planning, raising awareness among farmers about land management, promoting sustainable agricultural intensification, and developing local practices like planting *Eucalyptus* trees 100m away from cropland to avoid its allopathic effect on crop production. The results of the binary logit model showed that land ownership and forest-related income were significant factors influencing farmers' decisions to convert their agricultural land to forest land, while the number of years lived in the area and the TLU had a negative and significant influence. Based on the result of this study, it is recommended to raise farmers' awareness of appropriate land use techniques as well as soil and water conservation measures to enable them to effectively manage the land and balance the increasing rate of cropland conversion to forest land in the study area.

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Author's profile

Tesfanesh Ababu

She holds MSc in Forestry Economics and Management from Beijing Forestry University. She is Policy and socio-economics researcher at Central Ethiopia Forestry Development Center. She dedicated her thesis on the Economic Contribution of *Eucalyptus* Woodlot to the Local Households. Her areas of interest and research include Socio-economic, Natural resource economics, Agroforestry, land use and forest governance.

Alemtsehaye Eyasu

She holds MSc degree in Environmental system analysis from Wageningen University, Netherlands. She is a researcher in the field of Agroforestry, Natural Resource Management, Conservation Agriculture, Social, economic and ecosystem services analysis of land use /land cover change and value chain of fruit trees.

Mister Abebe

She holds MSc degree in Natural Resource Economics and Policy. She is a researcher working in the Policy and Socioeconomics research program at Central Ethiopia Forestry Development Center.

Alemayehu N. Ayana

He is a researcher and director of Policy and Socio-economics research program at Ethiopian Forestry Development (EFD). He is an interdisciplinary scientist in the field of natural resource economics, environmental governance, policy analysis, and socio-economic study of land use and climate change.

Asabeneh Alemayehu

He holds MSc in natural resource economics and Policy. He is a researcher and program coordinator of Policy and socio economics research program at Bahirdar Forestry Development Center. His expertise is in the field of Forest Economics, Ecosystem Services, Forest Management, Reforestation, and Agroforestry.

Mulatu Mengist

He holds a Master of Science in Forest and Environmental Science at University degli Studi della Tuscia.

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Environmental factors affecting living comfort perception in different localities in Sri Lanka

Living comfort perception in urban and non-urban localities in Sri Lanka

Mohamed Thariq Mohamed Gazzaly [a*], Mohamed Mujithaba Mohamed Najim [b]

[a] Department of Biosystems Technology
South Eastern University of Sri Lanka, University Park, Oluvil, Sri Lanka
e-mail: mgmthariq@seu.ac.lk
ORCID: https://orcid.org/0000-0002-4348-0396
* Corresponding author

[b] Faculty of Agriculture
Sultan Sharif Ali Islamic University, Tutong TB1714, Brunei Darussalam
e-mail: najim.mujithaba@unissa.edu.bn
ORCID: https://orcid.org/0000-0001-8016-9997

Abstract
Living in comfort and the consequent healthier life is a reaction to the environment indicated by the absence of environmental stressors. The present study investigated the factors influencing the living comfort perception in an urban and a non-urban locality in Sri Lanka. A survey using a pre-tested questionnaire was carried out to solicit the people’s perceptions on identified environmental factors randomly selecting fifty households from each locality. It was found that the factors i.e., water bodies, space, natural beauty, and biodiversity associated with the living comfort positively in the urban locality while the association was neutral in non-urban locality. The factors i.e., stray animals, dust and garbage negatively influenced living comfort in both urban and non-urban localities. The factors i.e., temperature, insects, flood, noise, smoke, vibration, and bad odor negatively influenced living comfort in the urban locality while the influence was neutral in non-urban locality. Further, the factors i.e., rainfall, wind, humidity and drinking water were not important for living comfort perception in both localities. The factors identified in this study are useful in zoning the localities according to their suitability in relation to public comfort perception. Further, the identified factors can be manipulated to improve the living comfort perception in urban and non-urban localities except for climatic factors.

Keywords
Nature; Space; Shade; Garbage; Stray animals.

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1. Introduction

Quality of life is the degree to which a person enjoys the important possibilities of his/her life. Possibilities result from the opportunities and limitations each person has in his/her life and reflect the interaction of personal and environmental factors. Hence, the environment and its quality are one of the most important factors in determining the quality of life (Keles, 2012). However, the effective evaluation of environmental factors is a difficult task. The evaluation of environmental factors such as beauty, fresh air, noise, fumes, and congestion cannot be precisely determined because people themselves are not very specific about their likes and dislikes (O'Riordan, 1983). Low quality environment in recent years because of accelerated urban development, increased population density, industrial development led to the undesirable conditions in cities i.e. reduction of safety, vitality and liveliness. Stathopoulos et al. (2004) revealed that there is an integrated effect of environmental factors i.e. wind speed, air temperature, relative humidity and solar radiation on the human perception, preference and overall comfort in an urban environment. De Looze et al. (2003) have emphasized three elements in defining comfort across disciplines: 1- comfort is a construct of a subjectively defined personal nature; 2- it is affected by factors of a various nature (physical, physiological, psychological); and 3- it is a reaction to the environment. From the environmental ergonomics perspective, human comfort is evaluated by considering the interaction between the thermal, acoustic, vibration, lighting and air quality environment as these factors can affect performance, productivity, health and safety of people and has therefore influence over their behavioral response (Parsons, 2015). However, the intention to evaluate the environmental factors have been commonly concerned with human responses to cold and hot conditions, rather than assessing the environment as a whole (Parsons, 2015) and to further strengthen this point Ortiz et al. (2017) noted that absence of environmental stressors is important for human comfort feeling. When someone selects a place for living, the financial affordability plays a major role but the choice will be influenced by many other factors such as safety and environment of the locality, access to facilities, pollution of different nature etc. Further, when lands are sold for housing, usually better environments that could afford better living comfort due to its location will cost more since there is a trend towards seeking for a place with positive environmental factors. On the other hand, information on environmental factors that affect living comfort in a locality will also help zoning the locality according to its suitability. The living in comfort offers everything someone needs to have a healthier life, from the biological perspective it is a maintenance of homeostasis, which is a reaction to the environment indicating the absence of environmental stressors. Many studies by Mohamed Thariq et al. (2010), Reffat et al. (2000), Pinto et al. (2017) and Ghasemi et al. (2015) are reported on the indoor comfort, comfort in environment, seating comfort etc. Jansen (2020) concluded that preference for different type of residential environment and underlying motivations vary between households in urban and rural areas. According Bulygina et al. (2020), environmental comfort in the daily life of people living in rural areas and urban areas differ. However, underlying factors which affect the environmental comfort of residents were not thoroughly analysed. According to the literature available, no study is reported from Sri Lanka on the environmental factors affecting the living comfort in a locality. It is important to have an understanding about the living comfort of a locality and how and what the factors of the particular locality affect the living comfort of people. Hence, the present study was carried out with the objectives of identifying factors which influence the living comfort in two different selected localities (urban and rural), which in turn may help to have understandings to evaluate localities in relation to their living comfort.

2. Literature review

The need for comfortable living conditions in the country is a fundamental prerequisite for sustainable development thus supporting and improving the comfort of living environment, including the workplace, has recently become more important (Mishchuk & Grishnova, 2015). Webster's Dictionary defines comfort as a state or feeling of having relief, encouragement and enjoyment. Slater (1985) defines comfort as a pleasant state of physiological, psychological and physical harmony between a human being and its environment. Richards (1980) stresses that comfort is a state of a person involving a sense of subjective well-being, in reaction to an environment or situation. According to Kolcaba (2003), comfort is "the immediate state of being strengthened by having the needs for relief, ease, and transcendence addressed in the four contexts of holistic human experience: physical, psychospiritual, sociocultural, and environmental". The aforementioned literature indicates that in the human comfort perceptions is influenced by the living environment. Hence, what environmental factors or attributes influence living comfort need to be taken into account in improving living comfort in a locality. According to Pinto et al. (2017), comfort and well-being are commonly used interchangeably and both are presented as concepts related to quality of life. The quality of environment of a region or of a territory determines its conditions for the people to live in comfort which ensures the well-being and the health however, it is often bypassed in the in urban planning process and given a secondary status when compared to the disaster risk resilience which is a primary need (Margiotta et al., 2021). Environmental elements and their relationship to city are fundamental for the attainment of a high standard of urban life (Tulisi, 2017). The relationship between human needs and the city is reciprocal, as human needs must be fulfilled through all elements of the city to have a decent and comfortable life (Alsayed, 2024) which requires the identification of the environmental factors. According to Matsuoka and Kaplan (2008), the nature needs, directly linked with the physical features of the environmental setting, were categorized in terms of contact with nature, aesthetic preference, and recreation and play. The urban land management models are expected to deliver suitable habitat to maintain the biodiversity, let climate regulation while maintaining aesthetic, recreational and educational benefits in addition to enhancing the urban quality of life and social interaction (Pelorosso et al., 2013). According to Brunette and Vogher (2014), green infrastructures can assume a strategic role in restoring and enhancing the ecological and environmental services (Isola et al., 2023) and livability in urban areas. Stathopoulos et al. (2004) found that weather parameters such as wind speed, air temperature, relative humidity and solar radiation influenced the overall comfort in an urban environment. Peng & Timmermans (2019) found that the openness of public space had significant effect on user comfort. According to Zali et al. (2016), existence of open and green spaces is very important in new urbanism perspective, on one hand for providing beauty, balance and improvement of life quality and vividness of neighborhood and on the other hand, as places for gathering and creating social interactions. Manteghi et al. (2015) found that different kinds of water bodies have the capacity to cool the ambient temperature for the air thus contributes for environmental comfort. According to Sangkertadi & Syafriny (2016), optimum wind speed and shading devices for open space in urban area in humid tropical environment may contribute for outdoor thermal comfort. Klemm et al. (2015) found that street greenery will contribute to create thermally comfortable and attractive living environments. The environmental comfort in living is secondary when compared to the disaster risk resilience needs, which is primary, for a locality or for a town planning. However, once the basic needs are fulfilled, the next level needs arise and become important, thus the environmental comfort and its underlying factors becoming the important criteria to be fulfilled. Under this theoretical background, the present study evaluated the underlying environmental factors affecting the living comfort in different localities.

3. Materials and methods

3.1 Site selection

Two Gramaniladari (GN) divisions (local administrative divisions) from Gampaha district in the Western province of Sri Lanka representing an urban and a non-urban area were selected in consultation with the divisional secretaries of Gampaha and Kelaniya. The GN divisions selected were Gangabada (an urban GN division from Kelaniya Divisional Secretariat Division - Fig.1A) and Keselwathugoda (a non-urban GN division from Gampaha Divisional Secretariat Division - Fig.1B). The above urban and non-urban conditions were selected for the study in order to gather the people's perceptions on living comfort in their respective living environments and also considering factors such as easy access and safety of the data collectors when visiting households and the cost factors. Though the urban/rural binarism is wildly to represent two opposite conditions, we for this study used the terms urban and non-urban to represent two opposite site conditions. Gangabada and Kehelwathugoda GN divisions are located within the Gampaha administrative district from the Western Province of Sri Lanka. The Gangabada GN division is located within the Kelaniya Divisional Secretariat division while Keselwathugoda GN division is located within the Gampaha Divisional Secretariat division. Gangabada GN division is 6 km from the Colombo city limits while Keselwathugoda GN division is 35 km away from Colombo city limits however this area is only 3 km away from Gampaha city limits. Gangabada GN division is located 20 km away from Gampaha city limits. These two locations are 24 km apart. With regard to the climatic conditions of Gampaha District, the minimum and maximum temperature is 21.6 °C and 37°C respectively. The average annual rainfall is 1.750 millimeters with hot wet zone climate. The rainfall is mainly during the periods of inter monsoon and southwest monsoon while during the period in January to April, dry climate exists all over the district (Gampaha District Secretariat, 2024). The population density of the Keselwathugoda and Gangabada GN divisions were 1,977/km^2 and 9,787/km^2 respectively. Tab.1 provides the characteristics on the land use in both study locations.

Land use	**Gangabada GN division (Urban)**	**Keselwathugoda GN division (non-urban)**
Built-up land	62.8%	48.2%
Vegetation	12.2%	46.9%
Bare land	2.7%	4.9%
Water bodies	22.3%	0.0%
Total	100%	100%

Tab.1 Land use characteristics of the study areas

3.2 Sampling and data collection

Samples were selected using the electoral lists of the respective GN divisions randomly based on random numbers generated by a computer. There were 777 families in Gampaha-Keselwathugoda GN division and 902 families in Peliyagoda-Gangabada GN division. Fifty households were selected from each GN division. Many variables were considered in the sampling. The age group selected was 25 - 55 years. The sample does not include children, elderly people and sick people because people's attitudes on environmental conditions may vary with age of a person and health conditions of the person. Both males and females were selected from both the sites. Perception of men and women may differ in their attitudes towards environmental factors that affect the living comfort. As environmental conditions vary with the time period of the day and as people may respond differently considering only the conditions at the time of surveying, data collection was done within the same time duration (9:00 am – 11:00 am) in several days. Preliminary data were collected through a questionnaire survey and site visits. For this purpose, fifteen households from each GN divisions were selected randomly and open questions were asked to collect preliminary data needed to design the questionnaire. The preliminary survey identified the factors temperature, rainfall, wind, humidity, water bodies, space, natural beauty, shade, biodiversity, stray animals, presence of insects, drinking water, flood, dust, noise pollution, vibration, garbage, smoke, odour and drainage as factors affecting or influencing living comfort in the study areas. Twenty environmental factors, which affect comfort in living in the study sites, were identified and these factors were included in the questionnaire, which was tested and refined employing a subsample. The improved questionnaire was used to collect data from the two study sites to solicit the people's perceptions on environmental factors, which affect their living comfort. The survey was conducted during weekends to make sure the chief occupant of the household available and respond. Some clarifications were given to the respondents to clarify the questions properly.

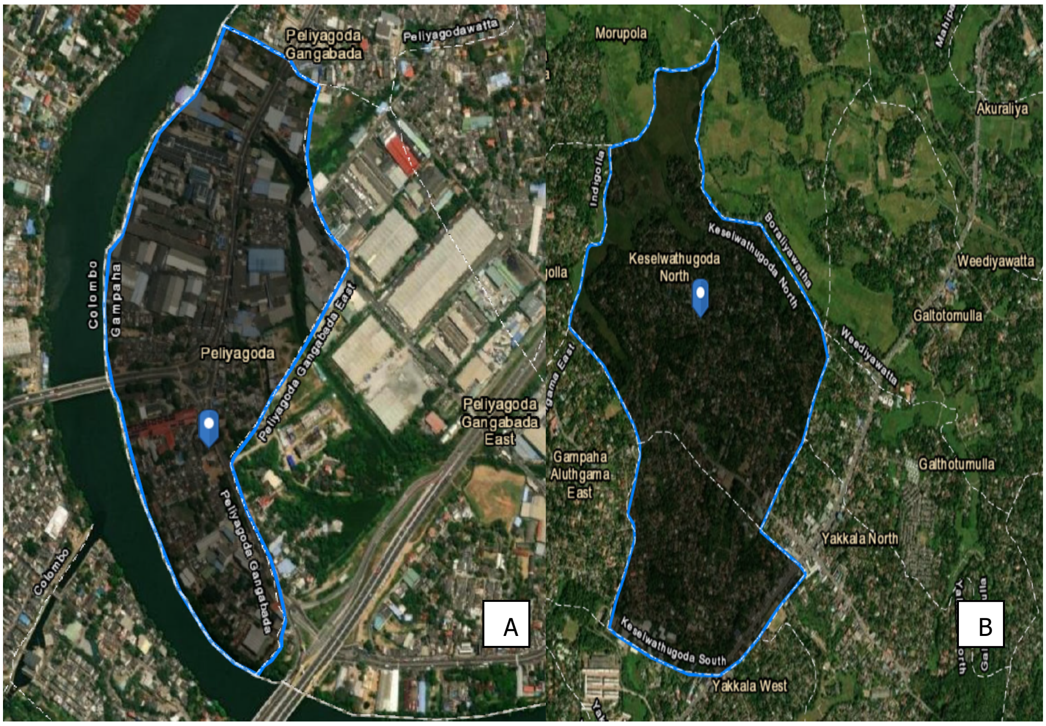

Fig.1 Gangabada (A) and Keselwathugoda (B) GN divisions in Gampaha district in Sri Lanka

Factors	Category				
	Strongly agree	Agree	Normal	Disagree	Strongly disagree
Temperature factor	1	2	3	4	5
Annual rainfall	1	2	3	4	5
Wind	1	2	3	4	5
Humidity	1	2	3	4	5
Water bodies	1	2	3	4	5
Space	1	2	3	4	5
Natural beauty	1	2	3	4	5
Shade	1	2	3	4	5
Biodiversity	1	2	3	4	5
Stray animals	1	2	3	4	5
Insects	1	2	3	4	5
Drinking water	1	2	3	4	5
Flood	1	2	3	4	5
Noise pollution	1	2	3	4	5
Dust	1	2	3	4	5
Smoke	1	2	3	4	5
Vibrations	1	2	3	4	5
Garbage	1	2	3	4	5
Bad odor	1	2	3	4	5
Drainage	1	2	3	4	5

Tab.2 Factors included in the questionnaire and their category level

The respondents were asked to rate each factor on five (5)-point scale where one (1) was considered strongly agree for its effect on living comfort and five (5) was considered strongly disagree. The factors included in the questionnaire and the five category levels were presented in Tab.2. In addition to the rating of each factor, respondents were asked to indicate on each factor whether its influence on living comfort was positive or negative or neutral.

3.3 Data analysis

The rating given by each respondent for each factor was entered into the excel sheet directly from the questionnaire and imported to SPSS for analysis. For the analysis of data, chi square test and two sample t-test were used. The Chi square test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies. The expected frequency for each aspect considered was taken from the data collected during the preliminary survey. Using this test, the current situation in the study sites were compared with the expectation of the people. Two sample t-test was used to find out whether there is a significant difference between the two sites. To analyze the participant's response on positive, negative and neutral category, percentages were calculated for each category having the response given for each category and given in Tab.3.

4. Results and discussion

When the overall results are considered, according to the respondents' perception from urban Peliyagoda-Gangabada GN division (Tab.3), most of the factors caused discomfort perception for living conditions. In contrary to this, according to the people's perception from non-urban Gampaha-Keselwathugoda GN division (Tab.3), most of the factors caused comfort perception for living except few aspects. The results from both localities indicate that the same factors have different effects on living comfort perception for urban and non-urban settings. From the survey from both localities, it was observed that Peliyagoda-Gangabada GN division is an urban locality featuring almost all of the urban characteristics whereas Gampaha- Keselwathugoda GN division is a non-urban locality with rural settings. The findings, in overall, agree with previous findings where it was indicated that urban climate is hotter compared to the rural climate within the same region because of the development of thermal profile from asphalt (the dark covers of streets) and roofs, bricks and concrete (Oke, 1992; Arnfield, 2003; Santamouris et al., 2001). Further, heat output by industry, low evapotranspiration, motor vehicles and households, in addition to the low ventilation capacity of regions that have buildings, temperatures of an ambient air inside urban areas can be higher than similar rural areas (Margiotta et al., 2021) which forms an Urban Heat Island (UHI) under the specific conditions.

4.1 Effect of climatic factors on living comfort perception

When temperature is considered, the results of our study indicate that the temperature is not a significant factor associated with living comfort perception in non-urban locality (Tab.4) though it is a significant factor negatively associated with living comfort perception in urban locality (Tab.3 and Tab.4). The temperature effects in urban locality agree with previous findings that temperature is the main factor influencing the living environment (Echevarria Icaza et al., 2016) which may affect the comfort in urban locality due to the formation of UHI. The maximum temperature in addition to the other microclimatic factors have strong relationship with outdoor thermal comfort in urban areas (Yin et al., 2012). In overall, though the majority of the respondents identified temperature as a negative factor for living comfort perception, its association with living comfort in non-urban locality was not significant (Tab.4). Because we observed, during the survey, that the non-urban locality is sparsely populated with lot of greens and shades (Fig.1B) that developed favourable microclimatic conditions which might have neutralized the negative living comfort perception caused by temperature in the same locality. Further, it should be noted that 44% of respondents (Tab.3) identified temperature as a neutral factor for living comfort perception while none identified temperature as positive factor.

Factor	Positive (%)	Neutral (%)	Negative (%)
Temperature	-	44	56
Rainfall	-	65	35
Wind	8	88	4
Humidity	-	94	6
Water bodies	25	47	28
Land facilities	89	11	-
Natural beauty	98	2	-
Shade	97	3	-
Biodiversity	94	6	-
Stray Animals	-	7	93
Insects	-	6	94
Drinking water	54	35	11
Flood	-	6	94
Noise pollution	-	9	91
Dust	-	3	97
Smoke	-	1	99
Vibrations	-	1	99
Garbage	-	-	100
Bad odor	-	1	99
Drainage	100	-	-

Tab.3 Positive, negative and neutral factors influencing living comfort

	Peliyagoda-Gangabada GN Division			Gampaha- Keselwathugoda GN Division		
Factor	χ^2	Probability	Significance	χ^2	Probability	Significance
Temperature	8.01	<0.01	**	2.11	>0.05	ns
Rainfall	2.15	>0.05	ns	2.24	>0.05	ns
Wind	2.33	>0.05	ns	1.55	>0.05	ns
Humidity	0.36	>0.05	ns	2.08	>0.05	ns
Water bodies	25.68	<0.001	***	2.06	>0.05	ns
Space	38.00	<0.001	***	2.28	>0.05	ns
Natural beauty	37.55	<0.001	***	2.26	>0.05	ns
Shade	39.50	<0.001	***	2.40	>0.05	ns
Biodiversity	39.50	<0.001	***	2.51	>0.05	ns
Stray Animals	34.32	<0.001	***	16.55	<0.001	***
Insects	24.41	<0.001	***	2.51	>0.05	ns
Drinking water	1.83	>0.05	ns	2.37	>0.05	ns
Flood	31.75	<0.001	***	2.13	>0.05	ns
Noise pollution	10.84	<0.001	***	2.18	>0.05	ns
Dust	13.02	<0.001	***	28.48	<0.001	***
Smoke	29.52	<0.001	***	2.69	>0.05	ns
Vibrations	32.73	<0.001	***	2.33	>0.05	ns
Garbage	19.58	<0.001	***	9.16	<0.001	***
Bad odor	9.52	<0.001	***	2	>0.05	ns
Drainage	39.03	<0.001	***	0.32	>0.05	ns

degrees of freedom = 4; *** - significant at 0.001 probability level; ** - significant at 0.01 probability level; ns - not significant at 0.05 probability level

Tab.4 Chi square value for the factors of living comfort from Peliyagoda-Gangabada and Gampaha- Keselwathugoda GN Divisions

Therefore, urban greening in addition to providing many ecological benefits, may function as neutralizer of temperature effects in urban localities (Isola et al., 2023). In the present study, we evaluated the overall living comfort perception (not only the thermal comfort) in urban and non-urban localities. There are other factors indicated by the higher percentage of respondents as affecting living comfort perception negatively than the temperature (Tab.3). The factors negatively affecting the living comfort perception are discussed in the following sections.

The results further indicate that factors i.e. rainfall, humidity and wind were not significant aspects associated with living comfort perception in both localities (Tab.4) studied and most of the respondents identified these as neutral factors (Tab.3). However, according to Ghasemi et al. (2015) the wind will have effects on comfort, safety, distribution of heat, dispersion of excessive humidity. Yin et al. (2012) found that the wind speed and relative humidity has strong relationship the thermal comfort in urban areas. The possible reason for obtaining the stated results in the present study could be that both localities in the present study fall under the low country wet zone climatic region in the same district in Sri Lanka where the climatic factors i.e., rainfall, humidly and wind are almost similar having the similar macro effects over the living environment with no significant effect on living comfort perception though these factors will have effects on thermal comfort. The present findings were supported further where 88% and 94% of the respondents indicated that wind and humidity were the neutral factors respectively in relation to living comfort perception (Tab.3). The present study provides the evidence based results on the association of the climatic factors on the living comfort perception of the respondents by comparing the urban and rural settings.

4.2 Effect of water bodies on living comfort perception

The factor 'water bodies' effect was significantly associated with living comfort perception in the urban locality (Tab.3). The results of this study indicates that the water bodies in the urban settings can influence the living comfort and can contribute to improve the living comfort in the urban locality. Our findings agree with Manteghi et al. (2015) where they concluded water bodies have a positive effect upon microclimate of the surroundings with passive cooling effects for urban spaces and buildings. The availability of water resources makes it possible to create a comfortable living environment in the city and water bodies can create an atmosphere of unity and continuity in the urban fabric and make the city more attractive comfortable for living (Kurochkina, 2020). In contrary, respondents' living comfort perception in the non-urban locality was unaffected by the water body factor. This may be due to the favorable microclimatic effects already exists in the studied non-urban locality therefore the presence or absence of water body is not a significant factor for the living comfort in non-urban locality. The higher percentage of residents (47%) from both localities identified water body as a neutral factor (Tab.3), which is contradictory with regard to the findings (Tab.4) where water bodies significantly associated with living comfort in the urban locality. We, through our site visit, observed that water body in the urban locality was in a bad condition caused by water pollution, which could have been the reason for respondents to identify it as a neutral factor mainly in the urban locality. The environmental safety of water bodies is important for their ecological safety and their contribution to comfortable urban environment (Kurochkina, 2020). The findings in the present study may indicate that clean water body (unpolluted water body) in the urban locality may create a positive microclimatic environment for living comfort in the urban locality. The polluted water body may produce bad odor thus creating unfavorable conditions and negatively affecting the residents' perceptions and these type of water bodies may not provide the expected ecological services and emotional values. The areas close to water body in Gangabada GN division is affected by seasonal riverine flood may be another reason for the residents to perceive the water as neutral factor and also for more percentage of residents (28%) consider water body as a negative factor compared the residents who consider as positive factor (25%). The factor 'water bodies' effect was significantly associated with living comfort perception in the urban locality (Tab.3). 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4.3 Effect of space on living comfort perception

Our study indicated that 'space' factor in the urban locality (Gangabada) is an important factor for the living comfort compared to the non-urban locality (Keselwathugod) (Tab.4). The space is required for the people to spend their leisure time, rest, and it is also important for the health and wellbeing of the people in urban settings. Most of the respondents (89%) identified space as a positive factor for living comfort, which indicates that it is comfortable to live in a locality where large open spaces are found. However, few respondents identified space as a neutral factor (Tab.3) which may indicate that few people are satisfied with limited space because it is difficult to maintain large space under urban conditions. In non-urban condition, living comfort perception was not associated with the space factor, the reason may be that the non-urban locality itself is spacious and not congested hence space factor is not a determinant of living comfort. Our findings are in agreeable with Chen and Ng (2012), where they stated that outdoor spaces are important and they contribute greatly to urban livability and vitality. The findings may indicate the need to have sufficient space in urban planning to improve the living comfort of an urban locality. The findings may indicate that the space is a more important factor than water bodies to the living comfort perception for unban locality.

4.4 Effect of natural beauty on living comfort perception

The factor natural beauty is significantly associated with living comfort perception in urban locality (Tab.4). The results showed that natural beauty is an important factor for living comfort perception in urban locality compared to non-urban locality. However, identifying the natural beauty as positive factor by most of the respondents from both localities (Tab.1) may indicate that it is an influencing factor for the living comfort, thus the importance of having nature contact in the urban areas to improve the living comfort. Our finding is comparable with Cervinka et al. (2011) where they stated that psychological well-being, meaningfulness and vitality were found to be robustly correlated with contact with nature. According to Kabisch et al. (2022), a misconception that cities as being artificial landscapes disconnected from nature exists. However, they argue that nature-based solution for urban localities can be integrated into urban areas through urban planning to improve the contact with nature in the cities. The green network (connections) or infrastructures (patterns) may be able to enhance quality of life with regard to the accessibility and human and environmental health (Tulisi, 2017). The natural beauty seems to equally important as space factor for living comfort perception mainly in the urban locality.

4.5 Effect of shade on living comfort perception

The shade is a significant factor in affecting the living comfort in urban locality whereas it is not in non-urban locality (Tab.4) indicating the importance of shade for positive living comfort perception in urban locality. The non-urban locality what we studied is found with natural green shade hence the living comfort perception of respondents was unaffected by shade. However, most of the people (97%) in both localities (Tab.2) identified shade as an important positive factor for living comfort. This indicates that though shade did not have significant effect on living comfort in non-urban locality, it is important for positive perception of living comfort. The findings indicate that increase in the shade level in urban locality can improve the living comfort. Our study is in accordance with Klemm et al. (2015) in which they concluded that street greenery forms a convenient adaptive strategy to create thermally comfortable and attractive living environments. The findings indicate that the shade factor is equally important as space and natural beauty.

4.6 Effect of insect factor on living comfort

The living comfort perception is negatively affected by insect factor in urban locality (Tab.4). Since the residents in the non-urban locality are normally exposed to insects, their perception is unaffected (Tab.4) by the insect factor which indicates that it is not an important factor for living comfort perception in such locality. However, the majority of the respondents (94%) identifying the insects as negative factor (Tab.3) for living comfort in both localities may indicate that the presence of insects is not favorable for living comfort perception. A study by Lemelin et al. (2016) found a mixed perception for the presence of insects, i.e., negative and positive depending on the species. The present study did not specify the insect's species rather considered the whole insect population. Hence, further investigations are needed to identify the effects of different insect species on the perception of respondents. The findings may indicate that the insect factor is one of the main contributors negatively affecting the living comfort perception in the urban localities. Here it is important to note that the green shade and green space which are highly associated positively with living comfort perceptions may attract the insects (a negative factor) into the urban areas. Therefore, the interaction effects need to be also addressed. Any future studies may take into account the interaction effects of main factors affecting living comfort perceptions.

4.7 Effect of stray animals on living comfort perception

The "stray animals" is a significant factor associated with the living comfort perception in both localities (Tab.4). Further, most of the respondents (93%) identified the stray animals as a negative factor (Tab.3) for living comfort in both localities indicating that presence of stray animals is not a favorable factor for living comfort perception. This finding is supported by Karanikola et al. (2012), where in a study at a city park in Greece they found that a large percentage of the participants (67.8%) declare that they are bothered by the existence of stray animals in the public areas of the city. Further, they observed that the citizens who are bothered by the existence of stray animals regard the behaviour of these animals as hostile. The findings in the present study showed that the stray animal factor is as important as insect factor in contributing for negative living comfort perception in urban localities.

4.8 Effect of noise and dust on living comfort perception

Though the noise factor associated with living comfort perception in urban locality (Tab.4) it was not associated with living comfort in non-urban locality. The reason may be that in general, the non-urban environment is less noisy further; the noise level may be acceptable for living comfort in non-urban locality. Having the results where most of the respondents identifying noise as a negative factor (Tab.3), it is concluded that the noise is not favorable for living comfort. Our finding is supported by Sheikh and Mitchell (2018) where they indicated that the quality of a "place" is highly influenced by our perception of sound in the surrounding environment. It therefore is important to maintain a noise level in the built environment that are perceived positively.

Our results (Tab.4) indicated that dusty air is a significant factor associated with living comfort perception in both localities. Further, most of the residents identified dust as a negative factor for living comfort (Tab.3). The findings of the study are in agreement with Nikolopoulou et al. (2009) where they suggested that as the concentration of particulate matter increases in the air (that means dusty level increase in the air) people perceive that the air is in poor quality, consequently the dusty air may be perceived by the residents as uncomfortable for living comfort. The respondents perceived both noise and dust are negative factors and contribute as equally as stray animals for living comfort perception.

4.9 Effect of garbage and bad odor on living comfort perception

According to our results, garbage is a significant factor negatively associated with living comfort perception in both urban and non-urban localities (Tab.3 and Tab.4).

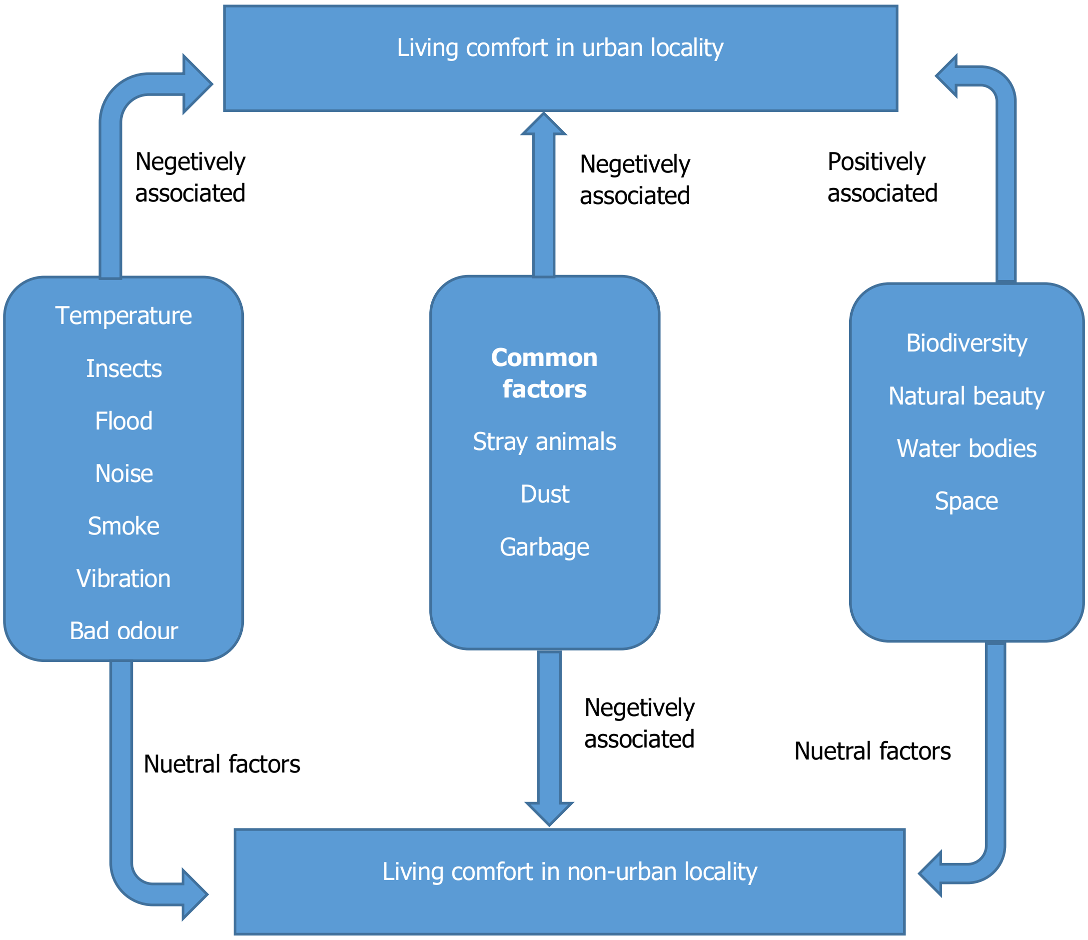

Fig.2 Factors affecting living comfort perception in urban and non-urban localities

The respondents perceived garbage as a common problem in their living environment and not favorable for improving their living comfort. Though the respondents perceived bad odour as not a problem affecting their living comfort perception in non-urban locality, it negatively affected living comfort perception in urban locality. In our opinion, the conditions for development of bad odour level is minimal in the non-urban locality and though bad odour is developed, diffusion takes place within a short period. This may be the reason for living comfort perception unaffected by bad odour in non-urban locality.

Fig.2 summarizes how factors identified associated with living comfort perception in urban and non-urban localities. The findings in the present study have wider implications for urban planning which need to integrates environmental comfort aspects affecting the living comfort perception of the residents.

Environmental comfort is of great significance on urban spatial planning and promotion of new urbanization and rural revitalization and also it can provide reference for planning and design in small and medium-sized cities (Liu et al., 2023).

5. Conclusion

The present study investigated factors which influence the living comfort perception in urban and non-urban localities in Sri Lanka. The study identified three group of factors i.e., positive factors, negative factors and neutral factors in relation to living comfort perception. Factors i.e., stray animals, dust and garbage were identified as common factors with negative association with living comfort in both urban and non-urban localities. These findings indicate the need for facilities in both urban and non-urban localities for waste collection and disposal which should be integrated at the urban and non-urban planning stage to improve living comfort, further, the need for management of stray animals and minimization of dust are significant for the comfort in the living environment.

It was found that the factors i.e., temperature, insects, flood, noise, smoke, vibration, and bad odor are important for urban localities since they have negative influence on living comfort and these findings provide importance insights for urban design and planning, on the other hand, these factors may not be important for living comfort in non-urban localities. However, the transformation of non-urban localities into urban localities is a continuous process happening through urbanization, the influences of these aforesaid factors need to be further investigated. The present study also found that the factors such as rainfall, wind, humidity and drinking water are not important for living comfort perception in both localities.

The factors such as water bodies, space, natural beauty, and biodiversity affects the living comfort perception positively in the urban localities but no positive or negative effects in non-urban localities. These findings indicate the need to integrate water bodies, space, natural beauty, and biodiversity into urban planning. In summary, the present study provides valuable insights about the factors that should be integrated and also the factors that should be eliminated or should be maintain at minimal level for the living comfort perception in an urban locality. Further, these factors will be useful in zoning the localities according to their suitability in relation to public perception. Despite the valuable insights, the study has some limitations. It was conducted in the Gampaha district in Sri Lanka.

The Gampaha district falls under low country wet zone according to the agro-ecological zones of Sri Lanka. The various agro-ecological zones may have varying level of influence on the living comfort perceptions due to the macro level climatic effects at urban and rural localities within the same zones. Therefore, it is necessary to test the conceptual model developed and presented in Fig.2 for various climatic zones and for different localities. Further, the presented study identified and investigated the effects of environmental factors on living comfort perception thus the study had the limited scope. Because, different factors identified may have varying level of effects on living comfort perceptions. Therefore, the comparative weightage of different factors and how it will influence the living comfort perceptions need to further investigated.

Finally, the identified factors can be manipulated to improve the living comfort perception in urban and non-urban localities except for the climatic factors.

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Author's profile

Mohamed Thariq Mohamed Gazzaly

He is senior academic presently working as a Senior Lecturer at the Department of Biosystems Technology, Faculty of Technology, South Eastern University of Sri Lanka, Sri Lanka. Dr. Thariq teaches courses mainly on animal production and human factors engineering for undergraduate students and research interest includes animal nutrition, goat production, climate resilient animal farming and agriculture ergonomics. He completed basic degree in Agriculture at the University of Peradeniya, Sri Lanka, Master Degree in Forestry and Environmental Management at the University of Sri Jayawardenapura, Sri Lanka and PhD in Ergonomics at the University of Moratuwa, Sri Lanka.

Mohamed Mujithaba Mohamed Najim

He completed his PhD in water resources engineering from University Putra Malaysia in 2004 and Master of Engineering in Irrigation Engineering and Management in 2000. His main areas of Research are Water Resources Management and Environmental Management. He has published more than 50 research papers.

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Technological applications in sustainable urban logistics: a systematic review with bibliometric analysis

Suzan Oguz [a]*, Mehmet Tanyas [b]

[a] Department of Foreign Trade, Cag University
Mersin, Turkiye
e-mail: suzanoguz@cag.edu.tr
ORCID: https://orcid.org/0000-0003-4876-3173
*Corresponding author

[b] Department of International Trade and Logistics
Maltepe University, İstanbul, Turkiye
e-mail: mehmettanyas@maltepe.edu.tr
ORCID: https://orcid.org/0000-0001-8934-3787

Abstract
Today, supply chains and logistics operations in urban areas face increasing customer demands for productivity, quality, sustainability and traceability. Traditional methods cannot adequately respond to the rapidly changing challenges and requirements of this sector. Therefore, new methods have been developed to make urban logistics activities more modern, environmentally sensitive and integrated with technology. This research aims to identify sustainable urban logistics and the role of technological applications on urban logistics. In this research, which is designed as a systematic study, firstly, based on the existing literature, the basic concepts, trends, researchers and countries working in the field of sustainable urban logistics are examined by bibliometric analysis method. It is observed that the most frequently used technology applications in sustainable urban logistics are last mile delivery, vehicle routing, optimisation, electric vehicles and crowdsourcing applications. This study is expected to contribute to the development and sustainability of urban logistics.

Keywords
Supply chain; Urban logistics; Sustainability; Technology.

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1. Introduction

In recent years, as a large proportion of the world's population has been living in cities, all activities related to logistics and supply chain management in cities are of critical importance. For this reason, governments around the world are working to design sustainable and efficient ways of delivering freight in urban areas (Juan et al., 2016). Cities are the sites of significant economic activity with an ever-increasing impact on regional dynamics (Boudoin et al., 2014). In addition to urbanization and demographic growth, concerns about urban logistics activities and greenhouse gas impacts in cities have increased due to the widespread use of e-commerce, new management principles and technologies such as just-in-time delivery, especially after the pandemic (Fried et al., 2024; Patella et al., 2021). The COVID-19 pandemic has profoundly affected urban logistics processes and urban mobility strategies. There is a common consensus that logistics operations need to become more flexible, environmentally sustainable and resilient in the post-pandemic era (Ravagnan et al., 2022). On the other hand, increasing urbanization, population growth, and changes in demand patterns for products that favor just-in-time solutions, coupled with reduced stocks in stores, have intensified freight movements in cities (Melo & Baptista, 2017). Due to increased freight movements in urban areas, modern cities face problems such as traffic congestion, air pollution and noise that reduce the quality of life (Patella et al., 2021). Efficient logistics services play a crucial role in the management of supply chains, exerting a substantial influence on the reduction of transportation expenses and the enhancement of customer satisfaction. According to Leng et al. (2024), it additionally has a role in mitigating greenhouse gas emissions and associated externalities, like air pollution, noise, and traffic congestion. Due to the presence of numerous diverse economic sectors, a city is supported by numerous supply chains. Furthermore, due to the inherent diversity among cities worldwide, the implementation of urban logistics is subject to substantial variations based on local attributes (Behrends, 2016). Furthermore, the rapidity of social, cultural, and economic processes has resulted in substantial transformations in urban areas. The development of cities is influenced by various factors, such as the significance of transportation planning, the interconnection between urban and regional planning and economic planning, the utilization of information tools, the emphasis on environmental sustainability, the growing emphasis on social planning, and the evolving management techniques employed by local governments (Russi et al., 2016). Urban logistics activities are critical not only for firms and consumers, but also for the spatial organization of cities and urban planning strategies. This is because improved logistics networks help to reduce urban traffic and achieve sustainable urban development goals. Therefore, for sustainable urban logistics, it is crucial for cities to plan and manage their logistics operations in line with their urban growth strategies. Sahu et al. (2022) emphasize that the efficiency of logistics operations and planning activities is critical for urban infrastructure and traffic balance. In their study, Baker et al. (2023) emphasize that the use of digital and innovative technologies is becoming increasingly important in achieving sustainable urban logistics. These technologies play a critical role in achieving goals such as increasing energy efficiency and reducing carbon emissions. Spadaro et al. (2022) state in their study that sustainability principles have become one of the main pillars of modern urban logistics processes. They emphasized how green logistics solutions enable the development of environmentally friendly logistics operations through energy efficiency and the development of environmentally friendly mobility strategies. Urban areas worldwide are making significant endeavors to effectively handle urban logistics with the aim of enhancing their logistical efficiency and mitigating adverse environmental and socio-economic consequences (Behrends, 2016). Urban logistics encompasses the entirety of transportation and delivery activities within highly populated urban regions. Urban logistics refers to the strategic management of logistics operations in urban areas, utilizing advanced information systems to enhance efficiency (Cardenas et al., 2017; Merdesic et al., 2023), This involves considering various factors such as the traffic environment, traffic congestion, safety, and energy conservation, all within the context of a market-based economy (Perboli et al., 2018). Urban logistics can be defined as the process of transporting goods using wheeled vehicles, as well as the associated activities involved in this transportation, within an urban setting (Fernandez-Barcelo & Campos-Cacheda, 2012). Urban areas serve as hubs for the production, distribution, and consumption of tangible goods. Urban logistics encompasses a comprehensive range of actions aimed at ensuring the provision of necessary materials for these activities. It encompasses all the transportation of goods that arises from the economic requirements of local businesses, such as the transportation and retrieval of all materials, components, consumables, mail, and garbage necessary for the enterprises to sustain their operations (Dablanc, 2011). The field of urban logistics has emerged as a significant element within the realm of urban planning. Efficient management of urban logistics is crucial for achieving long-term economic development. Currently, it is imperative to take into account several concerns, including traffic congestion, environmental impact, and energy conservation (Crainic et al., 2004; Taniguchi & Van Der Heijden, 2000). Enhancing comprehension of urban freight activity can facilitate planners in effectively accommodating freight vehicles by means of improved facility and infrastructure design and utilization. Additionally, it enables the exploration of the possible viability and advantages associated with different freight initiatives (Cherrett et al., 2012). Urban logistics remains an area in need of further analysis to understand the consequences of innovative developments and changing practices (Patier & Browne, 2010). Especially in recent years, the continuous increase in the population living in urban areas, pollution and safety concerns in cities, traffic and congestion problems, and new technological developments have attracted the attention of urban logistics researchers and policy makers (Lagorio et al., 2016). This study aims to examine the developments and technological applications in the field of sustainable urban logistics and to determine the importance of these developments in cities. Accordingly, the study is structured as a systematic study that aims to review the existing literature to uncover key ideas, trends and research directions in sustainable urban logistics. Firstly, a search was made in the Web of Science database using the concepts in this subject and the studies were visualized and interpreted through bibliometric analysis on the basis of type, year, author and countries. Following the literature review, information on the practices used in sustainable urban logistics activities is provided. It is expected that this study will contribute to the development and sustainability of urban logistics and guide the researchers who will work on the related subject.

2. Sustainable urban logistics

In recent years, the notions of "sustainability" and "sustainable development" have gained significant prominence in the realm of policy evaluations. According to the World Commission on Environment and Development (1987), sustainable development is commonly defined as the process of achieving development that satisfies the requirements of the current generation while safeguarding the capacity of future generations to satisfy their own needs. Currently, the impetus behind the pursuit of sustainable urban mobility arises from the imperative to establish cities that are ecologically sound, socially equitable, economically feasible, and conducive to the well-being of present and future generations (Yucesan et al., 2024). Currently, numerous cities across the globe are actively implementing sustainable transportation plans as integral components of their sustainability endeavors. According to Goldman and Gorham (2006), sustainability is intricately connected to several strategic policy objectives and exerts substantial effects on urban areas. The field of supply chains, logistics, and costs encounters progressively intricate obstacles as a result of shifts in economic frameworks, urbanization, urban planning, transportation systems, and the externalities linked to logistical operations in metropolitan regions. According to Cardenas et al. (2017), the ability to address these difficulties is heavily contingent upon the presence and advancement of transportation systems, infrastructure, efficient fleets, improved modes of transportation, and the sustainability policies implemented by enterprises. To enhance the sustainability of freight transportation, it is imperative to comprehend the characteristics of freight flows, as it is a derived demand. The driving forces influencing these flows encompass various aspects, including the geographical location of activities, transportation expenses, land prices, consumer preferences and service requirements, as well as prevailing rules governing freight transportation and land utilization. Hence, to alter freight transportation patterns and alleviate their consequences, it is crucial to take into account these determinants of freight flows, rather than solely concentrating on the movements of freight vehicles (Anderson et al., 2005).Urban logistics has a crucial function in satisfying human requirements, but it also results in detrimental effects on the environment, economy, and society (Russo & Comi, 2020). The expansion of urban logistics services has been driven by shifts in the supply chain, including just-in-time delivery, e-commerce, and door-to-door delivery. Consequently, there has been a rise in the number of deliveries and the presence of light commercial freight vehicles in residential areas. This trend has had notable implications for urban sustainability and livability (Baur et al., 2014). Urban areas globally have implemented objectives and tactics to promote energy sustainability and decrease greenhouse gas emissions. Logistics operations are crucial in attaining these objectives and strategies. The successful shift towards a more energy-efficient urban transport sector necessitates a comprehensive examination of many facets of transportation, encompassing both human transportation and urban logistics (Rosales & Haarstad, 2023).

2.1 Bibliometric analysis application

Bibliometric analysis is an analytical method often used in systematic literature reviews and involves the quantitative analysis of scientific studies (Lim et al., 2024). Bibliometric analysis is used to examine and evaluate large amounts of scientific data. While this method helps to understand the development of a particular subject, it also presents new trends in that field (Donthu, 2021). In this study, it is aimed to examine the studies on technology-based applications in sustainable urban logistics in 2010-2023 in the Web of Science (WoS) database within the scope of bibliometric analysis and to create visual maps. In this context, on March 10, 2024, Web of Science was searched through the categories and criteria specified in Tab.1 Vosviewer package program was used for the visual maps created within the scope of the study.

Category	Search Criteria
Keywords	Urban logistics, city logistics, sustainability, technology
Search string	Topic (containing keywords)
Types of documents	Article, Proceeding Paper, Book and book chapter, Editorial Material
Time range	2010-2023
Language	English

Tab.1 Search criteria in Web of Science database

As a result of the search using the categories and search criteria shown in Tab.1, 843 studies were found. The distribution of the studies by years is as shown in Fig.1. When Fig.1 is examined, it is seen that the related studies have generally tended to increase over the years, but the highest number of publications was made in 2022 with 149 publications.

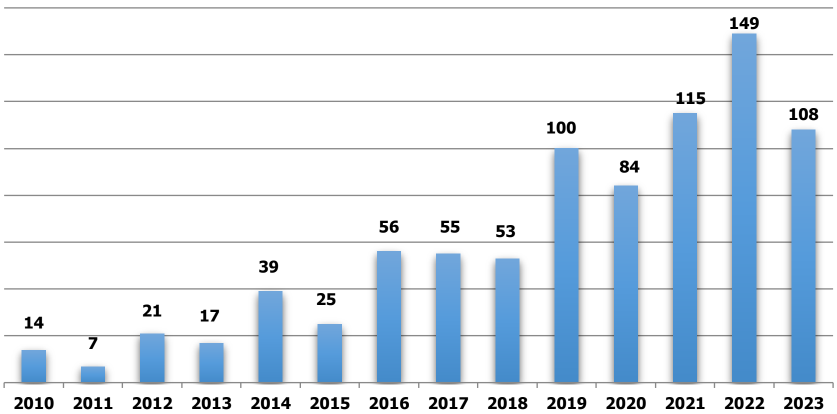

Fig.1 Number of publications by year

The 2020s have been a period of accelerating digitalization and technology-based applications. In particular, the COVID-19 pandemic has caused major disruptions in global logistics and supply chains, increasing the need for more sustainable, flexible and technology-based solutions. Moreover, the European Union's Green Deal strategies have exerted significant pressure on countries to adopt sustainable urban logistics and regulations with the objective of reducing carbon emissions. These policy orientations have accelerated the search for sustainable solutions in the logistics sector during the 2020s, leading to an increased focus on this area in scientific studies. The distribution of studies on technology-based applications in sustainable urban logistics according to publication types and web of science indexes is shown in Tab.2.

Type	**Numbers of publications**
Article	544
Proceeding Paper	265
Book and Book Chapter	22
Other	12
Web of Science Indexes	
Science Citation Index Expanded (SCI-E)	352
Social Sciences Citation Index (SSCI)	313
Conference Proceedings Citation Index - Science (CPCI -S)	223
Emerging Sources Citation Index (ESCI)	106
Book Citation Index	32

Tab.2 Distribution of publications according to types and indexes

When Tab.2 is examined, it is seen that the highest number of publications related to the subject in terms of publication type is article with 544 publications. In terms of index, it is seen that the related publications are mostly published in SCI-E indexed journals with 352 publications. The most commonly used keywords in studies on technology-based applications in sustainable urban logistics are shown in Fig.2.

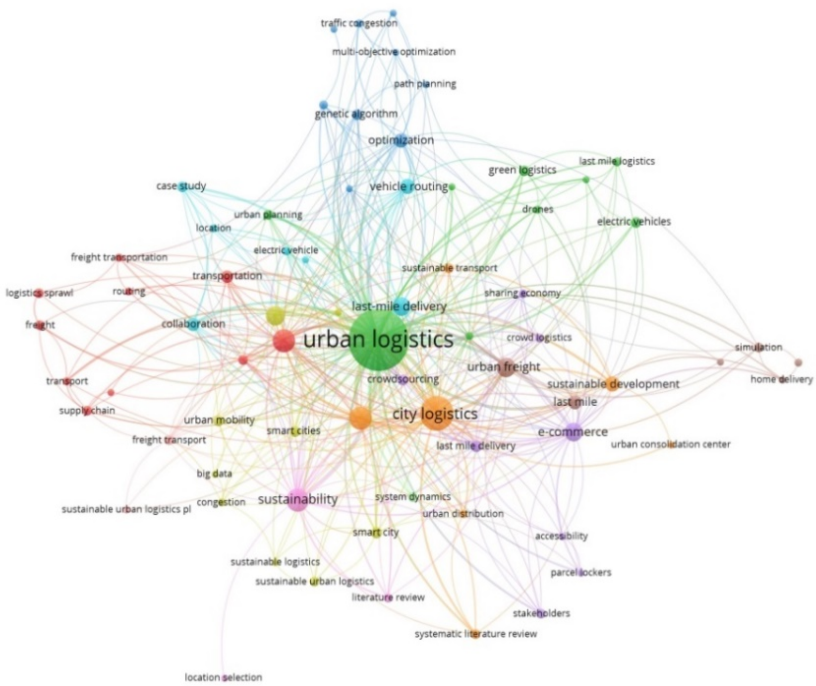

Fig.2 Most used keywords (elaboration from VosViewer)

When the distribution of keywords in the studies included in the scope of the analysis in Fig.2 is examined, it is observed that there are 72 keywords used at least five times. The most frequently used keywords were "urban logistics" and "city logistics", which were used 322 and 103 times, respectively. The concept of "sustainability" used 47 times, ranks third in terms of frequency of use. The keywords used for technological applications in urban logistics and the number of times they are used are shown in Tab.3.

Keywords	Number of uses
Last mile delivery	30
Vehicle routing	33
Optimization	17
Electric vehicles	13
Crowdsourcing	12

Tab.3 Keywords used for technological applications in urban logistics

When Tab.3 is examined, it is seen that the keywords last mile delivery, vehicle routing, optimization, electric vehicles and crowdsourcing are prominent in studies on sustainable urban logistics. These key concepts play a strategic role in reducing the environmental impact of logistics operations, lowering carbon emissions, improving delivery times and optimizing energy consumption. On the other hand, it reveals how technological innovations in the logistics sector contribute to the achievement of sustainability goals of cities and provides an important guide in shaping future logistics processes. Information on these concepts and their use in sustainable urban logistics is provided in the following paragraph. The countries with the highest number of publications on the subject are shown in Fig.3.

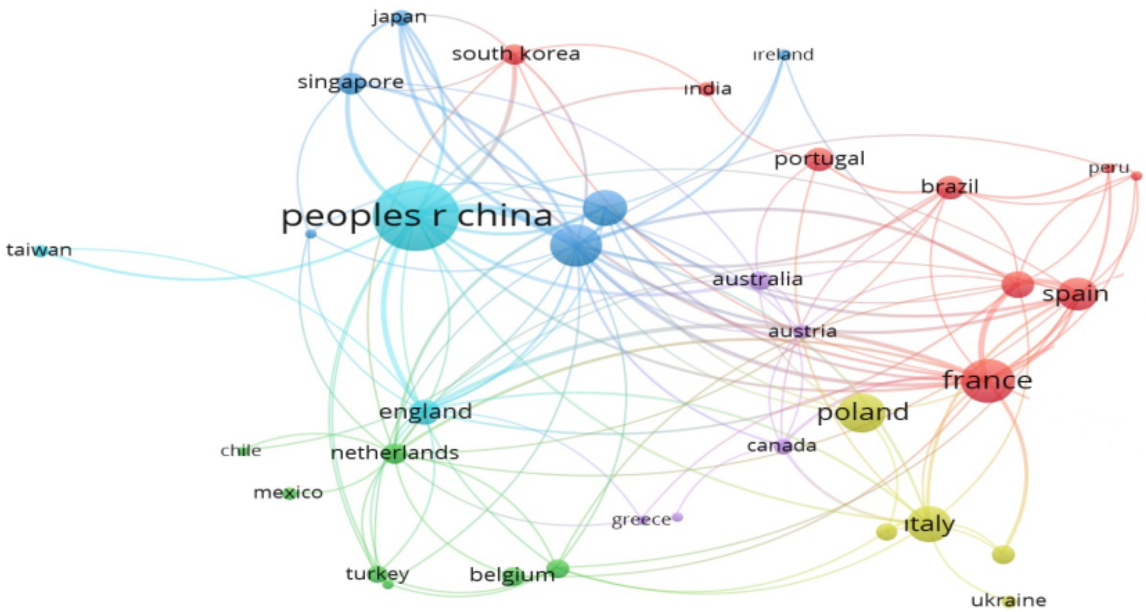

Fig.3 Countries with the most publications (elabotation from VosViewer)

Fig.3 shows the countries with the highest number of publications on technology-based applications in sustainable urban logistics. A total of 38 countries were included in the publications analyzed within the scope of the analysis, with the condition of at least five publications. Among these countries, it is seen that China (227 publications) has the highest number of publications using the related concepts. China is followed by France (87 publications), USA (80 publications), Poland (70 publications) and Germany (59 publications). The fact that China has the highest number of publications using related concepts can be attributed to China's rapidly growing logistics sector and its large investment in technology-driven solutions in this field. China has become an important hub of global supply chains and is pioneering technological innovations to improve the efficiency of logistics processes and minimize environmental impacts.

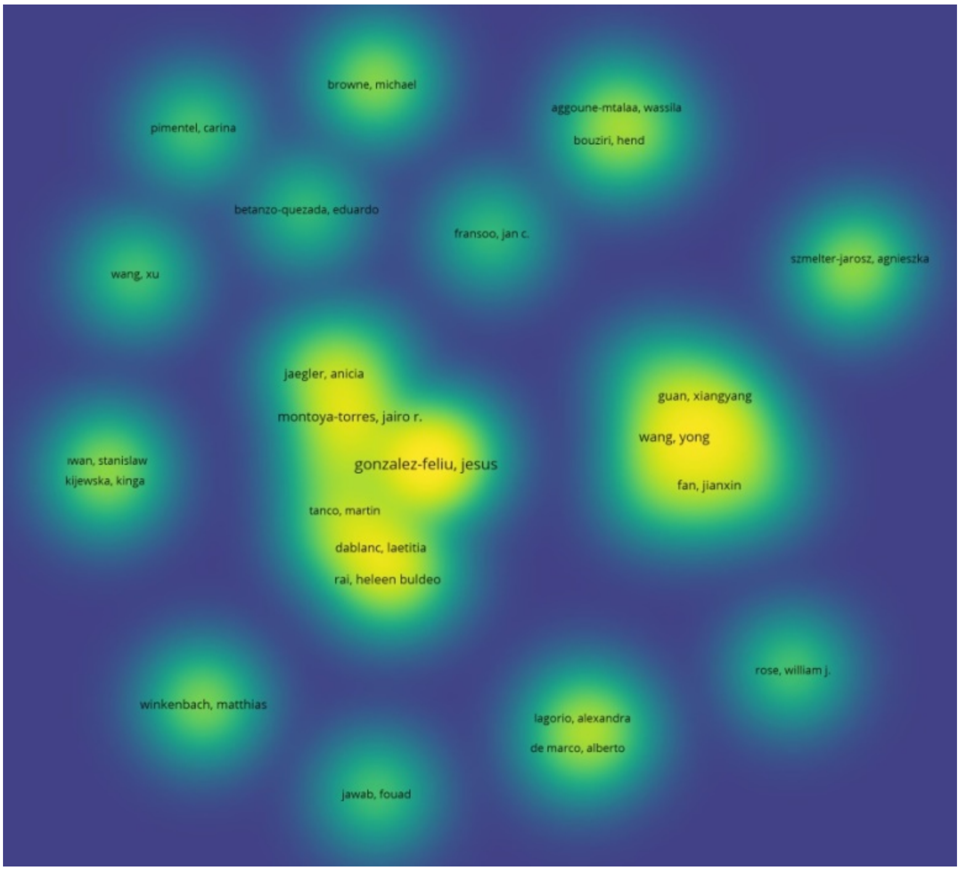

Fig.4 Researchers with the most publications and co-authorship (elaboration from VosViewer)

Fig.4 illustrates the distribution of publications and co-authorships among scholars who have made significant contributions to the field of technology-based applications in sustainable urban logistics. This figure shows the frequency with which the authors work together and the intensity of their collaborations. In the context of the analysis, it was observed that a total of 37 researchers had a minimum of five publications. The color of the field containing the names of the researchers varies based on the number of co-authorships, as depicted in Fig.4. Names with a vibrant blue hue are indicative of a limited quantity of co-authorships. Authors exhibiting a prevailing yellow hue tend to have a higher frequency of co-authorships. Jesus Gonzalez Feliu has the greatest number of co-authorships in this topic, with a total of 24 publications. According to the rankings, Yong Wang holds the second position with 14 publications, while Jairo R. Montoya-Torres ranks third with 13 publications. The researchers with the highest number of citations are presented in Tab.4.

Author Name	Number of citation
Jesus Gonzalez Feliu	302
Winkenbatc Matthias	277
Laetitia Dablanc	264
Alexandra Lagorio	226
Roberto Pinto	225
Jairo R. Montoya-Torres	210
Yong Wang	206
William J. Rose	193
Andrés Muñoz-Villamizar	184
Haizhong Wang	175

Tab.4 Most cited researchers

When Tab.4 is examined, it is seen that Jesus Gonzalez Feliu (302 citations) is the most cited author in the studies on the research topic. Winkenbatc Matthias (277 citations) ranks second and Laetitia Dablanc (264 citations) ranks third. The number of citations received by the countries where publications on the subject are made is shown in Fig.5.

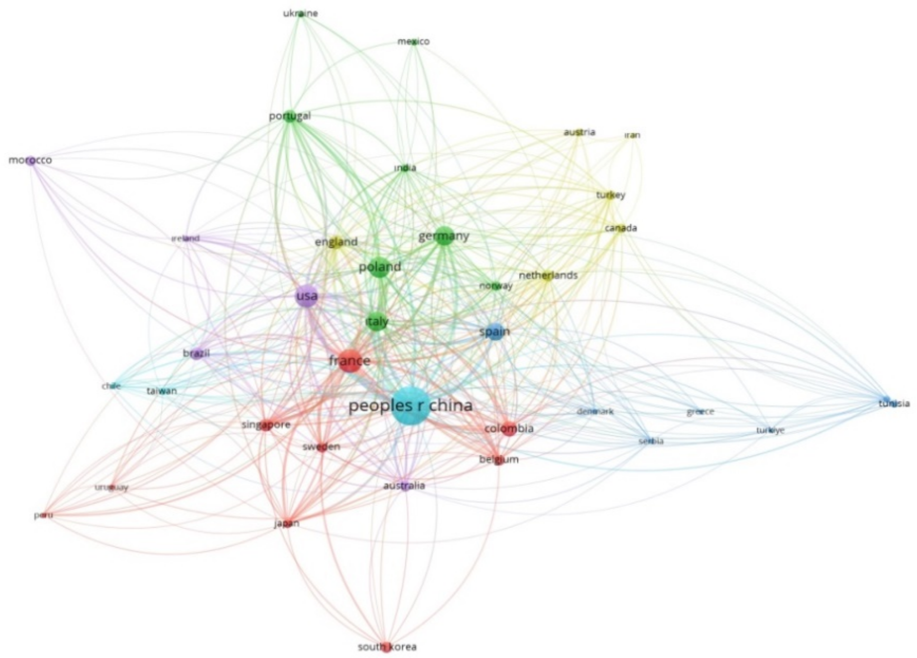

Fig.5 Most cited countries

Fig.5 shows the 39 countries with at least five publications and citations among the most cited countries. In this context, the most cited country is China (2,036 citations - 227 publications). China is followed by the USA (1,584 citations - 80 publications), France (1,410 citations - 87 publications), Italy (1,333 citations - 58 publications) and the UK (983 citations - 30 publications). There are also clusters and connections between countries.

Journal Name	Number of Publications
Sustaniability	71
Transportation Research Part E: Logistics and Transportation	20
Research in Transportation Business & Management	16
Transportation Research Part A: Policy and Practice	14
Journal of Transport Geography	14
Energies	13
Computers & Industrial Engineering	12
Applied Sciences	12
Transport Policy	11
Sustainable Cities and Society	10

Tab.5 Most published journals

Tab.5 shows the 10 journals with the highest number of publications. Sustainability journal was the most published journal with 71 publications (1,093 citations). In second place is Transportation Research Part E: Logistics and Transportation with 20 publications (495 citations). Research in Transportation Business & Management ranks third with 16 publications (213 citations). Sustainability journal stands out as the journal with the highest number of publications in the related field. As its name suggests, the journal focuses on sustainability in logistics processes by publishing in a multidisciplinary field such as not only urban logistics but also sustainable development, environmental management and technology-based solutions.

2.2 Technological applications in sustainable urban logistics

The presence of commercial and industrial transport in urban areas significantly affects the quality of life in cities, primarily owing to external issues such as pollution and congestion (Abouelrous et al., 2023). The European Commission has implemented a range of measures and strategies aimed at mitigating the adverse effects of urban logistics on both congestion and the natural environment. One illustrative instance involves the growing adoption of cargo bicycles in urban logistics, which can be attributed to their enhanced energy efficiency, decreased emissions, and diminished traffic disruption (Melo & Baptista, 2017). The field of urban logistics has received significant attention in recent years. However, it is important to note that this area of study is continuously developing due to shifts in individuals' behaviors, including the rise of e-commerce and increased awareness of environmental concerns. Additionally, advancements in technology have facilitated the emergence of novel delivery methods, such as electric vehicles with enhanced autonomy, unmanned aerial vehicles (drones), and non-motorized or driverless vehicles. Nevertheless, despite its significance and increasing attention, the existing body of research pertaining to urban logistics is fragmented, impeding a comprehensive comprehension of the subject matter and posing challenges in identifying areas that require attention (Lagorio et al., 2016). This section explains the technology-based concepts used in sustainable urban logistics studies, which are shown in Tab.3. Today, technological innovations play an important role in making urban logistics processes more sustainable and efficient. In particular, digital platforms, data-based decision support systems and automation solutions enable more efficient use of resources and optimization of logistics operations (Marzani & Tondelli, 2024). Urban development is linked to social, economic and technological developments. New technologies create impactful changes in urban and regional systems. The city adapts to new opportunities related to ICT, energy and mobility (Russo et al., 2016). The importance of urban logistics is increasing as a result of increasing urban population density and the spread of e-commerce. Enhancing urban logistics efficiency and mitigating environmental effect necessitate the use of several solutions such as last-mile delivery, electric vehicles, vehicle routing, optimization, and crowdsourcing. When employed with caution, these solutions have the potential to mitigate urban traffic congestion, enhance air quality, and yield cost savings in logistics-related expenses. These strategies exemplify state-of-the-art logistics techniques that are bolstered by advancements in technology and infrastructure.

Last Mile Delivery

The final stage of delivery, known as last-mile delivery, is widely acknowledged as a costly phase in the supply chain, accounting for a substantial proportion of the total cost, which can range from 13% to 75%. Wei et al. (2024) state that this stage includes all the essential activities in the delivery process, from the last transit point to the final drop-off destination in the delivery chain. The current literature on last-mile delivery primarily examines the efficient use of resources, operational procedures, energy usage, distance coverage, and time management (Cardenas et al., 2017; Gevaers et al., 2011; Giuffrida et al., 2022; Golinska & Hajdul, 2012; Halldórsson & Wehner, 2020; Park et al., 2016; Ranieri et al., 2018; Staricco & Brovarone, 2016; Wiese et al., 2012). The concept of last-mile delivery pertains to the deliberate and systematic organization and implementation of delivery services, typically involving the conveyance of merchandise from specified locations, such as warehouses, to prearranged destinations as specified by customers. The term "last mile" denotes the moment when a courier package departs from the transportation system, namely the ultimate phase in the delivery procedure (Wei et al., 2024). The concluding phase of business-to-consumer parcel delivery involves the transportation of packages to consumers' residences, cluster/collection sites, or warehouses, until the recipient either retrieves the parcel or redirects it to an alternative address. The emergence of retail and e-commerce trends has resulted in a heightened need for urban freight and last-mile delivery. The issue at hand is of significant importance to urban planners, parcel carriers, and people alike, as they endeavor to address the challenges posed by the escalating volume of freight within urban environments (Lyons & McDonald, 2023). Sustainable urban logistics encompasses last-mile delivery solutions that focus on efficiently managing transportation to the final recipient, with the aim of reducing environmental harm and generating social advantages.

In order to decrease external expenses and enhance customer service, logistics organizations must explore autonomous delivery alternatives (Engesser, 2023). Autonomous vehicles are one of the most prominent examples of technological innovation in urban logistics processes. These vehicles increase the efficiency of logistics operations while also ensuring environmental sustainability. Studies on the integration of autonomous vehicles into urban delivery processes reveal the positive effects of this technology on logistics operations (Belkouri et al., 2022). E-commerce companies are making efforts to provide increasingly prompt and efficient delivery services to their clients in order to boost their sales and market dominance. In this context, the organization endeavors to prioritize business efficiency through the adoption of strategies that facilitate the establishment of streamlined supply chains, resulting in cost reduction and enhanced delivery speed and efficiency. Hence, there is a need for activities that are both time- and cost-effective, while also being ecologically friendly, in order to effectively utilize resources (Prajapati et al., 2023). Especially in densely populated areas, accurately identifying delivery points contributes to reducing urban congestion and helping urban logistics operations achieve environmental sustainability goals. Currently, there is a growing trend in late mile delivery solutions that promotes the use of electric cars and the implementation of smart route planning techniques. These initiatives aim to identify the most efficient delivery routes, ultimately contributing to the reduction of carbon emissions.

Vehicle Routing

The optimization problem of vehicle routing involves the determination of optimal service sequences and routes from a warehouse to consumers that are geographically separated. This problem takes into consideration operational restrictions (Merdesic et al., 2023). Efficient management of transportation and distribution operations in the logistics business relies heavily on vehicle routing.

The field of urban logistics involves the effective administration and synchronization of transportation and delivery activities within highly populated metropolitan regions. This involves considering multiple elements, including population density, fluctuations in traffic patterns, customer preferences, and adherence to environmental rules (Merdesic et al., 2023). Manufacturing organizations strategically optimize the routing of their logistics network to minimize logistical expenses and maximize profits in a fiercely competitive market. Hence, the incorporation of efficient logistics management within the supply chain and the prompt addressing of consumers' demands are seen as supplementary avenues for generating profits (Lo & Chuang, 2023). When there is a strong demand and the package sizes are tiny, it is more cost-effective to use smaller delivery vehicles like cargo bikes and walkers. These vehicles are more ecologically friendly compared to larger delivery trucks (Bayliss et al., 2023). Hence, the implementation of a proficient vehicle routing strategy has the potential to enhance a company's profitability through the mitigation of transportation expenses. The selection of shorter routes has the potential to decrease fuel consumption and enhance operational efficiency through the reduction of empty turns. Efficient routes additionally contribute to environmental sustainability through the mitigation of carbon emissions and alleviation of traffic congestion.

Optimization

Traditional supply chain models primarily prioritize operational efficiency through the reduction of overall cost, lead time, defective products, unused capacity, and processing time. However, contemporary supply chain models have expanded their scope to encompass environmental and social objectives alongside economic performance. The significance of this matter is heightened when taking into account the various phases of the supply chain, namely procurement, production, storage, distribution, and transportation. Additionally, it is crucial to consider the different types of supply chains, such as forward, reverse, and closed loop, as well as the different levels of decision making, namely strategic, tactical, and operational. Furthermore, the supply chain environment, characterized by certainty or uncertainty, also plays a noteworthy role in this context (Jayarathna et al., 2021). The prevalence of logistics optimization has experienced a substantial surge in recent decades. Organizations are required to make critical decisions while evaluating and modifying their logistics strategies, hence enhancing the efficiency of associated operational processes. The progress in computational capabilities, modeling tools, and organizations' commitment to dedicating time to modeling research has facilitated the rapid resolution of previously inefficient models (Bartolacci, 2012).

The transportation and logistics of goods are closely linked to climate change, particularly in relation to global warming caused by a range of pollutant sources. Hence, it is imperative to enact efficacious measures and regulations aimed at mitigating the escalating environmental harm caused by the rising emissions of vehicle pollution. Additionally, it is crucial to foster the establishment of sustainable and low-carbon regional transportation and logistics systems (Zhang et al., 2018). Currently, it is imperative for logistics enterprises to develop strategies that include the environmental consequences when formulating the most viable and economically efficient route plan for a certain delivery or service requirement.

Electric vehicles

Over 50% of the global population resides in urban regions, resulting in significant obstacles for urban transportation. These challenges include traffic congestion, the prevalence of private transportation, air pollution, noise pollution, and reliance on energy (Duarte et al., 2016). Prevalent instances of these effects include the influence on traffic congestion created by commercial vehicles, the decrease in road capacity resulting from frequent stops for loading or unloading activities, and the subsequent increase in energy consumption and emissions. Electric cars utilize an electric motor as their power source, as opposed to a traditional internal combustion engine, and are comparatively smaller in size when compared to regular commercial vehicles. Electric vehicles are more convenient for parking compared to vans or trucks powered by internal combustion engines in logistical operations. Additionally, they are widely acknowledged by the public as being safer and more ecologically beneficial (Melo et al., 2014). Electric vehicles are widely recognized as a significant technological advancement that has the potential to enhance the resilience and sustainability of supply chains through the mitigation of greenhouse gas emissions and air pollution (Khan et al., 2023).

The use of electric vehicles plays a critical role in reducing carbon emissions as well as improving energy efficiency in cities. They not only reduce energy consumption in logistics processes, but also affect the spatial and temporal management of cities. Accordingly, urban planners are taking steps to reduce traffic congestion and air pollution by making strategic decisions such as the location of charging stations and the integration of electric vehicles into traffic (Martinelli, 2024). Therefore, regarding urban logistics, electric vehicles are increasingly being regarded as a more ecologically sustainable option. The use of electric vehicles within urban settings is progressively gaining significance in relation to both economic and environmental sustainability, owing to their lower carbon emissions compared to conventional fossil fuel-powered automobiles.

Crowdsourcing

Crowdsourcing is a strategic approach employed by enterprises or institutions to mobilize individuals using digital platforms, such as websites or applications, with the aim of accomplishing a certain objective. The emergence of this strategy can be attributed to the rapid expansion of internet users, the widespread presence of collaborative networked networks, and heightened consumer consciousness. The creation of the sharing economy has been facilitated by various causes, leading to the development of new business modes (Bin et al., 2020). Currently, crowd logistics pertains to the practice of corporations or retailers delegating the distribution of products to public entities that possess flexible schedules, ample time, and transportation capabilities, utilizing the internet as a medium. Mass logistics offers the benefit of enhancing distribution efficiency and minimizing mobility when compared to conventional logistics methods (Renard et al., 2014). According to Samad et al. (2023), crowd logistics refers to a conceptual framework in which logistical activities are chosen from a group of individuals who are either private or public travelers. These logistics operations are then facilitated through an online platform, with the aim of providing advantages to the relevant stakeholders. The organization and execution of urban logistics have undergone substantial transformations due to the ongoing growth of the sharing economy and advancements in information and communication technologies. The concept of mass logistics has recently gained prominence as a novel approach to organizing logistics operations, particularly in the context of urban logistics. As mass logistics becomes increasingly crucial in addressing the final stage of delivery in numerous locations, the ongoing participation of mass workers has emerged as a significant factor impacting the expansion of the mass logistics platform (Huang et al., 2020). Hence, crowdsourcing in the context of urban logistics is widely acknowledged as an effective approach. This phenomenon enhances the economic growth of the local community, expedites the process of delivery, and contributes to the expansion of logistical networks.

3. Conclusion

The efficient transportation of material flows from the producer to the end user is one of the main objectives of logistics today. Current scientific approaches focus on finding solutions to different problems at various logistics system stages. However, the efficiency of the functioning of logistics systems differs from issues related to improving overall productivity, including the end-user. Social, economic and technological progress are all related to urban development. Transitions in economic structures, urbanization, urban planning and transportation systems, as well as externalities related to logistics activities in urban areas, make supply chains and logistics issues more complex than ever. The development and advancement of transportation networks, infrastructure and logistics operations in the context of environmental sustainability is critical to tackling these issues.Urban logistics is a critical component for the development of cities in terms of both economic and environmental sustainability. With the growth of cities, effective management of logistics operations requires efficient use of urban infrastructure and reduced environmental impacts. Effective management of urban logistics improves the quality of life in cities by enhancing environmental sustainability and is a driving force in increasing competitiveness by helping businesses reduce costs. Urban and regional systems are actively changing and evolving through new technologies. Cities are adapting to new opportunities in the areas of energy, mobility, information and communication technologies. Especially in recent years, urban logistics has become increasingly important due to the growth of e-commerce and the increase in urban population density. Implementation of various strategies such as crowdsourcing, electric vehicles, vehicle routing, optimization and last stage delivery are crucial for increasing urban logistics efficiency and reducing environmental impacts. When implemented correctly, these strategies can reduce traffic in cities, improve air quality and save logistics-related costs. The findings of the study are broadly in line with the main trends towards sustainable urban logistics processes in the existing literature (Duarte et al., 2016; Cardenas et al., 2017; Bin et al., 2020; Ravagnan et al., 2022; Gargiulo & Sgambati, 2022; Rosales & Haarstad, 2023; Baker et al., 2023; Marzani & Tondelli, 2024). In particular, the integration of autonomous and electric vehicles into logistics processes offers significant opportunities to both increase operational efficiency and reduce carbon emissions. Duarte et al. (2016) stated that the use of electric vehicles in the logistics sector has a significant potential to reduce environmental impacts, and these findings are supported in this study. Bin et al. (2020) emphasize that the integration of crowd logistics and other technological innovations plays a key role in ensuring sustainability in

logistics operations. Belkouri et al. (2024) emphasized that the integration of autonomous and electric vehicles into urban logistics processes is critical for increasing energy efficiency and reducing carbon emissions.
Another striking element in the bibliometric analysis is the diversity of keywords used in studies from different countries. While studies in China focus more on concepts such as 'electric vehicles' and 'optimization', research in Europe focuses on topics such as ‘last-mile delivery’ and ‘crowdsourcing’. These differences suggest that each country is turning to different technologies according to its own sustainability strategies. Therefore, this study aims to reveal how sustainable urban logistics is addressed in different disciplines and countries.
An important gap in terms of contributing to the literature and guiding researchers in the field is the limited number of comprehensive studies on sustainable urban logistics and technology-based applications used in this field in international and national studies. Based on the results of such a bibliometric analysis, researchers working in the field of sustainable urban logistics can have a deeper understanding of the relevant literature. It is recommended that future studies should consider different databases instead of focusing only on specific indices and evaluate the studies in these databases in the analysis. In addition, the use of visualization tools such as VOSviewer will enable comprehensive analyses in other databases such as SCOPUS, EBSCO Host, etc. without being limited to Web of Science. Again, in future research, it will be possible to analyze the data obtained by using tools such as Citespace and R Studio, which are different visual mapping programs, more comprehensively and to make comparisons on a more solid basis. Using these methods, research on sustainable urban logistics can contribute more to the literature and help improve knowledge in this field.

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Author’s profile

Suzan Oguz

She is an Assistant Professor at the Foreign Trade Department of Cag University in Mersin, Turkiye. She received her doctorate degree from the Department of International Trade and Logistics at Akdeniz University in Antalya, Turkiye. Her research interests are international trade, logistics and supply chain management.

Mehmet Tanyas

He is a Professor Doctor at the Department of International Trade and Logistics at Maltepe University in İstanbul, Turkiye. He is also the head of the International Trade and Logistics Department at the university. His research interests are logistics and supply chain management.

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REVIEW NOTES – International Regulation and Legislation for the Energy Transition

Governance of the energy transition: the role of local authorities in Italy

Valerio Martinelli

Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: valerio.martinelli@unina.it
ORCID: https://orcid.org/0009-0007-8703-6573

Abstract

Starting from the relationship between urban planning and mobility management, TeMA has gradually expanded the view of the covered topics, always remaining in the groove of rigorous scientific in-depth analysis. This section of the Journal, Review Notes, is the expression of continuously updating emerging topics concerning relationships between urban planning, mobility and environment, through a collection of short scientific papers written by young researchers. The Review Notes are made of four parts. Each section examines a specific aspect of the broader information storage within the main interests of TeMA Journal. This section, International Regulations and Legislation for the Energy Transition, explores the challenges and opportunities in the urban context to understand the evolving landscape of the global energy transition. The contribution explores how Italian local authorities contribute to the energy transition, in line with European directives. It highlights the importance of territorial governance plans and urban transformation tools in promoting the use of renewable energies and reducing emissions. Renewable Energy Communities (RECs) are identified as key instruments, thanks to the direct involvement of citizens and local energy autonomy. Finally, the contribution also highlights the challenges related to regulatory fragmentation and the need for greater coordination.

Keywords

Energy transition; Renewable energy comunities; Local regulations; Urban planning.

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1. Role of local planning authorities in the energy transition

The energy transition, supported by the UN 2030 Agenda, aims to reduce the use of fossil fuels in favour of renewable energy by promoting local production (Savino, 2023). This need is both environmental and geopolitical, as international crises have exposed energy systems to high and unstable costs. In this context, the shift to a decentralised model translates into opportunities to innovate production systems, making consumers key players in the transition and promoting respect for local energy resources. Moreover, the energy crisis can push urban contexts towards a more sustainable future (Cumo et al., 2022; Papa et al. 2016). Local authorities, such as regions and municipalities, play an essential role in adapting European directives to the needs of their territories, as established by the Piano Nazionale Integrato per l'Energia e il Clima (PNIEC). Directives such as Renewable Energy Directive (RED II) and the Clean Energy for All Europeans package (CEP) entrust local authorities with the concrete implementation of targets to increase the use of renewables and reduce greenhouse gas emissions (Cutini, 2023). In Italy, the transition is regulated on several levels, from European directives to national strategies, from Piani Energetici Ambientali Regionali (PEAR) to municipal plans. This system allows a flexible response to local specificities but can slow down progress due to bureaucratic obstacles and regulatory fragmentation (Sarrica et al., 2018). The regions, with Law No. 10/1991, have acquired relevant competences for the efficient use of energy and the development of renewables. Despite this, they must comply with national regulations and European obligations, limiting regional autonomy. This configuration creates territorial differences that risk hindering the harmonisation of progress towards national targets (Di Gesù, 2021). Regions and municipalities play a key role in facilitating authorisation processes for renewable energy infrastructure, which are often slowed down by fragmented regulations (Barbaro & Napoli, 2023). Local action goes beyond planning and includes implementing sustainable measures, initiating partnerships for renewable energy projects and offering tax incentives to promote decentralised energy models and local energy autonomy (Legambiente, 2023). Among the innovative solutions proposed by the EU with RED II are energy communities: legal entities that enable citizens, entities and small businesses to produce and share renewable energy. Local authorities support the adoption of these configurations that not only reduce CO_2 emissions but also strengthen the local economy through self-production and energy sharing (Lennon & Dunphy, 2024; Trevisan et al., 2023).

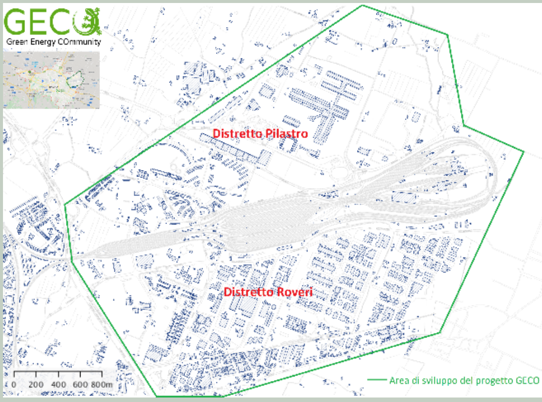
2. Renewable energy communities as a key instrument for energy transition

Renewable Energy Communities (RECs) represent an innovative approach to promote energy transition. The EU's RED II Directive establishes a regulatory framework to incentivise RECs but leaves it up to Member States to define the operational, technical and financial details. This has led to significant differences between countries, influenced by local geographical, cultural and political factors. Therefore, effective implementation of the Directives at national level is essential in order to transform European objectives into local actions (Hoicka et al., 2021). RECs are based on a decentralised and shared model of energy production and consumption, which reduces dependence on fossil fuels. Through collective self-consumption, they contribute to the reduction of greenhouse gas emissions and lower energy costs for members, while also helping to combat energy poverty and encouraging active community participation. Local authorities are crucial in promoting RECs by facilitating the removal of regulatory barriers and the adoption of appropriate regulatory frameworks (Bashi et al., 2022). According to a study by Elemens for Legambiente, RECs in Italy can significantly contribute to decarbonisation by shifting consumption from fossil to renewable sources. The study predicts that by 2030 RECs could generate a capacity of around 17.2 GW, covering 30% of the production increase required by the PNIEC (Legambiente, 2022). In Italy, the RED II directive was transposed by Decree-Law no. 199/2021. The Piedmont region anticipated the national legislation with Regional Law No. 12/2020, launching the first REC in Magliano Alpi, implemented in collaboration with the Polytechnic University of Turin. This project demonstrated how local authorities can act as promoters of the energy transition (Musolino et al., 2023). Some regions, such as Piedmont, Lombardy and Emilia-Romagna, have introduced concrete incentives by allocating European funds to support RECs, while others face difficulties due to budget constraints and administrative obstacles. This gap between regions reflects the complexity of multi-level governance, which can create regulatory barriers that slow down the energy transition (Gargiulo & Papa, 2021). To overcome these obstacles, local authorities are experimenting with public-private partnerships and collaborations with universities. One example is the RECOCER project in Friuli, which involves local authorities and universities to provide technical support for RECs. Local authorities are therefore essential players in promoting RECs, but more widespread dissemination would require greater regulatory harmonisation at national level. Effective coordination between European, national and local levels is crucial to achieve an energy transition that minimises environmental impact and respects territorial specificities (Krug et al., 2022).

3. The role of territorial governance and urban transformation for energy transition

The close relationship between energy autonomy and territorial development, promoted by EU regulations to support energy communities, has given rise to several implementation models (REScoop.eu, 2020). To stimulate the development of efficient distributed generation, it is essential to start with local planning. The energy transition requires an integrated approach that combines urban and energy planning, actively involving local governments to adapt urban and territorial spaces to the new renewable energy infrastructure (Martinelli, 2024). Local authorities must develop plans that are aligned with sustainability goals and facilitate the implementation of renewable energy (Lai et al., 2021; Mazzeo & Polverino, 2023). A central aspect is participation and sustainability, especially for local authorities in the context of decentralisation and liberalisation processes, which require a revision of energy governance. This revision aims at promoting forms of self-government in vulnerable and marginal areas, starting with the strengthening of existing levels of government. Integrating energy planning into urban plans is essential to reduce greenhouse gas emissions and promote the systematic adoption of renewable energy (Cecchini, 2023). A spatial knowledge framework that identifies energy consumption and potential supply from renewable energy sources is needed to develop scenarios on future energy demand considering demographic and urban development (Bevilacqua & Milazzo, 2022). Local governments can integrate energy communities through strategies that emphasise sustainability and resilience. Energy planning should promote a long-term vision for sustainable, low-impact cities by enhancing a sense of community and active participation (Neves et al., 2024). By integrating energy communities into urban planning, energy losses can be reduced and efficiency increased through local energy management, contributing to the sustainability and resilience of cities. Spatial planning optimises the use of local energy resources, improving urban autonomy and sustainability (Gjorgievski et al., 2023). Energy planning can be included in spatial planning tools, such as Piani Urbanistici Comunali (PUC) to identify areas suitable for renewable installations while avoiding conflicts with other land uses. Some Italian municipalities, such as those in Emilia-Romagna, have already allocated areas for solar and wind power plants, promoting urban energy self-sufficiency. To this end, the Piano d’Azione per l’Energia Sostenibile e il Clima (PAESC), adopted by many municipalities, integrate energy and climate objectives, promoting CERs and local energy efficiency. Instruments such as PAESCs support the use of green infrastructure, such as solar roofs and central heating systems, and promote Positive Energy Districts (PEDs), where renewable energy production exceeds local energy consumption, generating a redistributable or storable surplus (Derkenbaeva et al., 2022). In Italy, the PED concept is growing, with some cities collaborating with universities and research centres to design sustainable, self-sufficient neighbourhoods equipped with smart grids for energy management. The integration of energy and land use planning optimises the use of resources, increasing urban energy efficiency and fostering local autonomy. However, the spread of RECs is limited by urban planning constraints and bureaucratic complexities, which require a uniform and simplified regulatory framework. Local authorities play a central role, collaborating with institutions and citizens to implement sustainable solutions and promote community involvement. Economic support through dedicated funds and incentives is essential, as is greater regulatory harmonisation to facilitate the transition to a decarbonised energy system.

Piano d'Azione per l'Energia Sostenibile e il Clima (PAESC) of Bologna, 2021



The "Piano d'Azione per l'Energia Sostenibile e il Clima (PAESC)" of Bologna, 2021, approved in 2021, is a strategic document aimed at reducing CO_2 emissions and strengthening territorial resilience to climate change. Aiming to align with European directives and reduce emissions by 40 % by 2030, the PAESC integrates urban energy and climate policies and promotes energy transition and environmental sustainability. Priorities include the deployment of RECs and Positive Energy Districts (PEDs) as models of urban energy self-sufficiency. The integration of RECs into Bologna's urban policies is articulated in specific instruments, such as the Piano Operativo Comunale (POC) and the Piano Urbanistico Generale (PUG). These instruments identify areas suitable for the installation of renewable energy production plants and encourage collective self-consumption. In addition, they provide incentives and constraints for new buildings and renovations to integrate photovoltaic and storage systems, facilitating building participation in CERs. The city promotes sustainable neighbourhoods and Positive Energy Districts (PEDs), areas with a low environmental impact where the production and consumption of clean energy is maximised. The GECO (Green Energy COmmunity) project, active in the Pilastro and Roveri neighbourhoods, is a significant example of this: in these neighbourhoods, shared technologies such as photovoltaic and biogas plants encourage energy efficiency and active participation of residents. On the regulatory side, the municipality has revised building regulations to facilitate the installation of photovoltaic systems and energy sharing between buildings. These tools, favouring collective participation, include RECs as a key element in the city's sustainability and resilience strategy.

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Author's profile

Valerio Martinelli

He is an engineer, with a master's degree in Building Engineering-Architecture at the Department of Civil, building and Environmental Engineering of the University of Naples Federico II. He is currently a first year Ph.D. student in Civil Systems Engineering at the same department. His research activity focuses on the study of Renewable Energy Communities.

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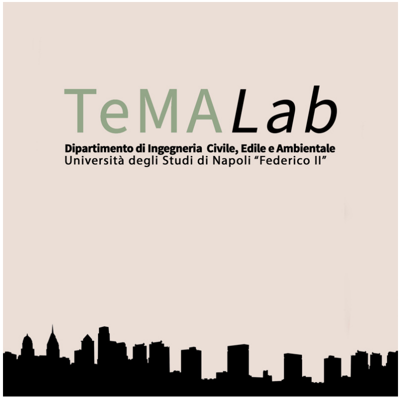

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REVIEW NOTES – Urban strategies, programmes and tools

Strategies and instruments for active mobility: the main Italian policies

Annunziata D'Amico

Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: annunziata.damico@unina.it
ORCID: https://orcid.org/0009-0005-5481-8064

Abstract

Starting from the relationship between urban planning and mobility management, TeMA has gradually expanded the view of the covered topics, always remaining in the groove of rigorous scientific in-depth analysis. This section of the Journal, Review Notes, is the expression of continuously updating emerging topics concerning relationships between urban planning, mobility and environment, through a collection of short scientific papers written by young researchers. The Review Notes are made of four parts. Each section examines a specific aspect of the broader information storage within the main interests of TeMA Journal. In particular, the Urban strategies, programmers and tools section presents the different strategies and tools for active mobility implemented internationally.

This work aims to highlight the various actions undertaken at national and local level to promote the spread of active mobility in Italy, providing a general overview of the tools and strategies adopted and also presenting concrete examples of solutions implemented in some cities.

The numerous positive experiences at local level allow us to highlight the attention of Italian cities to reduce dependence on the car (and motorcycle) mode in daily travel, in favor of lower-impact modes of transport This trend of promoting active travel (on foot and by bicycle), which is more ecological and healthy, could contribute to achieving the goal of improving the quality of urban environments and the quality of life of people.

Keywords

Walking; Cycling; Italy; Urban strategies; Active mobility.

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1. Active cities: the challenge of soft mobility in italian cities

The paradigm of urban mobility is undergoing profound transformation. New global scenarios, characterized by climate and social emergencies, are pushing cities to completely rethink their transport systems, focusing on sustainable and low environmental impact solutions. On the Community front, there is the objective of climate neutrality by 2050, with the ambitious goal of reducing greenhouse gas emissions in the transport sector by 90% compared to 1990 levels (D'Amico, 2024; EC, 2022).

Cities, faced with global challenges such as climate change and social inequalities, are radically rethinking the way they design and manage urban mobility (Gaglione & Ayiine-Etigo, 2022), proposing alternative approaches to conventional transport planning.

By combining different modes of transport, such as public transport, walking, cycling and micromobility, and integrating them with innovative technologies, we can create more efficient, flexible and sustainable mobility systems. In fact, sustainable mobility refers to a transport system that favours intermodality and low environmental impact travel methods, capable of reducing pollution, noise, congestion and road accidents, safeguarding the environmental heritage.

For years, European policies have been directed towards promoting low-emission and zero-emission mobility. The cornerstone of European urban mobility policy is based on Sustainable Urban Mobility Plans (SUMPs) introduced by the 2013 Urban Mobility Package. SUMPs provide a framework for cities and municipalities to plan and implement solutions to urban mobility policy challenges across the functional urban area. Europe encourages the large-scale adoption of SUMPs, which have been widely used by local authorities, planners and stakeholders as an effective, robust and flexible tool for planning urban mobility measures (Commission Recommendation (EU) 2023/550).

In order to ensure the effective flow and interaction of the entire trans-European transport network (TENT-T), the revised TEN-T Regulation (2024) reinforces the role of cities as vital enablers of sustainable, efficient and multimodal transport and collect and regularly submit to the Commission data on urban mobility indicators. Furthermore, the Regulation designates 431 cities as urban nodes and sets specific requirements for them. These include the adoption by urban nodes of a sustainable urban mobility plan. As highlighted in the EU Recommendation 2023/550 the European Commission invites each Member State to implement a national programme to support cities in planning sustainable urban mobility.

In Italy, SUMP have been regulated since 2017 with the Decree of the Ministry of Infrastructure and Transport n. 397, which defined the guidelines. This was updated with Decree n. 396 of August 2019, which was approved with the explicit aim of promoting a homogeneous and coordinated approach to the preparation of SUMP throughout the national territory. National Decree n. 396 requires all municipalities with over 100,000 inhabitants, excluding metropolitan areas that must have an integrated SUMP, to adopt a Sustainable Urban Mobility Plan.

To encourage the adoption of SUMPs, Italy in 2022 provided a bonus in the form of funding for rapid mass transit and cycling projects. Starting in 2023, the adoption of the SUMP becomes an essential requirement to access any funding related to public transport and cycling mobility (EU Urban Mobility Observatory, 2022).

Developing a SUMP means undertaking a strategic mobility planning process, in a medium-long term time horizon (10 years), aimed at identifying innovative and sustainable solutions from a financial, social and environmental point of view, which take into account future territorial dynamics.

In 2022, the Italian Ministry of Infrastructure and Sustainable Mobility (MIMS) published a "Vademecum" (MIT, 2022) for the drafting of the SUMP based on Italian and European guidelines. The Vademecum presents a series of operational and procedural guidelines useful and supportive to Italian municipalities and metropolitan cities in the preparation of SUMP. According to the "Vademecum", the drafting of the SUMP is then divided into four well-defined procedural steps:

- Preparation of the knowledge framework;

- Definition of the objectives;
- Construction of the plan "scenario";
- Definition of the monitoring plan.

The Italian guidelines also provide for the addition of two further procedural steps:

- Strategic environmental assessment (known as VAS);
- Adoption and approval of the SUMP.

In Italy, a SUMPs Observatory has been created, with the patronage of the Ministry of the Environment and Energy Security, which aims to be a point of reference for those who address or manage the issue of urban mobility from a strategic, participatory and sustainability perspective. The Observatory, aimed first of all at Italian cities and conceived and designed for them, was born as an evolution of the European network ENDURANCE, conducts an ongoing survey on the state of the art of SUMPs in Italy. The Observatory networks Municipalities, Unions of Municipalities, Provinces and Metropolitan Cities that are committed to sustainable planning of urban mobility and promotes access to information and services, strengthening the network of cities active in sustainable mobility (Italian SUMPs Observatory).

According to the latest data from the Italian SUMPs Observatory (updated to November 2023), a total of 211 Sustainable Urban Mobility Plans have been drawn up in Italy. Of these, 80 have already been approved, demonstrating a concrete commitment by many local administrations towards more sustainable mobility. Another 57 SUMPs have been adopted and are being implemented, while 74 are still being drawn up. These data highlight a positive trend, but also underline the need to accelerate the planning and implementation processes of the interventions envisaged by the SUMP.

2. Active mobility policies in Italy

In Italy, as in most European cities, historic centers are particularly relevant as places of identity, memory and belonging, playing a fundamental role as economic and social nucleus.

The quality of life in cities is closely linked to the quality of the urban environment. It is clear that to make cities more liveable and attractive, it is necessary to drastically reduce negative factors such as vehicular traffic, climate-altering emissions, and noise.

"Friendly cities", characterized by a high quality of life, are urban contexts where efficient, integrated and sustainable collective mobility is combined with a wide range of public services and high-quality infrastructures (Busi, 2023).

Efficient and sustainable mobility requires a profound cultural change that goes beyond the centrality of the private car and enhances other modes of travel (Cecchini, 2023).

To build sustainable and pleasant cities, the challenge that city authorities, both national and international, have been putting in place for some time now is the implementation of adequate strategies and innovative solutions to manage traffic and promote more eco-friendly and healthy mobility choices.

The promotion of active travel, on foot and by bicycle, could contribute to achieving the goal of improving the quality of urban environments and the quality of life of people. In fact, active mobility represents a huge potential to improve air quality, reduce congestion and promote a healthier lifestyle. Furthermore, the redevelopment of pedestrian and cycle paths allows for the creation of a more efficient and safe network, which connects neighbourhoods, workplaces and services, thus improving accessibility and social inclusion (Gargiulo & Sgambati, 2022).

In this regard, many Italian cities have made enormous progress and have implemented a series of initiatives and programs aimed at developing services for cycling and pedestrians integrated with urban functions and the main mobility hubs. Additionally, many cities have expanded their cycling and pedestrian infrastructure in recent years to increase their resilience in the face of the COVID-19 pandemic (Cirianni et al., 2022).

The different measures adopted by cities to promote active mobility vary from city to city and reflect territorial specificities, the needs of citizens and the strategic objectives of each administration, in line with national and international political guidelines.

Some of these strategies are illustrated below and allow us to highlight the attention of Italian cities to reduce dependence on the car (and motorcycle) mode in daily travel, in favor of lower-impact modes of transport (foot, bike,TPL), highlighting the greater competitiveness of soft transport modes.

Bolzano (TRENTINO-ALTO ADIGE) – *School Streets*

The SUMP of the city of Bolzano was approved in 2022 and places a strong emphasis on pedestrian mobility, recognizing its importance for the quality of urban life, the health of citizens and environmental sustainability.

Among the complementary strategies planned to encourage pedestrian mobility especially for the new generations, the SUMP of Bolzano promotes a series of initiatives starting from the systematic Home - School trips of primary school children including: the "Nonni Vigili" service, the Pedibus service, School Streets and bus accompaniment (SUMP of Bolzano, 2022).

In particular, the School Streets were introduced for the first time by the city of Bolzano in 1989 and are areas around schools where, at certain times, vehicular traffic is limited or prohibited, thus creating pedestrian and cycle areas. This simple and economical measure reduces pollution and promotes the health of children and families.

This initiative has been successfully replicated in many other cities, and is identified as an effective tool for improving road safety and air quality in school areas, helping to solve current urban problems. Furthermore, School Roads also represent a response to the urgent need to make our cities more child-friendly.

Parma (EMILIA-ROMAGNA) – *SUMP*

In recent years, solving problems related to traffic and mobility in the urban area has been a strategic objective for the Municipal Administration of Parma.

The SUMP of Parma, approved in 2017, aims to adopt a series of strategies to progressively discourage the use of private cars in the most central areas, while promoting the most environmentally friendly types of travel. Limited Traffic Zones and pedestrian areas have been established for many years, and Car Sharing and Bike Sharing services have been implemented for a decade now (Municipality of Parma, 2024).

With regard to cycling mobility, the Plan promotes a vision aimed at encouraging the use of bicycles for regular trips (home-work and home-school), as well as for those related to free time. To this end, the Plan scenarios define, among the main actions to be taken, the completion of cycle networks in line with the Biciplan (approved in 2009), the identification of new strategic itineraries and the development of a network of complementary services (bike sharing stations, bicycle parking, etc.).

The plan provides for encouraging the spread of cycle logistics initiatives: use of cargo bicycles for the delivery of goods. Parma, thanks to its compact and flat urban layout, promotes the delivery of goods with ecological means, in line with the new regulations on sustainable mobility, to reduce emissions and develop low environmental impact logistics activities.

Milano (LOMBARDIA) – "*Cambio Biciplan"*

"Cambio" is the Biciplan of the Metropolitan City of Milan that identifies the objectives of the development of cycling, starting from the current demand for mobility and the potential of the territory.

It is called "Cambio" because it wants to bring the metropolitan territory to change its point of view and bring citizens to change the way they move around the territory.

"Cambio" identifies super-cycle corridors at the metropolitan level and integrates them with the municipal cycle paths, in particular, the Biciplan provides for the creation of 24 super-cycle lines: 4 circular, 16 radial and 4 greenways. The super-cycle paths are designed for heavy bicycle traffic and suitable for a high cruising speed, compatible with widespread use of bicycles, even electric ones, for daily trips of medium length (between 5 and 15 km); these super-cycle paths intersect with the greenways and the secondary network of routes generating a widespread and efficient cycle network (Metropolitan City of Milano, 2021).

The 2035 objectives for the Metropolitan City are ambitious: with 750 km of infrastructure, reaching 20% of total travel on the territory by bicycle and 10% of intermunicipal travel.

The ambition of this project is to integrate multiple aspects: environmental protection, safety, economic development and general well-being. The development of cycling leads to a reduction in climate-altering emissions, to the creation of green corridors for the protection of biodiversity, to making travel safer for all types of cyclists, to improving public health by increasing daily opportunities for exercise and movement. Furthermore, a reduction in travel congestion is correlated with an increase in productivity and the development of local economies.

Torino (PIEMONTE) – "BIPforMaaS"

"BIPforMaaS" is the new strategic project of the Piemonte Region, which intends to create the conditions for the diffusion of MaaS services in the urban and metropolitan area of Turin and throughout the territory of the Piemonte Region, starting from the BIP electronic ticketing system (Regione Piemonte, n.n.).
The implementation objectives of the "BIPforMaaS" project include:
1) to create and consolidate a new integrated tariff system for local public transport (TPL), based on pay-per-use and best fare logics, which allows users to freely access all regional TPL services also through smartphone apps that allow the purchase and use of travel tickets;
2) to create a "MaaS ecosystem", made up of the Piemonte Region and other local authorities, mobility operators, stakeholders and citizens, enabled by a technological infrastructure and a system of tariff rules and policies, capable of facilitating the creation of new digital services for mobility according to the MaaS paradigm for a more integrated, accessible and sustainable local mobility system.
In Europe, the country that has made the most progress towards mobility as an integrated service is Finland, which since 2010 has been supporting several pilot projects in urban and rural areas with the aim of spreading a new concept of mobility that involves the integration of multiple public and private transport services (local public transport, ride-sharing, car-sharing, bike-sharing, scooter-sharing, taxi, car rental) combined in a single service and with a single payment system accessible through a dedicated platform.

Padova (VENETO) – "*MetroMinuto Padova"*

"Metrominuto Padova" is a sustainable mobility project that aims to increase urban pedestrianization, through the creation of a schematic metro map indicating the places of greatest cultural, historical, tourist interest and services in the city.
The map indicates distances and travel times between the various points of the metro map, so as to encourage non-motorized mobility over short distances and better understand the effectiveness of walking in the city (Padovanet, 2022).
The project, based on the model of the city of Pontevedra, in Galicia (Spain), also replicated in other cities, aims to make the city easily reachable in a few minutes, with rapid, comfortable and sustainable travel.
The scheme is based on a representation of the city in terms of reciprocal distances between the places of interest and the relative average travel times for pedestrian travel, identifying the routes of greatest usability and interest with different colors.
The city of Padova is characterized by a strong focus on sustainable mobility and the "Metrominuto Padova" project is part of the program of interventions on mobility that, in an urban context, are implemented to improve the quality of life of citizens and reduce the environmental impact of traffic.

3. Conclusion

Active mobility represents a fundamental lever for achieving the environmental sustainability objectives set at international and national level.
Starting from the general regulatory guidelines, also through the drafting of procedural guidelines prepared by the Italian government in order to create homogeneous approaches to sustainable mobility planning, a crucial aspect of the planning process is the ability to interpret these operational guidelines by adapting them flexibly to individual contexts.
The growing attention to sustainable mobility is leading many Italian cities to invest significantly in the creation of infrastructures dedicated to pedestrians and cyclists. Thanks to tools such as SUMP, it is possible to plan targeted interventions to promote active mobility, improving the quality of urban life and contributing to the reduction of pollution and traffic. Furthermore, new technologies are facilitating the spread of innovative solutions for shared mobility and for a more efficient management of urban spaces (e.g. MaaS services).

This document illustrates some of the most significant experiences carried out in Italy in the field of promoting active mobility, demonstrating the vitality and diversity of the approaches adopted.
The numerous positive experiences at local level demonstrate how investing in infrastructures dedicated to active mobility and incentive measures can lead to significant results in terms of quality of life and urban efficiency. However, consolidating these tools requires a constant commitment from all actors involved, in order to overcome resistance and ensure the long-term sustainability of these policies.

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Author's profile

Annunziata D'Amico

She is an engineer, Ph.D. student in Civil Systems Engineering at Department of Civil, Building and Environmental Engineering of University of Naples Federico II. Currently, her Ph.D. research concerns the topic of MaaS and soft mobility in urban systems for children, to encourage walkability and more sustainable and active mobility.

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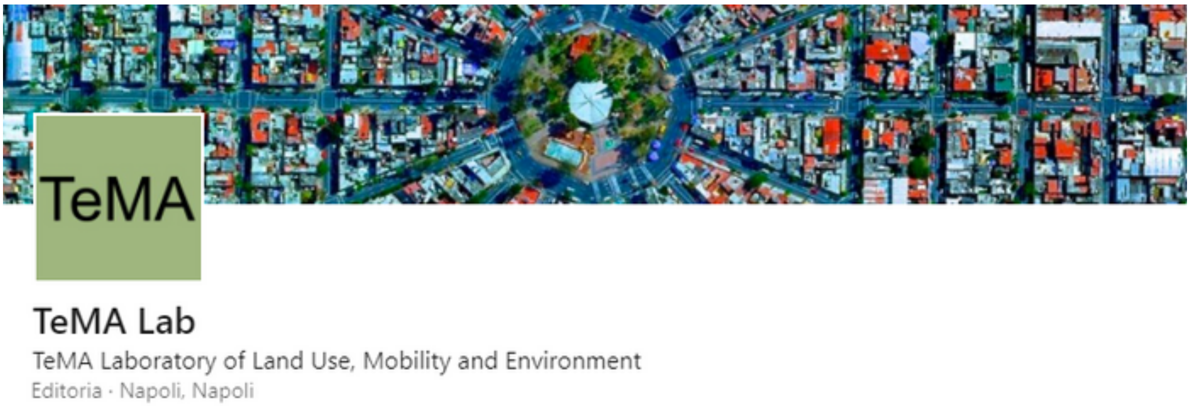

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REVIEW NOTES – Urban Practices

Global warming or global warning? A review of urban practices for adaptation to urban floods

Stella Pennino

Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: stella.pennino@unina.it
ORCID: https://orcid.org/0009-0008-4439-0078

Abstract

Starting from the relationship between urban planning and mobility management, TeMA has gradually expanded the view of the covered topics, always remaining in the groove of rigorous scientific in-depth analysis. This section of the Journal, Review Notes, is the expression of continuously updating emerging topics concerning relationships between urban planning, mobility and environment, through a collection of short scientific papers written by young researchers. The Review Notes are made of four parts. Each section examines a specific aspect of the broader information storage within the main interests of TeMA Journal. In particular, the Urban Practices section aims at presenting recent advancements on relevant topics that underline the challenges that the cities have to face. This note provides an overview of the challenges that global warming poses and the risks in terms of climate change that it generates for territories and cities, with a specific focus on the urban flooding phenomenon. The challenges that adaptation to urban flooding events commonly faces are outlined, and a brief review of international case studies is carried out. Finally, the results of the review are discussed highlighting some key threads of adaptation to urban flooding practices and three significant examples of adaptation in urban areas are reported, within a perspective of integration and sharing of know-how on the topic.

Keywords

Climate change; Adaptation; Urban practices; Case studies; Urban floods.

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1. Introduction

Extreme weather events are natural phenomena, occurring at considerable distances in time, and have always been part of human experience and people's historical memory. These events are characterized as rare at a particular place and time of year, with unusual characteristics in terms of magnitude, location, timing, or extent (World Metereological Organization, 2023). Over the past 10 years, we have become accustomed to witnessing these phenomena more conspicuously in terms of frequency and intensity, annually reporting at least one phenomenon that emerges on a global scale and connotes itself as "the phenomenon of the year," sometimes earning a familiar household name, such as Charon or Katrina.

The year 2024, however, from the beginning, heralded itself as the year when certain global thresholds would be crossed (World Metereological Organization, 2024). Flood-related disasters of rare severity have occurred in almost every region of the world, events that are expected to occur with a 100-year frequency but are challenging traditional forecasting techniques.

In May, one of the worst weather disasters in the country's history struck southern Brazil, particularly the state of Rio Grande do Sul (Pan American Health Organization, 2024). Images of the thousands of displaced people, whose homes were completely destroyed or washed away by the tumult of the water, shocked the world. The damage and impacts in terms of economy and human lives were already present in the collective imaginary, but thousands of people losing everything: housing, possessions, jobs and sources of livelihood, is a consequence that was not yet perceived as close.

Hurricanes and other phenomena typical of the earth's tropical area, such as cyclones and typhoons, are themselves natural phenomena, and it is not surprising to hear about them annually in the rainy season. These phenomena, however, have a natural origin, but they have consequences that are less and less natural and manifest other worrisome aspects of coastal flooding hazards. Hurricane Milton marked 2024 for the mass evacuation that affected more than 5 million people in Florida, in the southern United States (Mazzei & Taft, 2024), and caused total destruction, coming to cost over 34 billion in damages (Isidore, 2024).

Europe has also been the setting of disastrous and alarming phenomena. Spain has seen one of the most severe floods in the last 100 years, with more than 200 deaths and unprecedented images of stacks of cars submerged and stuck in urban streets, a glaring sign that the icons of modernity and contemporary security are nothing against the uncontrolled power of natural phenomena that should dictate the rules of our expansion and development (NASA Earth Observatory, 2024). The Spanish case is emblematic in that it embodies, on the one hand, the power that meteorological-climatic contingencies, in this case the cold drop phenomenon, can achieve in a context of climate change; but also, the severity of the effects that erroneous urban expansion choices and deficient prevention and civil protection measures can generate, especially in terms of human lives.

These epochal events, nevertheless, although surprising in terms of magnitude, do not come unexpectedly. With two months to go, it is almost certain that 2024 will be the hottest year on record since the pre-industrial age, with the global average temperature reaching +1.54 °C, even exceeding the limit identified as an extreme not to be surpassed in the Paris Agreements (World Meteorological Organization, 2024). As temperatures gradually rise, accelerated by the increase of greenhouse gases in the atmosphere, the oceans and seas are also warming, going on to alter the water cycle with tangible consequences in terms of precipitation and dynamics between aquifers, reservoirs and waterways.

2. Urban flooding and climate change

These phenomena have long been studied and are among the objects of the IPCC Assessment Reports. There are multiple ways in which rising temperatures influence the occurrence of flooding phenomena, and there are multiple types of flooding that can occur.

Warmer air holds more moisture, and wetter air leads to more abundant and intense rainfall. For every degree increase in global warming, about 7 percent more extreme daily precipitation is expected (World Meteorological Organization, 2024). Intense rainfall, occurring in contexts characterized by other phenomena such as: increased urbanization, soil sealing, and inadequate and backward urban drainage systems, leads to a first type of urban flooding: pluvial flooding, caused by extreme rainfall in urban environments and which can potentially occur anywhere as rainfall intensity increases. This phenomenon occurred in the recent flooding of the Valencia region, during which streets suddenly filled with water turned into actual rivers, dragging whatever was in the way.

Increased rainfall intensity and extreme rainfall patterns (alternating long periods of absence with intense events concentrated in a few hours or days), can contribute to the occurrence of fluvial flooding, flooding caused by the sudden increase in river flows that, combined with excessive and unnatural anthropization of river floodplains, subjects inhabitants and infrastructure to disastrous flooding. At a time when the effects of climate change were not yet so obvious, many cities that have sprung up along rivers have unabashedly increased urbanization and subsequent sealing along their banks, eliminating the natural river floodplains that are supposed to absorb the natural flooding phenomena that occur remotely over time. The anthropization of the banks has also caused a degradation of the natural ecosystems that helped absorb and manage rainwater, further reducing the resilience of urban areas to these phenomena (Rentschler et al., 2024). Fluvial floods are thus also potential types of urban flooding, often coupled with or dependent on related pluvial flooding phenomena, as was the case with the disastrous floods in southern Brazil.

In parallel, among the most obvious consequences of global warming is the melting of glaciers and polar ice caps, a phenomenon that contributes to sea-level rise. This phenomenon exacerbates coastal flooding that occurs in the case of storms and storm surges, as well as in the cases of typhoons, hurricanes and cyclones, phenomena whose intensity is in turn increased by the increased moisture in the air due to higher temperatures. This convergence of phenomena leads to an increase in the power of these increasingly extreme events, a prime example of which was Hurricane Milton in Florida. This type of flooding, referred to as tidal or coastal flooding, is in turn made more dangerous by the combination with other non-climate-sensitive urbanization phenomena, which has seen heavy coastal urbanization, with sealing of soils and often the failure to provide for warning, emergency, or infrastructure systems that can protect the built environment and the citizens from these phenomena.

Compared to the phenomenon of extreme heat, the subject of the previous review in this series (Pennino, 2024b), urban flooding has more tangible consequences and is now central to the concerns of the very citizens who witnessed it directly or indirectly this year, more than ever before. It is therefore an urgent priority to adapt urban environments to these phenomena that will continue to occur, and to make communities more resilient and ready to deal with them.

3. Adaptation to urban floods, a review of case studies

As the types of urban flooding are multiple, involve different causes and produce manifold effects, the strategies and interventions that can be put in place in terms of adaptation are also varied and differentiated. First, starting with the most normalized strategies in the current way of transforming the built environment, there is the need to implement, redesign and adapt gray infrastructure, that is, all the built infrastructure such as drainage networks, catch basins, and culverts that are integrated into urban environments precisely to manage stormwater runoff and its eventual accumulation during downpours. These infrastructures have often been built without considering climate change forecasts, and thus prove unsuitable for the increasingly extreme weather phenomena affecting our cities. It is therefore necessary to adapt the existing infrastructure, improve or enlarge it where required, so to adapt it to the new forecasts of weather phenomena caused by climate change.

A parallel strategy that has been emerging as a major player in recent years is that of replacing gray infrastructure or, more often, supplementing that with green and blue infrastructure. This strategy involves the creation of alternative infrastructures, based on natural elements such as tree cover, plantings, creation of natural basins, and the integration of ecosystems into the built environment, that help recreate the natural capacity of soils and plants to absorb and retain water and moisture, offloading the pressure put on gray infrastructure, and providing numerous additional benefits to citizen, such as a mitigation of surface and air temperatures, and a restoration of local ecosystems and biodiversity, as well as the pleasantness of urban environments.

These solutions are partly assimilable to another broad category of adaptation strategies, that of nature-based solutions (NBSs). This category, in fact, proposes the use of natural elements that perform the same function as gray technologies or infrastructure, and thus have a lower environmental impact as well as a lower cost of production and numerous additional benefits. These include, in addition to the aforementioned green and blue infrastructure, all those technological solutions that integrate natural elements centrally in solving climate challenges, including green roofs and walls, permeable pavements, rain gardens, and numerous others.

Preserving soil and ecosystems is intrinsically linked to safeguarding the urban and peri-urban landscape, which serves as a strategy for maintaining environmental characteristics while protecting the cultural and social value of natural spaces near urban areas. To effectively address the risks of urban flooding, control mechanisms for landscape variation should be designed to reflect local features and respond to emerging environmental challenges (Cialdea, 2023). This integrated approach would ensure resilience while balancing ecological preservation and the socio-cultural significance of these landscapes.

Solutions that include physical adaptation of cities, however, are not the only way and are not sufficient to adapt urban systems, which in addition to natural and built spaces are also composed of urban actors and functions. Indeed, strategies that rely on tools for monitoring and warning of these phenomena, enabling real-time analysis of phenomena and consequent early warning communications, are crucial. In parallel, evacuation and emergency plans and the appropriate training and preparation of the citizenry for these phenomena are fundamental, to coordinate the response of the population in these extreme situations while limiting damage and, above all, avoiding loss of life.

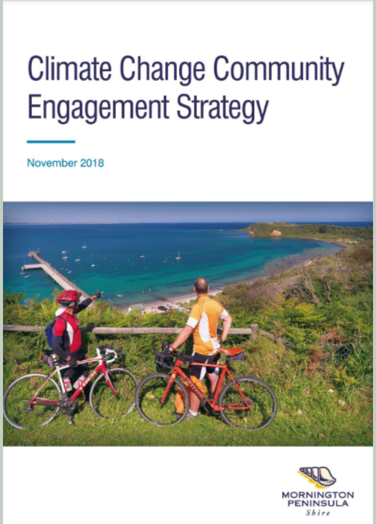
As summarized in the first paper in this series (Pennino, 2024a), adaptation to climate change is now a central issue in the international debate on climate change. As the issue is closely linked to cities, both as a problem and as a potential, the many guidelines provided by international organizations and the many successful cases collected in special repositories provide useful food for thought.

With reference to the topic of this paper, there are already many cities that have implemented urban flood adaptation strategies. In this review are reported three case studies of different types from three exemplary databases focused on this central issue in the climate change adaptation discourse:

- Climate-ADAPT, the Environmental Information platform which collects and makes available for consultation the European adaptation case studies, coordinated by the European Environment Agency under the aegis of the European Commission;
- The Climate Change Adaptation Resource Center of EPA, the United States Environmental Protection Agency, whose projects fit in the goal of the organization which involves understanding and addressing climate change to protect human health and the environment;
- CoastAdapt, an Australian online platform the National Climate Change Adaptation Research Facility (NCCARF) of the Department of Environment and Energy of the Australian Government, that supports communities in adapting to coastal climate change impacts with tools, case studies, and data-driven guidance.

Each of the case studies was carried out in a different geographic area and is a strategy for adapting to the three different types of urban flooding: coastal, riverine and pluvial.

2.1 Community conversations: building engagement to mainstream climate adaptation in Mornington Peninsula Shire Council



The Mornington Peninsula Shire Council developed a comprehensive coastal adaptation initiative to address the increasing risks of flooding by prioritizing community engagement and education. Recognizing that public participation is crucial for effective adaptation, the Council facilitated "community conversations" where they shared scientific insights about climate change impacts while actively listening to residents' experiences and concerns. This participatory approach not only built trust but also empowered residents to take ownership of adaptation strategies, ensuring that the solutions were both practical and relevant to local needs.

As a result, the Council integrated community perspectives into flood risk management plans and established policies that reflect the unique characteristics of the coastal environment. Their initiatives included the development of green infrastructure solutions, the protection of natural ecosystems, and the implementation of flood mitigation strategies that addressed specific vulnerabilities. The Council also prioritized collaboration with stakeholders, such as environmental experts, local planners, and community groups, to create tailored solutions that promote long-term resilience.

Moreover, the project emphasized the importance of maintaining cultural and social ties to the environment, ensuring that natural spaces retain their ecological and community significance. Educational campaigns and public workshops strengthened the community's collective awareness of climate risks and the necessity of adaptive measures. By prioritizing transparency, inclusiveness, and cooperation, the Council laid the foundation for a sustainable and resilient coastal area, ready to face the ongoing challenges posed by climate change and extreme weather events.

This case study serves as a valuable example of how participatory governance and community-centric approaches are essential in addressing climate adaptation. It highlights the importance of integrating local knowledge, scientific research, and practical interventions to build coastal resilience, protect the environment, and support the social fabric of Mornington Peninsula's coastal communities.

Organization: The Mornington Peninsula Shire Council

Source: CoastAdapt, National Climate Change Adaptation Research Facility; 2016

Retrieved from: https://coastadapt.com.au/case-studies/community-conversations-building-engagement-mainstream-adaptation-mornington-peninsula

2.2 Smart growth along the riverfront helps manage stormwater in Iowa City, Iowa

Iowa City was among the hardest hit communities from the 2008 Iowa River floods with extensive flooding along the riverfront. In 2009, EPA and FEMA worked with the state organization, Rebuild Iowa, to identify policy options to accommodate growth in the Riverfront Crossings District and add green infrastructure and open space to reduce flooding. Subsequent EPA assistance on brownfields redevelopment and green infrastructure helped the city develop a master plan to rebuild the riverfront while protecting the environment, promoting equitable development, and helping address the challenges of climate change. The Riverfront Crossings Master Plan aims to create a resilient riverfront community park through using flood mitigation measures and stormwater best management practices to protect against future flooding.

The plan would relocate vulnerable properties and infrastructure away from the floodplain and guide future development away from the most vulnerable areas. The Riverfront Crossings Master Plan promotes green infrastructure, vegetated buffer zones and public spaces along rivers and streams to reduce flooding, runoff, and erosion. While this plan did not explicitly incorporate climate projections, it can help Iowa City better manage projected increases in extreme rainfall, stormwater runoff and flooding along the riverfront. The Riverfront Crossings Master Plan will help Iowa City transition a high risk flood prone area with critical community infrastructure into a public riverfront park that provides recreational amenities, and helps the community adapt to current and future high river flows.

Organization: EPA, FEMA and Rebuild Iowa

Source: EPA (United States Environmental Protection Agency) Climate Change Adaptation Resource center; 2024

Retrieved from: https://www.epa.gov/arc-x/smart-growth-along-riverfront-helps-manage-stormwater-iowa-city-iowa

2.3 The economics of managing heavy rains and stormwater in Copenhagen — The Cloudburst Management Plan, Denmark

Copenhagen experienced four major rainfall events in the period 2011-2016, resulting in severe damage that was expensive to repair. These types of events are expected to be more intense and more frequent as a result of climate change. The city has drawn out a Cloudburst Management Plan that aims to reduce the impacts of flooding due to heavy rains. The plan included an assessment of the costs of different measures (traditional versus new options including adaptation measures), the cost of the damage despite the measures and the resulting financial impact. The results showed that continuing to focus on traditional sewerage systems would result in a societal loss compared with the alternative solution. The alternative adaptation measures aim to store or drain excess water at ground level. The plan consists of four surface solutions as well as pipe-based solutions, including:

- stormwater roads and pipes that transport water towards lakes and the harbour, e.g. in the built-up area of central Copenhagen;
- retention roads for storing waters;
- retention areas to store very large water volumes, e.g. parks that could turn into lakes during flood events;
- green roads to detain and hold back water in smaller side streets.

The traditional sewerage system was estimated to cost DKK 20 billion (EUR 2.6 billion) compared with DKK 13 billion for the alternative solution. Despite capital investments in the traditional sewerage system, financial losses from flooding would remain high (net loss of DKK 4 billion). On the other hand, the chosen combined solution — consisting of expanding the sewer network and surface projects focusing on water retention and drainage — would result in a net saving of DKK 3 billion. The plan is also likely to contribute to a growth in property values, increased employment, upgrade of urban spaces and increased tax revenues. The Cloudburst Management Plan was developed during 2013 and includes 300 surface projects. The projects have started to be implemented at around 15 projects per year for the next 2030 years. The projects are prioritised according to the level of flood risk, a socio-economic assessment and the availability of co-benefits.

Organization: The City of Copenhagen Technical and Environmental Administration

Source: Climate-ADAPT, European Environment Agency; 2018

Retrieved from: https://climate-adapt.eea.europa.eu/en/about/climate-adapt-10-case-studies-online.pdf/@@download/file

4. Considerations from case studies

With the increasing trend of global warming, confirmed by the 2024 data, and the dangerous consequences this will have on water-related extreme weather events and their impact on urban areas, it is a top priority for cities to adapt to these foreboding phenomena. The discipline of urban planning is therefore central to integrating these predictions and the responses provided through climate change adaptation into current and future transformations of urban systems. In recent years, driven above all by the great transformations that have affected contemporary society and the territory, this discipline has been forced to deal with a great many new factors, emergencies and problems, whose complexity and problematic nature have favoured the development of a great many research paths, empirical explorations and experiments (Savino, 2023). In this transitioning scenario, climate change intersects with unresolved issues from the previous century—such as housing emergencies, territorial imbalances, peri-urban expansion, unused properties, territorial risk, and urban regeneration—while also amplifying challenges like conflicts over space, water, raw materials, and land (Cutini, 2023). It further intensifies economic dynamics, such as the extractives economy, growing inequalities, and shifts in production, consumption, and income distribution, profoundly affecting urban planning practices and professionals (Cecchini, 2023). In dealing with these complex issues, it is necessary to be "conscious and critical" (Busi, 2023) in analyzing the complexity of these phenomena, and it is imperative to adopt multi-disciplinary approaches, both in research and in real-world implementation (Aurigi, 2023). It is therefore necessary not to give in to overly specific concepts and entrust them with the entirety of the solution, but rather to evaluate in detail the economic and social feasibility, applicability, usefulness, or side effects in different contexts on a case-by-case basis (Monti, 2023).

In the case studies reported, contingent climate risk, whether past, present or projected, was the opportunity that allowed for the implementation of integrated, multi-sectoral strategies that constituted a multifaceted response aimed, while adapting urban space, at strengthening communities and improving their provision of services and quality of life.

In the case of Iowa City, river flooding allowed administrations to rethink a city space, proposing a multifunctional master plan with a high impact on the urban fabric. The project design incorporated several of the most widely accepted adaptation strategies, from green infrastructure to stormwater management practices. The plan also explicitly considered the promotion of equitable development, and reclaimed a brownfield, giving back to citizens a valuable urban space in direct contact with the river. This case study highlights how planning to increase resilience means on the one hand protecting economic properties while protecting and preserving the environment, and at the same time providing citizens with better urban social spaces.

No written plan, however, is sufficient to prepare the city and its residents for extreme weather events. The Mornington Peninsula Shire Council case study embodies some of the most important principles for developing resilience in communities. It is an inclusive adaptation initiative that, in addition to scientific planning, has included a major commitment to public participation, education and outreach. Participatory approaches are crucial to trigger bottom-up adaptation initiatives from citizens themselves and to improve citizen response to adaptation actions implemented by government. Finally, collaboration among stakeholders and participatory approaches help maintain and strengthen social and cultural ties to the land and environment, and their community relevance.

The case study of Copenhagen, focusing on urban flood risk, conveys a concept as fundamental as it is not obvious: it is more effective to invest comprehensively in adaptation than to spend repeatedly on actions to repair damage caused by extreme weather events. Indeed, with the Cloudburst Management Plan, the city has equipped itself with valuable gray-green mixed infrastructure, improving the livability of urban spaces but also ensuring a prompt response to increasingly frequent and disastrous heavy rain events. Indeed, there are numerous co-effects of the plan, including increased employment and upgrading of urban public spaces.

All three cases presented help to gain a deeper understanding of the potential of comprehensive planning at the city level that incorporates adaptation to flooding, whether riverine, storm or coastal, into urban planning for the benefit of the community.

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Author's profile

Stella Pennino

She is an engineer and Ph.D. student in Civil Systems Engineering at the Department of Civil, Building and Environmental Engineering of the University of Naples Federico II. Her research activities concern adaptation of the urban environment to climate change-related hazards and vulnerability measures, with the aim of mainstreaming sustainability in urban planning decision-making.

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REVIEW NOTES – Urban planning literature review

Exploring approaches and solutions for urban safety: a focus on the elderly

Tonia Stiuso

Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: tonia.stiuso@unina.it
ORCID: https://orcid.org/0009-0006-2474-8138

Abstract

Starting from the relationship between urban planning and mobility management, TeMA has gradually expanded the view of the covered topics, always remaining in the groove of rigorous scientific in-depth analysis. This section of the Journal, Review Notes, is the expression of continuously updating emerging topics concerning relationships between urban planning, mobility, and environment, through a collection of short scientific papers written by young researchers. The Review Notes are made of five parts. Each section examines a specific aspect of the broader information storage within the main interests of TeMA Journal. In particular, the Urban planning literature review section presents recent books and journals on selected topics and issues within the global scientific panorama.

For the third issue of TeMA magazine, volume 17th, this section provides a comprehensive overview of the challenges and solutions related to creating safe and accessible cities for older people. Various scientific sources and practical resources are used to illustrate effective approaches and innovative strategies. The contribution aims to examine these challenges and proposed solutions in the scientific literature, with a special focus on books, journal articles and reports. In particular, the difficulties related to the walkability of urban spaces will be analysed, with a focus on the perception of safety, not only in terms of the prevention of acts of violence, but also with regard to the safety of the physical conditions of streets and roads, as well as the risks arising from traffic.

Keywords

Urban safety; Urban planning; Literature review; Elderly; Walkability.

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1. Introduction

The safety of the elderly in urban areas is an issue of growing relevance, reflecting an increasingly pressing demographic and societal challenge globally (Callista et al., 2021). Increasing life expectancy and an ageing population confront cities with the need to create safer and more inclusive environments for a population that, despite the passing of years, wishes to continue to actively participate in the life of the urban community (UN-Habitat, 2020).

By 2030, three out of five people will live in cities, and it is estimated that 22% of the global population will be over 60 years old by 2050 (World Health Organisation, 2007). It is therefore becoming increasingly urgent to plan more accessible and safer cities for the elderly in order to reduce risks such as accidents, social isolation and vulnerability to crime (Cialdea, 2023). Most elderly people wish to remain in their homes and neighbourhoods, but many health and social care systems are unable to support alternative solutions (Gargiulo et al., 2021; Lord et al., 2018). Mobility is considered essential to ensure the independence and safety of older people, and the perception of safety plays a central role in this, wich is influenced by the urban system, which is based on the physical, functional and socioeconomic characteristics of the context (Gaglione et al., 2019). So, it is necessary adopting an integrated perspective that considers three areas of safety: personal safety, road safety and safety from crime (Won et al., 2016). Personal safety concerns the risk of falls, which are the leading cause of hospitalisation of the elderly in North America (Pillay et al., 2021). Lighting, safe paving and frequent benches reduce the perceived risk of falling. In fact, road safety is related to the risk of collisions, intersections and interactions with other users, which are increased in the elderly due to lower responsiveness and frailty (Kim, 2019). Finally, the perception of safety versus crime influences movement choices (Patil et al., 2024).

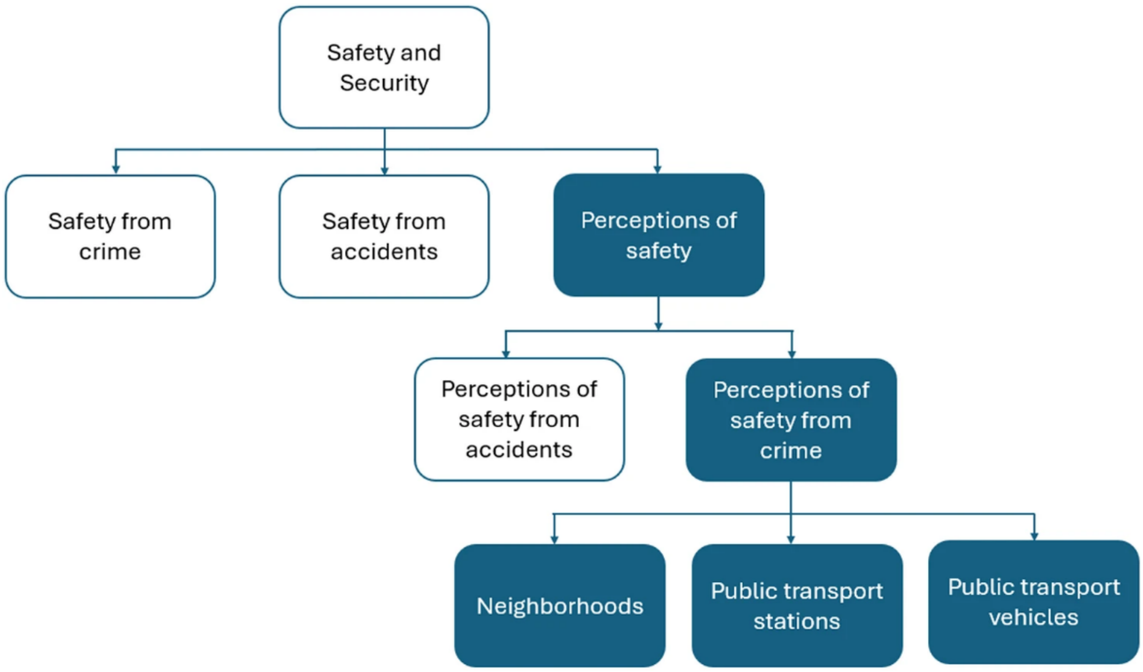


Fig.1 Source: The concepts of safety and security in urban transportation. (Masoumi & Fastenmeier, 2016)

The presence of high-density housing and services promotes mobility, while vandalism and incivility increase the sense of insecurity and the risk of avoiding certain areas (Marquet & Miralles-Guasch, 2015). Neighbourhood social cohesion contributes to improved physical and mental health (Ruijsbroek et al., 2016). Furthermore, the sense of insecurity among the elderly is particularly high, approaching that found in women. According to the ISTAT data, 26.9 per cent of men and 40.4 per cent of women aged 75 and over avoid going out alone at night out of fear, percentages well above those of younger age groups. Moreover, when they find themselves alone outside the home at night, the elderly show greater insecurity: 19.6 per cent of men and 38.7 per cent of women over 65 say they feel little or no security. The influence of fear of crime is also significant for this age group: 27.7 per cent of men and 35.8 per cent of women over 65 believe that crime affects their habits "a lot" or "quite a lot" (ISTAT, 2018).

2. Challenges and solutions developed at international level

Today's cities face a number of challenges related to the urban and public spaces for older people: mobility, accessibility to services, road safety, quality of street lighting and access to emergency services (Gargiulo et al., 2021). In recent years, many urban governments and international organisations have adopted an integrated approach, combining prevention and social support interventions and strategies (Callista et al., 2021). Many countries at the international level have prioritized accessibility and mobility in their urban planning, without focusing solely on safety measures (Gargiulo & Sgambati, 2022). The growth of the elderly population in most European countries poses a challenge to health and care systems, but also to urban safety for the elderly (Battarra et al., 2018). The perception of safety and the ability to move independently in public space are crucial elements in promoting active and healthy ageing, and local authorities are crucial in promoting interventions and solutions that ensure this (Mariotti et al., 2018; Arup, 2019). These interventions can include, for example, street lighting, efficient public transport, inclusive public spaces and the integration of assistive technologies that can support the mobility and perceived safety of older people (Masoumi & Fastenmeier, 2016; Papa et al., 2018). It is equally crucial to recognise the different needs of urban and rural areas in order to develop flexible and tailor-made solutions (Savino, 2023). Ensuring urban safety for older people in a rapidly changing demographic society means not only improving the physical accessibility of cities, but also promoting their well-being and social inclusion. Nations with ageing populations need to create urban environments that are conducive to healthy ageing, i.e. 'healthy ageing', and improve the quality of life of older people by integrating their well-being as a priority in urban development policies (Arup, 2015; Duc-Nghiem et al., 2016). Technology is playing an increasing role in urban safety for the elderly (Battarra, 2018), with the development of assistive tools such as GPS monitoring systems for the elderly with dementia and the use of smart cameras in high-density housing areas, in fact, some cities are experimenting with the use of sensors and wearable devices to monitor and protect older people living alone (University of Waterloo, 2022). Moreover, according to the Global AgeWatch Index 2014, the quality of life of older people varies widely according to local socio-economic conditions, and where older people benefit from strong public services, secure pensions and a safe environment, the perception of security is high (Cecchini, 2023). In contrast, in low-income states, often in Africa and Asia, the life experience of the elderly is completely different (Monti, 2023). Only a minority receive a pension and many work in informal sectors, without any structured social support (Global AgeWatch, 2014) and in these conditions, old age is often synonymous with insecurity and dependency, and the perception of stability is minimal (UN-Habitat, 2012). Social pensions, on the rise in many emerging countries, represent an important change, offering a minimum of economic security. This suggests that the perception of security in old age is closely linked not only to national wealth, but also to political commitment to ensure support for the elderly (Global AgeWatch, 2018).

2.1 New Urban Agenda (2016)

The New Urban Agenda addresses the issue of the safety and security perception of older people in urban space by recognising the importance of creating cities that respond to the specific needs of older people. In particular, the Agenda emphasises the need to adopt governance policies that include older people in decision-making processes related to urban and territorial development and this inclusion implies the promotion of fair and safe access to physical and social infrastructure, with a special focus on ensuring that these services are designed with the specific needs of older people in mind, both in terms of safety and accessibility. The agenda adopts an integrated approach, taking into account not only age, but also gender and socio-economic status. This approach is crucial to enable a better understanding of the context and conditions of older people. In addition, the specific vulnerabilities of the elderly female population are addressed, and it recognises that elderly women often experience a greater perception of insecurity in urban space because elderly women not only live longer, but often face more precarious living conditions, such as living alone or with limited economic resources (United Nation, 2016).

2.2 Sustainable Development Goals (2015)

In 2015, the United Nations promoted 17 goals for sustainable development, known as the Sustainable Development Goals (SDGs). These aim to safeguard the planet and the well-being of its inhabitants (Stiuso, 2024). They leverage a novel economic approach. The SDGs concerning gender equality and citizens' safety are three, specifically referring to their sub-goals:

- Goal 03: Ensure healthy lives and promote well-being for all at all ages:
  - Target 3.4 is a sub-goal to reduce premature mortality from non-communicable diseases and promote mental health.
  - Target 3.6 is a sub-goal to halve global deaths and injuries from road traffic accidents.
  - Target 3.8 aims to achieve universal health coverage.
- Goal 10: Reduce inequalities:
  - Target 10.3 is a sub-goal to ensure equal opportunities and reduce inequalities.
- Goal 11: Sustainable cities and communities:
  - Target 11.2 entails ensuring accessibility to transportation and safety on streets;
  - Target 11.7 aims to provide universal access to green and public spaces, making them accessible and safe for women, children, and the elderly.

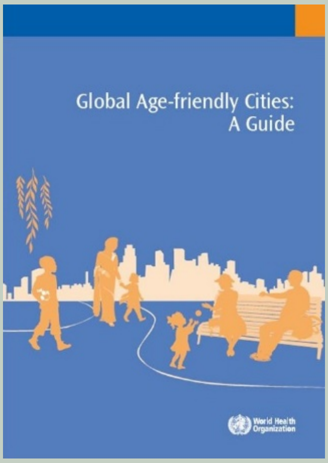
The 2030 agenda with the Sustainable Development Goals seeks to address the challenges that the elderly population will face in the future, facing increasingly populated cities and, ensuring not only access to health services and mobility infrastructure, but working on inclusion within public spaces, favouring the active participation of the elderly. It is also necessary to take into account the perception of safety in urban spaces, which for this vulnerable segment of the population is compromised by the fear of accidents, overcrowded streets and hard-to-access spaces, and only in some cases the fear of theft and muggings (Bennet, 2022).

3. Best practices

It is, therefore, a global challenge that simultaneously sees the ageing and urbanisation of the population and in this context, there have been many studies and programmes that have tried to address the problem, so that the inclusion, participation and security of this vulnerable segment of the population can be promoted. The good practices examined in this work provide an overview of the solutions adopted at international level to create more accessible and safe urban environments for older people. The issue of elderly safety in cities is mainly addressed in relation to aspects such as accessibility, mobility and health but with few direct references to real and perceived safety. Policies tend to focus on improving urban infrastructure, such as safe and accessible roads, efficient public transport systems and healthy environments that promote active ageing. However, the perceived safety of older people, their sense of vulnerability in the urban environment, is often only a secondary aspect of policies and the debate tends to focus on the physical characteristics of cities, rather than on the social factors that influence their emotional and psychological well-being. There has been a growing focus on large urban centres, since most of the issues to be addressed relate to the physical characteristics of the urban system, i.e. density of the built environment, poor lighting on pedestrian routes, and traffic, all of which contribute to the perceived insecurity of spaces.

This is also confirmed by an ISTAT study from 2018, which shows that fear increases in municipalities with more than 50,000 inhabitants.

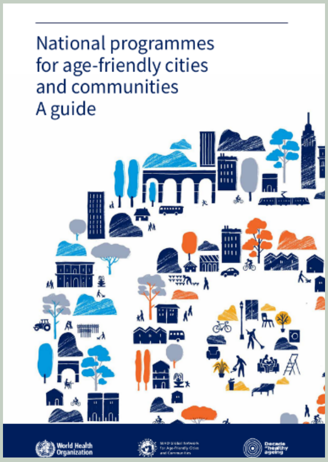
Global age-friendly cities: a guide - World Health Organization



Editor: World Health Organization
Pubblication year: 2007
ISBN code: 9789241547307
Retrieved from:
https://iris.who.int/handle/10665/43755

The document "Age-friendly Cities: A Guide", developed by the World Health Organization (WHO), responds to the global challenges of population ageing and urbanization, proposing a model of "age-friendly" cities, to improve the quality of life of older people and promote their health, participation and safety, making them a valuable resource for families, communities and the economy. To develop concrete criteria, WHO has involved groups of elderly people in 33 cities around the world. The feedback gathered was complemented by the views of caregivers and public and private service providers and led to the creation of a set of checklists to assess cities' suitability for older people.

National programmes for age-friendly cities and communities: A guide - World Health Organization



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The programme is part of the UN Decade for Healthy Ageing, which promotes actions to change the perception of safety in cities, ensure access to people-centred health services and foster environments that enable older people to live independently. Cities that are friendly to the elderly are designed to be inclusive and to support active ageing. The programme encourages older people to participate in urban planning, access essential services and create safe, healthy and accessible spaces for all.

Safety Programs for Older Adults - New York City Department of Transportation's (NYC DOT)

Retrieved from: https://www.nyc.gov/html/dot/html/about/olderadults.shtml

The Office of Safety Education and Outreach of the New York Department of Transportation (NYC DOT) Senior Road Safety Program is designed to support older adults in safe driving in the urban environment. Through a series of workshops and the publication of the Streetwise newsletter, the initiative provides practical advice and raises awareness on road safety, addressing specific dangers for older people. In addition, workshops organised by the NYC DOT discuss the principles of Vision Zero, an initiative focusing on safety, engineering and traffic control to improve road safety in general. The programme therefore not only provides information, but also works to listen to the concerns of older people, making the city safer and more accessible for them. In addition, NYC DOT has developed a Senior Pedestrian Zones map and 17-point action plan to reduce these risks, also collaborating with the NYPD for education and enforcement. Since 2009, the programme has made improvements in over 41 priority areas, with significant results in terms of reducing accidents, confirming the effectiveness of interventions aimed at making urban spaces safer and more inclusive for older people.

Ageing and the City: Making Urban Spaces Work for Older People - HelpAge International

Editor: Siôn Eryl Jones
Publisher: HelpAge International
Pubblication year: 2016
ISBN code: 978-1-910743-17-1

The report "Ageing and the City: Making Urban Spaces Work for Older People" examines the unique challenges to the quality of life of older people in cities caused by urbanization and aging of the world's population, especially in low- and middle-income countries. The report focuses on three key themes: inclusive use of urban spaces, healthy ageing and urban safety for older people. The report highlights the need to reduce traffic and promote safe, accessible public spaces that encourage physical activity and socialisation. The final recommendations of the report include creating inclusive urban spaces, enhancing public transport and integrating older people into safety planning.

Elderly on Track - EIT Urban Mobility

Retrieved from: https://www.eiturbanmobility.eu/projects/elderly-on-track/

The Elderly on Track (ElTra) project promoted active mobility among older people to improve their physical and mental health and foster social cohesion. Given the increase in the elderly population in Europe and the impact of the pandemic on the social networks of older people, the project aimed to reconnect older people with their communities and natural environment. Implemented in Rubí, in the Metropolitan Region of Barcelona, the project examined the relationship between the comfort and perception of older people and various physical and environmental parameters during their walks. Rubí is part of the World Health Organization's "Cities for the Elderly" programme and has developed a strategic plan for the elderly.

Shaping Ageing Cities: 10 European case studies - Arup, Help Age International, Intel and Systematica

Editor: Siôn Eryl Jones
Publisher: HelpAge International
Pubblication year: 2015
ISBN code: 978-1-910743-17-1
Retrieved from: https://ifa.ngo/publication/demographics/shaping-ageing-cities-10-european-case-studies/

Shaping Ageing Cities explores the social and physical structure of ten European cities to analyse the influence of ageing populations and urban growth on the lives of older people. The research, conducted by Arup, HelpAge International, Intel and Systematica, focuses on themes such as society, mobility, built and digital environments. With global ageing and increasing urbanization, the study aims to understand how to address these changes. The safety of older people is addressed through inclusive urban design, which aims to improve accessibility, safe mobility and the creation of protected public spaces, reducing social and physical vulnerability.

4. Conclusion

The ageing of the population and the increasing concentration of inhabitants in large cities lead to a focus on the consequences that these phenomena will have on all segments of the population (Busi, 2023). In particular, the elderly, who belong to the weakest segment of the population, together with women, children, etc. (Stiuso, 2024), are more vulnerable to the risks present both in terms of safety and crowding, thus compromising their perception of public space, which for this reason very often becomes inaccessible. Their perception of safety is influenced by the availability and accessibility of health services, the existence of infrastructures designed to facilitate mobility and the presence of spaces that reduce the risk of social isolation, The latter can increase feelings of insecurity and vulnerability. To increase the perceived safety of older people, it is necessary to invest in accessible infrastructure such as wide and well-maintained sidewalks, ramps, pedestrian traffic lights well visible and adapted to the needs of those who move with less agility. The literature emerges that, the perception of safety and safety in the urban environment can be influenced both by the absence of facilities and services and by the socio-economic situation. Indeed, older people with fewer resources live in neighbourhoods where transport and infrastructure are poor and less efficient. This situation leads to isolation and, due to fear of accidents and difficulty in calling for help, reduced freedom of movement. Thus, improving accessibility to public transport and creating safe and adequate housing would strengthen the sense of security and belonging, helping to reduce the sense of exclusion. Therefore, it becomes necessary to collect age-disaggregated data in order to know the needs and problems of all population groups and to be able to intervene in a targeted manner (Aurigi, 2023; Cutini, 2023), making urban space more inclusive and safer. Furthermore, it is necessary to take a holistic approach to understanding the entire urban system, since influences take into account many factors that change according to area, neighbourhood, time of day or population segment.

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Author's profile

Tonia Stiuso

She is an engineer, PhD student and research fellow at the Department of Civil, Building and Environmental Engineering at the University of Naples Federico II. Her research currently focuses on the theme of urban sustainability, in particular the study of gender inequalities and adaptation to climate change.