

SPECIAL SECTION

Development trends in urban systems

Łukasz SADOWSKI¹, Agnieszka A. TUBIS²^{*}, and Kristina ČIŽIŪNIENĖ³

¹ Wrocław University of Science and Technology, Faculty of Civil Engineering, Wrocław, Poland

² Wrocław University of Science and Technology, Faculty of Mechanical Engineering, Wrocław, Poland

³ Vilnius Gediminas Technical University, Faculty of Transport Engineering, Vilnius, Lithuania

1. INTRODUCTION

The last decade has been marked by rapid technological, industrial, social, and environmental transformations that have profoundly impacted the evolution of contemporary cities. Academic discourse has coalesced around three major research trends: the smart city, the sustainable city, and the resilient city. While originally explored independently, recent research increasingly demonstrates the interconnectedness and synergy among these approaches. A growing number of researchers and urban decision-makers now recognize that sustainable and resilient urban development is inseparable from the intelligent use of technology, sustainable infrastructure governance, and inclusive civic engagement.

The Bulletin of the Polish Academy of Sciences: Technical Sciences has a long-standing tradition of publishing Special Sections devoted to critical challenges in science and engineering. This current section builds upon that tradition, offering a comprehensive insight into the rapidly evolving field of urban systems. It is worth noting that the specific theme of urban development appears for the first time in a Special Section of BPASTS. However, it has previously been addressed in individual articles focusing on technological advancements and civil engineering. The rapid technological progress in the development of sustainable and resilient cities, along with the critical role of transportation and infrastructure in supporting the daily lives of residents, has created a growing need to devote more attention to these issues.

Despite the increasing academic interest in urban systems, the engineering and technological aspects of sustainable urban development remain underrepresented in mainstream technical science journals. This Special Section, “Development trends in urban systems”, aims to fill this gap by bringing together contributions that bridge engineering, digital technologies, and systems thinking in the context of complex urban environments.

The Special Section presents ten high-quality scientific contributions that reflect these dominant trends. Out of approximately 34 submissions, 10 articles were accepted following rigorous peer review, resulting in a 29.4% success rate.

The themes addressed in this section directly correspond to international research and policy agendas, such as the United Nations Sustainable Development Goal 11 (Sustainable Cities and Communities), the European Union’s mission on 100 climate-neutral and smart cities, and the New Urban Agenda adopted by UN-Habitat. These frameworks emphasize the need for systemic, data-driven, and inclusive approaches to urban transformation – principles well reflected in the articles presented here. A distinguishing feature of the included studies is their methodological innovation – from the use of artificial intelligence and data mining techniques to optimize infrastructure and transport systems, to the integration of empirical tools such as mobile eye-tracking and urban wind tunnel simulations. These diverse approaches reflect a growing emphasis on experimental validation and data-informed decision-making in urban research. The interdisciplinary nature of this Special Section is a deliberate response to the complexity of urban challenges. By combining insights from civil and mechanical engineering, urban studies, transport economics, data science, and environmental planning, the contributions illustrate how integrated research efforts can produce actionable knowledge for cities. Several articles offer clear practical implications, supporting urban planners, transport authorities, and infrastructure managers in making evidence-based decisions aimed at improving urban resilience, mobility efficiency, and residents’ quality of life.

Importantly, this Special Section is a direct result of the activities of the Urban Innovation Center (Centrum Innowacji Miejskich – CIM, <https://cim.pwr.edu.pl>), an interdisciplinary initiative based at the Wrocław University of Science and Technology. CIM brings together researchers and practitioners in the fields of architecture, engineering, technology, mobility, and social sciences, promoting urban innovations rooted in sustainability, inclusivity, and resilience. Several of the articles included here are outcomes of collaborative work within CIM’s thematic groups and partner projects.

*e-mail: agnieszka.tubis@pwr.edu.pl

Manuscript submitted 2025-08-09, revised 2025-08-09, initially accepted for publication 2025-08-19, published in November 2025.

Of particular note, selected articles are grounded in educational and research initiatives carried out under the U-Team project (<https://uteam.pwr.edu.pl/>) – an alliance of European universities aiming to develop joint research and education strategies in support of urban transformation. This international collaboration has contributed not only to the thematic depth of the section but also to the diversity of perspectives and methodological approaches.

This publication aims to present the main research challenges and results described in the articles accepted for the special section. To structure the review of included articles, we have grouped them into two key thematic areas:

1. Urban mobility and transport systems.
2. Urban infrastructure and building engineering.

Each article has been summarized with emphasis on research objectives, methodology, and key findings. The review concludes with a synthesis of common themes and final remarks on emerging directions in urban system research.

2. RESEARCH PRESENTED IN THE SPECIAL SECTION

The Special Section opens with a review article – “*Smart, sustainable, and resilient: The triple imperative of urban transport transformation*” by A.A. Tubis and Ł. Sadowski. The article explores the three foundational pillars driving the transformation of urban transport systems, grounded in the prevailing city development paradigms. It presents a comprehensive literature review focused on key research trends related to sustainable development, resilience, and smart cities, as well as their respective impacts on the evolution of urban transport systems. The study employs both systematic and narrative literature review methods. The findings confirm the strong influence of all three paradigms on urban mobility patterns. Within the discussion, the authors identify the principal challenges and outline future directions for the development of public transport systems in sustainable and resilient smart cities.

The article that did not directly align with any of the predefined research areas is the publication titled “*Enhancing mobile eye-tracking in extreme urban lighting conditions*” by M. Rusnak, Z. Koszewicz, F. Hackemer, I. Garaszczuk, A.T. Duchowski, and R. Karnicki. Despite its thematic distinctiveness, this contribution remains intricately connected to the smart city paradigm, particularly in the context of leveraging advanced technologies in urban research. Eye-tracking technology plays a significant role in supporting empirical studies focused on urban development, offering insights into human behavior, spatial perception, and the design of public spaces. However, the effectiveness of mobile eye-tracking in field conditions is highly dependent not only on the quality of the collected data but also on the comfort of study participants, which can influence measurement reliability and participant compliance. In response to these limitations, the objective of the study was to develop and test an innovative sunshade designed specifically for mobile eye-tracking devices. The proposed solution aimed to enhance data accuracy and participant comfort during outdoor urban studies. The results confirmed the effectiveness of the sunshade in enhancing data quality and participant com-

fort, thereby supporting the broader application of eye-tracking technologies in smart city research.

2.1. Urban mobility and transport systems

Urban mobility is a critical area of research in the context of sustainable city development. The development of sustainable cities necessitates innovative approaches to urban mobility. In large metropolitan areas, residents often travel significant distances multiple times a day, creating strong demand for efficient and effective transportation systems. At the same time, transport remains one of the primary contributors to environmental pollution. A critical challenge lies in developing low- and zero-emission transport systems that not only respond to mobility needs but also foster behavioral change among urban residents. This broader research context underpins several recent studies that contribute to the discourse on sustainable urban mobility.

In the article “*Digital maturity in tram systems: Model design and practical application*” by A.A. Tubis and M. Rydlewski, M. Skiba presents a novel digital maturity model specifically designed for tram systems (DMM-TRAM). Developed based on a literature review and case studies of real transport systems, the model comprises five dimensions divided into fifteen analytical areas. Expert interviews and stakeholder consultations supported the validation process. Applied to the tram system in Wrocław, the model proved to be an effective diagnostic and planning tool that reflects the unique characteristics of tram transport and meets the methodological criteria defined for digital maturity assessments.

Another significant contribution, titled “*Synthetic urban agglomeration modeling to enable big data applications in transportation systems*” by M. Zawodny and P. Mackiewicz, addresses the challenges of data scarcity in urban transport modeling. This study employed Monte Carlo simulations to generate synthetic urban agglomerations, comprising 100 transport analysis zones (TAZs), along with a corresponding travel demand matrix. By eliminating the biases present in urban areas and reducing research costs, this approach supports scalable, repeatable experiments and facilitates forward-looking research on smart cities that have yet to be developed.

Focusing on safety and user experience, the article “*Geographic Information System-based assessment of cyclist safety in urban environments*” by K. Romańczukiewicz and J. Górniak-Zimroz examines cyclist safety in Wrocław. Using accident data, traffic density indicators, and spatial data from Geographic Information Systems (GIS), the study identified high-risk areas requiring targeted improvements. The outcomes are intended to support urban planners and policymakers in fostering a safer, more sustainable transport environment with improved public safety outcomes.

The final article, “*Pedestrian wind comfort evaluation in large cities in Poland*” by A. Kocoń, R. Kłaput, A. Pistol, and A. Szela, explores the pedestrian experience in cities increasingly dominated by high-rise buildings. These structures can significantly affect wind conditions at street level. The study was conducted in two stages: field research combining interviews, surveys, and environmental measurements; and wind tunnel experiments. The findings emphasize, among others, that

warmer air improves wind comfort, pedestrians are more sensitive to gusty winds, and threshold wind speeds for sitting are lower than for walking, indicating that pedestrian wind comfort is closely tied to the nature of physical activity.

Together, these studies reflect a multidimensional approach to sustainable urban transport, addressing digital transformation, data-driven modeling, user safety, and environmental comfort. They highlight the complex interplay between technology, infrastructure, and human behavior in shaping the future of mobility in modern cities.

2.2. Urban infrastructure and building engineering

Sustainable and resilient cities are founded on reliable critical infrastructure, integrated green and blue urban systems, and buildings developed in line with sustainability principles. The challenges associated with designing and implementing sustainable urban infrastructure and real estate are addressed in Research Area 2, which encompasses five publications.

The topic of sustainable construction is discussed by A. Jakubczyk-Gańczyńska, A. Siemaszko, and M. Poltavets in *“Metaheuristic optimization for efficient construction management of building projects”*. This article aims to adapt metaheuristic optimization methods—particularly the harmony search algorithm (HSA) – to enhance smart construction management technologies. The study integrates biologically inspired systems with anticipatory thinking approaches. As a result, the authors propose an innovative modification of the HSA by incorporating system control models and systemology into the initialization phase. The findings demonstrate that the introduced modification improves the reliability of each element in the decision vector, enhances algorithmic performance, reduces the number of iterations required, and accelerates optimal decision-making processes in construction projects.

Support for decision-making in real estate investments is further explored in *“Decision tree models for technical due diligence in land development”* by M. Waga, E. Radziszewska-Zielina, and B. Sroka. The objective of this article is to present a decision-tree-based model designed to assist in evaluating land property acquisitions. In this context, decision trees are applied as tools supporting the technical due diligence (TDD) process, aimed at minimizing investment risks by identifying potential legal, technical, environmental, social, and economic constraints associated with development projects. The results confirm that decision trees can serve as a crucial instrument for investors, even in cases of limited training data, facilitating more informed decisions regarding land purchases.

Housing construction represents another critical element of urban infrastructure, directly influencing residents' quality of life. This theme is addressed by J. Iwko, A. Dobrowolska, A. Klaus-Rosińska, D. Kuchta, K. Pochybełko, D. Skorupka, and D. Dudziak-Gajowiak in *“Bridging stakeholder perspectives to improve residential construction quality in growing urban environments”*. The article seeks to identify key factors affecting quality across different phases of residential construction projects, based on the perspectives of internal stakeholders. The study involved 56 respondents representing various groups engaged in building projects. The results highlight a lack of

consensus regarding the factors that most significantly impact the perceived quality of residential developments.

The structural aspect of urban buildings is explored by T. Stęplowski in the article *“Funicular shaping method in the iterative design of reinforced concrete arches with variable cross-sections in urban areas”*. The primary aim of this article is to determine the optimal shape of reinforced concrete arches with variable cross-sections using multi-criteria optimization, targeting the reduction of tensile stress, structural deflection, and material volume. The methodology combines traditional graphical statics with advanced nonlinear finite element analysis. The findings confirm that this approach contributes to the development of sustainable urban infrastructure through the efficient use of construction materials.

An often overlooked but essential component of urban infrastructure is the sewer network, which services both residential and industrial zones. As such, the publication *“Sustainable rehabilitation of urban sewers using in-situ lining techniques”* by T. Abel was also included in this special section. This article analyzes how imperfections in underground pipelines affect their structural integrity and evaluates the applicability of cured-in-place pipe (CIPP) technology as an eco-friendly solution for the rehabilitation of aging and damaged sewer systems. The results confirm that the CIPP method significantly increases the circumferential stiffness of the composite system while contributing to the protection of soil, groundwater, and surface water resources.

Together, these studies offer a comprehensive view of the multifaceted efforts required to build sustainable and resilient urban infrastructure – from construction technologies and structural design to environmental engineering and investment risk mitigation.

3. CONCLUDING REMARKS

The idea for this Special Section emerged from research activities within the Urban Innovation Center and the U-Team project, which brings together scholars from various disciplines to tackle the challenges of urban transformation. The articles presented in this Special Section provide valuable insight into the contemporary challenges faced by urban systems and highlight the role of research in shaping the cities of the future. By integrating the perspectives of sustainable development, technological innovation, and urban resilience, the contributions emphasize that holistic and interdisciplinary approaches are essential to addressing complex urban problems.

The diversity of the topics covered, ranging from mobility and infrastructure to safety and quality of life, reflects the broad scope of current urban research and confirms the need for collaboration across academic, civic, and industrial sectors. The Special Section not only documents innovative scientific work but also exemplifies the outcomes of institutional initiatives such as the Urban Innovation Center and the U-Team project, which aim to bridge the gap between theory and urban practice.

This Special Section continues the long-standing tradition of thematic issues published in the Bulletin of the Polish Academy of Sciences: Technical Sciences. Recent Special Sections ad-

dressed topics such as “Lightweight structures in civil engineering” (Vol. 71(1), 2023), “Structural control and health monitoring” (Vol. 71(1), 2023), and “IIoT and AI-based optimization” (Vol. 71(6), 2023). We hope this collection will likewise become a valuable and lasting reference for future research. We would also like this Special Section to serve as an inspiration for other research groups and to encourage additional authors to contribute to future sections dedicated to urban development trends.

We hope that the presented research will serve as both inspiration and a point of reference for scholars, practitioners, and policymakers working towards smarter, more inclusive, and resilient cities. Selected articles offer concrete implementation potential in fields such as public transport optimization, spatial planning, and digital infrastructure management. Future research in this field should further explore the role of digital twins, urban-scale simulations, and citizen-generated data in shaping urban strategies. Additional attention could be given

to governance frameworks and financing models that facilitate the large-scale deployment of the proposed solutions.

All submitted papers underwent a rigorous peer-review process, typically involving two to four independent reviewers, most of whom were international experts in the field. This ensured a high scientific standard of the published contributions.

ACKNOWLEDGEMENTS

Guest Editors would like to express their sincere gratitude to all authors of papers included in this Special Section. We are also thankful to all reviewers whose efforts and valuable comments significantly contributed to improving the quality of the papers. We deeply appreciate the support of the Editorial Board for providing the opportunity to present this Special Section. The high quality of the published papers reflects the dedication and professionalism of both the authors and reviewers.



Łukasz Sadowski is a Professor of Civil Engineering at the Wrocław University of Science and Technology. He currently serves as Vice-Dean for Research and Scientific Cooperation at the Faculty of Civil and Environmental Engineering. In addition, he heads the Department of Materials Engineering and Construction Processes and is Director of the Urban Innovation Center – a cross-disciplinary initiative connecting academia, industry, and local governments to drive innovation in sustainable urban development.

Driven by a research-oriented mindset, his work bridges theoretical insight and engineering practice, with a focus on building materials, surface engineering, nondestructive testing, sustainable construction, and AI-supported diagnostics. He is particularly passionate about reducing the environmental footprint of the construction industry by rethinking material use and applying the principles of the circular economy.

Łukasz completed his MSc, PhD, and DSc, all with distinction, at WUST and became a Full Professor in 2023. He has been recognized with fellowships from the Foundation for Polish Science and the Ministry of Science and Higher Education. In 2021, he received the Waclaw Żenczykowski Medal for outstanding scientific and technical contributions to civil engineering.

He has authored or co-authored over 300 scientific publications, including more than 140 in JCR-indexed journals, and holds four patents. His ongoing projects focus on recycled concrete, smart diagnostics, and cement – polymer composites.

His current research explores the development of intelligent concrete technologies based on industrial CO₂-enriched copper slag to create low-emission construction materials in collaboration with TU Delft.

Łukasz has held international research fellowships in the UK, France, Germany, Portugal, and Australia. He is an experienced reviewer and Section Editor for Civil Engineering in the Bulletin of the Polish Academy of Sciences: Technical Sciences and serves on the editorial boards of Structural Concrete, Journal of Structural Design and Construction Practice, The Journal of Adhesion, and Journal of Materials: Design and Applications.

He is Vice-Chair of the Polish Young Academy of the Polish Academy of Sciences and actively participates in scientific committees and organizations, including RILEM and the Polish Union of Construction Engineers and Technicians.

At his core, Łukasz views civil engineering as a platform for innovation where science meets sustainability, and smart thinking transforms into smarter infrastructure.



Agnieszka Tubis holds a master's degree and a Ph.D. in Organization and Management with a specialization in Logistics from the Wrocław University of Economics. She was awarded the degree of Doctor Habilitation (postdoctoral degree) in the discipline of Transport at Warsaw University of Technology. She is currently employed as a Professor at the Department of Maintenance and Operation of Technical Systems, Wrocław University of Science and Technology. In addition, she holds the position of Advisor to the Vice-Rector for Digital Development at WUST.

She is the author and co-author of over 180 scientific publications. She conducts research focused on the design and improvement of logistics processes, risk assessment in cyber-socio-technical systems, and building the resilience of supply chains. She is also an expert in sustainable city logistics systems, sustainable transport, and operational risk management in transport companies. Her current research focuses on the design and management of resilient and digitalized urban transport systems aimed at sustainable development and improving the quality of life of residents. In pursuit of this objective, she develops assessment methods and tools that support the decision-making processes of urban system stakeholders.

She is a long-term trainer and business advisor in Polish production, trade, and service companies. She has completed seven business internships and worked in urban and regional passenger transport companies, freight transport operators, production companies, and a company that develops IT transport solutions. She participated in 18 R&D projects (national and international), which concerned, among others, risk management and the improvement of transport and logistics systems.

She currently serves as President of the Polish Logistics Society and Vice-President of the Polish Maintenance Society. She represents Poland in the General Assembly of the European Federation of National Maintenance Societies (EFNMS) and is a board member of the European Safety, Reliability & Data Association (ESReDA). From 2020 to 2024, she was an expert in the Logistics and Transport Processes Section of the Transport Committee at the Polish Academy of Sciences. Currently, she is a member of the Committee on Civil and Mechanical Engineering of the Wrocław Division of the Polish Academy of Sciences. She is a member of the Scientific Councils of two research centers at the Wrocław University of Science and Technology – the Urban Innovation Center and the Sustainable Development and Climate Protection Center.



Kristina Čižiūnienė, Associate Professor, was awarded the Doctor's degree in Social Sciences and Economics. Ms. Kristina Čižiūnienė has been working as an academic staff member for 14 years at the Department of Logistics and Transport Management, Faculty of Transport Engineering, Vilnius Gediminas Technical University, and her total teaching experience is 21 years. She holds an excellent track record as an expert in lecturing and training specialists in transport, logistics, service logistics, human resource management, organization of industrial practices, and marketing in logistics. She has been a team member and senior expert on the project. VP2-1.4-ŪM-05-V-01-006 "Promoting innovative business establishment". She has gained solid knowledge and experience in preparing and developing teaching materials in English for the study programs and modules taught at the Faculty of Transport Engineering. Experience mostly related to this particular application is the following:

1. 2021–2023 project "Provision of context-aware intelligent services for operational cargo transportation management (KAİPTOKSTV), no. 01.2.2-LMT-K-718-03-0030.2. 2014–2015 project No. VP2-1.4-ŪM-05-V-01-006".

2. Ms. Kristina Čižiūnienė was a senior expert of the project "Promoting innovative business establishment" and was responsible for business development, patent analysis, and legal matters. The senior expert of the project ensures the planning, coordination, allocation of functions, and performance monitoring; the project work involves contacting the students throughout events and consultations, and collaboration with business partners.

3. 2012–2013. Project "ATVERK" was organized by the Lithuanian Engineering Industry Association, LINPRA. From 20.02.2012 till 26.03.2012. Ms. Kristina Čižiūnienė was a project Manager from 26.03.2012 – mentor. During the project, the following training was organized in Lithuania and Finland: Training on non-formal development of entrepreneurship based on the model Demol. Additionally, Ms. K. Čižiūnienė was responsible for: coordination; contacts; communications and implementation; organization and consulting activities with Lithuanian institutions of higher education, students, and legal persons.

Her areas of scientific and research activities are connected to transport, logistics, management, economics, human resources, marketing, and transport engineering.

Kristina Čižiūnienė is an author and co-author of over 100 scientific publications indexed in the Web of Science, Scopus, Ebsco, and other databases, as well as several monographs and handbooks for students.