

Smart, sustainable, and resilient: The triple imperative of urban transport transformation

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Abstract. Among the major trends currently reshaping the organization and functioning of modern cities are the concepts of sustainable development, digital transformation, and urban resilience. The rapid advancement of these concepts in recent years is reflected in the growing volume of scientific publications across all three areas. This article aims to analyze these key research trends related to the development of contemporary cities and to identify their impact on urban public transport systems, which constitute a critical element of citizen services. Two complementary literature review methods were applied: a systematic review and a narrative review. The systematic review was designed to identify publications associated with each of the analyzed research trends, while the narrative review provided the basis for evaluating the influence of these developmental concepts on public transport systems in cities. The findings indicate strong interconnections between the notions of smart cities and sustainable cities, while the concept of resilience, as the most recent approach, draws upon selected assumptions of both. All three concepts exert a considerable influence on urban mobility. Sustainable development alters residents' transport behaviors, smart mobility enhances the implementation and efficiency of transport processes, and well-functioning public transport systems play a crucial role in urban crisis management. Based on the analysis of research trends in public transport and ongoing technological transformations, the study identifies the main challenges and potential directions for the future development of urban public transport.

Keywords: literature review; challenges; developments; research trends; city.

1. INTRODUCTION

For several decades, there has been a strong urbanization trend resulting in more than half of the world's population already located in urbanized areas, and according to United Nations projections, this amount will increase to two-thirds of the population by 2050 [1]. The continued growth of this trend means that cities face increasing challenges in terms of transport, urban infrastructure, servicing residents, and air and urban space pollution. The observed rapid urban growth also creates social and economic inequalities among residents, who do not always have equal access to the benefits of urban living [2]. Therefore, contemporary cities should pursue sustainable and inclusive urban development strategies, including improved public transport, the promotion of energy-efficient buildings and green spaces, and investment in social services to improve the residents' comfort of living [1].

An analysis of publications addressing the transformations occurring in the development of contemporary cities reveals three predominant conceptual and research trends: the smart city, the sustainable city, and the resilient city. Literature offers numerous definitions for each of these concepts; therefore, it is valuable, in the introduction, to present selected compilations that synthesize their key elements. These integrated definitions provide a coherent framework for understanding the scope and interconnections of the three concepts, serving as a foundation

for the subsequent analysis of their role in shaping future urban mobility systems.

- A sustainable city is a complex and dynamic entity that integrates environmental, social, economic, and governance dimensions to create a resilient, inclusive, and productive urban environment. It aims to provide a high quality of life for its inhabitants while ensuring the preservation and efficient use of resources for future generations [3–5].
- A smart city is an integrated urban development model that applies data-driven and technology-enabled solutions – such as IoT, big data, and machine learning – to improve the efficiency, sustainability, and quality of urban services, fostering active collaboration between public authorities, private stakeholders, and citizens [6–8].
- A resilient city is an urban system capable of withstanding, adapting to, and recovering from economic, social, and environmental shocks by combining sustainability, adaptability, and inclusivity with robust risk management and collaborative, multidisciplinary governance [9–11].

These concepts stem from the ongoing environmental changes and respond to the changing conditions of society, industry, and government. Of particular relevance to their development are phenomena such as digital transformation, climate change, and emerging threats (e.g., digital, terrorist, transport, and health). It is worth noting, however, that while the initial work shows a clear focus of researchers' attention on each of these concepts separately, more recent publications indicate the need to integrate them [12–14]. As a result, these concepts are now not being developed as separate 'silos' but are integrating their potential to create increasingly better living conditions for their inhabitants.

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This article aims to present the highlighted three main research trends related to the development of contemporary cities and their impact on urban public transport systems, which are critical in serving residents. The results presented in this article are primarily the result of a literature survey based on two research methods and a process of inference regarding the selected common research trend of urban mobility. As such, the main contribution of this article should be identified as:

- The development of the smart, sustainable, and resilient city's characteristics represents a compression of knowledge concerning these three concepts.
- Identifying the impact of the concepts studied on public transport systems based on literature research.
- Defining challenges and further developments for public transport systems in sustainable, resilient, and smart cities.

In addition to the introduction, the article structure includes Section 2, which presents the research methodology. Section 3 then describes the three development trends analyzed based on literature research. Section 4 indicates the impact of these concepts on the development of urban public transport systems and identifies the main research trends. The literature analysis made it possible to formulate the main challenges and recommended directions for further developments, which are presented as part of the discussion described in Section 5. The conclusions formulated are described in Section 6 (Fig. 1).

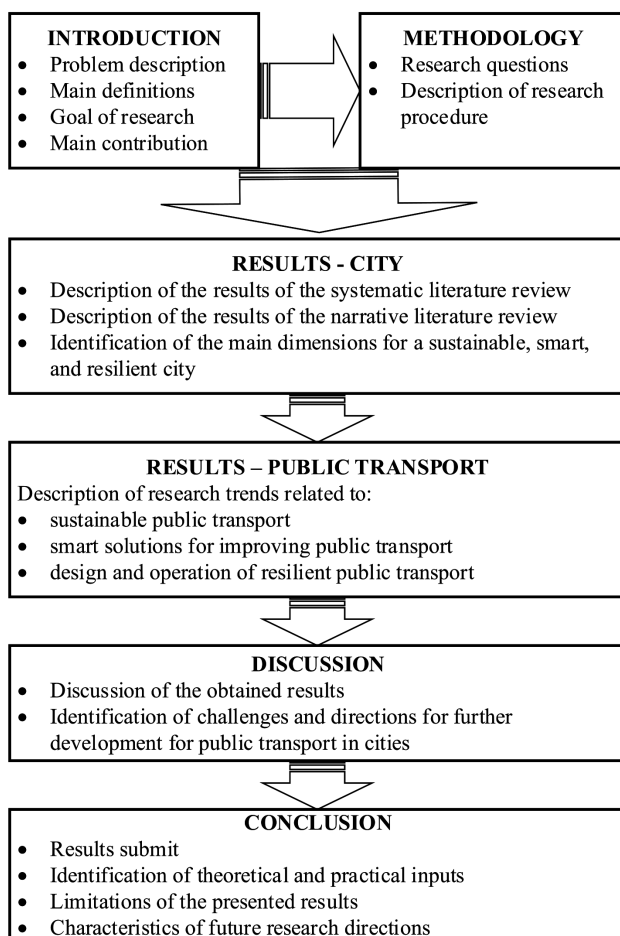


Fig. 1. Article structure

2. METHODOLOGY

The research conducted was theoretical. They aimed to prepare a characterization of the research space, describing the main development trends of contemporary cities and their impact on changes introduced in public transport. The research was limited to three basic development concepts: sustainability, digital transformation, and building resilience.

Accordingly, three research questions were posed:

- RQ1: What research trends are currently occurring within the sustainable/smart/resilient city concept?
- RQ2: How do the concepts being researched influence the transformation of public transport?
- RQ3: What challenges will shape the further transformation of urban public transport?

Answering these questions requires research following the research procedure outlined in Fig. 2.

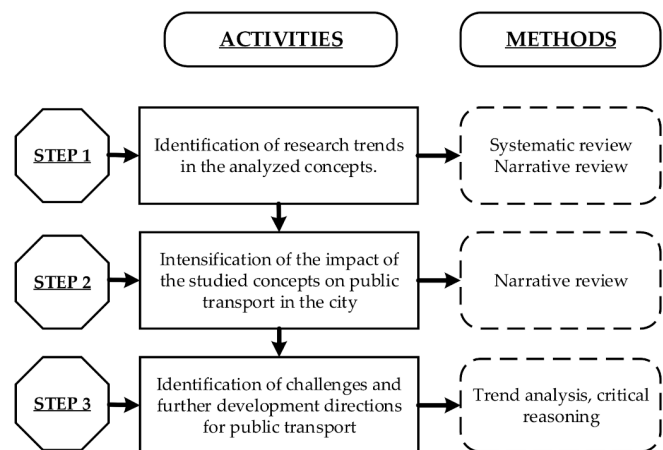


Fig. 2. Research procedure

The Scopus database was used for research due to its numerous document collections compared to the WoS database regarding the concepts analyzed. Two methods of literature review – a systematic review and a narrative review – were used in the research on leading urban development concepts.

The systematic review aimed to investigate the development of each research concept considered in this study. Beyond mapping their development, the review also enabled the identification of prevailing research trends, which subsequently provided the conceptual framework for the narrative review. The systematic review was guided by a set of core keywords, as outlined in Section 3.1, ensuring the retrieval of literature most relevant to the scope of each concept. These trends were distilled primarily from review papers and the most frequently cited contributions within each dataset, reflecting both the current state of the field and its scholarly influence.

Building on this foundation, the narrative review examined curated sets of documents corresponding to each of the three research concepts. The primary objective of this stage was to identify the key transformation dimensions inherent to each concept. This analytical process facilitated the organization of research trends into coherent thematic domains and, through comparative

synthesis, revealed shared analytical dimensions across the concepts. Among these, mobility emerged as a recurring and central theme, occupying a pivotal position in the overall analysis.

A narrative literature review was used to investigate the impact of the development concepts on urban public transport systems. Documents categorized under mobility-related dimensions were adopted for analysis, which was then supplemented by additional articles identified in earlier studies. All papers used are indexed in the Scopus database.

Based on the conclusions drawn from the literature review and the characterized research trends, the next step involved identifying future challenges and directions for further research on the development of public transport systems that meet the requirements of sustainable, resilient, and smart cities.

3. RESULTS – CITY

3.1. Systematic literature review

The substantial number of publications in global scientific databases evidences the importance of the three concepts analyzed related to urban transformation. A growing development trend can be seen in the last decade, as confirmed by the systematic review results. The numerical results from this literature review for the three urban research trends analyzed are presented in Table 1.

Table 1

Summary of the systematic literature review

Search results	Sustainable city	Smart city	Resilient city
Total number of publications	80 856	68 976	8 351
Limitation of publications to the years 2000–2024	76 548	67 155	7 678
Limitations to reviewing papers	2 688	1 716	382

Concerning the sustainable city concept, after restricting the number of publications to the period 2000–2024, a clear upward trend can be seen from around 200 papers per year between 2000 and 2003, through a steady increase to 1190 in 2010, 6530 in 2020, up to 12 303 in 2024. Restricting the collection of publications by document type and to the keyword ‘Literature Review’, 211 documents were taken for analysis. Researchers from China, Australia, and the United Kingdom have produced the most significant literature reviews on sustainable development. The main subject areas targeted by the reviews included environmental science (29%), social sciences 23.6%, energy 17.5%, and computer science 12.2%.

The growth of the smart city concept is no longer as regular as that of the sustainable city. Restricting the analysis to the period 2000–2024 shows that in the initial analysis period, the number of annual publications was insignificant and did not exceed 100 papers per year. It has only been since 2009 that a slow increase in research interest in this area has been observed. The first significant boost is recorded between 2012 (472 papers) and

2013 (806 papers). The most significant increase in the number of publications is registered between 2016 (2582 papers) and 2017 (5339 papers). This trend continues; as of 2019, the annual number of publications exceeded 7000 documents (8202 in 2024). Similarly to the sustainable city concept, publications were limited to documents in which ‘Literature Review’ appeared among the keywords. On this basis, 190 documents were accepted for analysis. The most significant literature reviews in this area came from Australia, India, Italy, and the UK. However, the main subject areas reviewed were related to computer science (19.6%), social sciences (14.9%), engineering (14.5%), environmental (12.7%), and energy (12.3%).

The resilient city is the ‘youngest’ concept related to the transformation of modern cities, as evidenced by the systematic literature review results - the smallest number of papers identified. Until 2008, a maximum of a dozen or so publications per year appeared. Only in 2013 did the annual published research results exceed 100 papers. Since that year, there has also been an increase in interest in this topic. It has only been since 2022 that more than 1000 papers have been published annually. Of the papers analyzed, only 382 papers were registered for review. Most of these were prepared by researchers from the United States, China, and the United Kingdom. These publications fall primarily into the subject areas: environmental science (21.9%), social science (20.2%), engineering (13.3%), and energy (10.5%).

3.2. Narrative literature review

Based on a systematic literature review, the main research trends associated with each of the three urban concepts analyzed were identified. Then, based on the selected documents, the dimensions of the transformation realized within each of the concepts studied were characterized.

The most important concept at present is sustainable urban development. The concept of sustainability is based on three pillars: social, economic, and environmental. Therefore, sustainability research focuses on creating cities that enable all their inhabitants to meet their own needs now and improve their well-being without harming the environment or threatening the living conditions of others today and in the future [15]. Characteristics for the leading trend related to the sustainable city are shown in Table 2.

Despite the ever-growing number of studies and publications on the smart city, there is still no clear definition of the concept. In most cases, the attention of researchers has focused on the role of technology in urban development, and for this reason, alternative terms for the concept can be found in the literature, such as digital cities, intelligent cities, wired cities, information cities, ubiquitous cities, and sensing cities [37]. In this regard, many researchers emphasize that the concept is a vision of urban development that aims to integrate multiple IT solutions to manage city resources better [38]. Increasingly, however, the research for this area emphasizes sustainability, efficiency, and quality of life, with technology being only a tool for implementing projects related to this technology [39]. Therefore, the literature review indicates that technology is the mainstream research related to the smart city concept and plays a critical role. However, the dimensions of the smart city described in the lit-

Table 2

Dimensions of the sustainable city

Dimension	Research trends	Example sources
Resource management	• Resource efficiency (e.g., water, energy) • Use of renewable energy • Reverse logistics and waste minimization	[16, 17]
Mobility	• Promotion of public, low-carbon, and accessible transport • Reduction of car traffic in city centers • Low- and zero-emission zones, development of pedestrian zones • Development of cycling and scooter infrastructure • Implementation of sharing economy models (car-sharing, bike-sharing)	[18–21]
Green infrastructure	• Development of parks, urban gardens, green roofs, and walls • Protection of green areas and biodiversity • Creation of green corridors for animals	[22–24]
Compact city	• 15-minute cities • Dense, well-planned development	[25–27]
Technology	• Using technology to manage traffic, energy, and water • Developing systems for monitoring air quality, noise, and pollution • Digital public services	[28–30]
Social inclusiveness and participation	• Involving residents in decision-making processes concerning cities • Taking care of social and cultural diversity • Access to education, health, and public space for all social groups	[31–33]
Adaptation to climate change	• Developing infrastructure that strengthens resistance to floods, heat, and droughts • Water retention • Climate neutrality strategies	[34–36]

erature relate primarily to its use for defined urban development objectives. In line with this, five smart city dimensions have been formulated and are presented in Table 3.

The greatest challenge of the coming years is balancing climate change, building, and managing urban resilience [59, 60]. Urban resilience refers to the ability of a city and its systems to adapt to dynamic changes regarding social, economic, environmental, and political situations [61]. The concept also integrates different approaches to preparing cities for and responding to emerging disasters and extreme events [62]. Therefore, one of the key issues addressed in research in this area is the impact of climate change on critical urban infrastructures and urban

Table 3

Dimensions of the smart city

Dimension	Research trends	Example sources
Smart environment	• Smart energy grids – monitor and manage energy consumption • Smart waste management • Quality of air, water • Smart green spaces management – e.g., monitoring of city trees • Emission monitoring	[29, 40–42]
Smart living	• Public safety • Healthcare • Smart education • Smart tourism	[43–46]
Smart mobility	• Intelligent transportation systems • Internet of Vehicles • Smart traffic management • Vehicle tracking • Autonomous vehicles • AI and machine learning algorithms to navigate and reduce the risk of accidents • Digital platforms to connect passengers with drivers	[30, 47–49]
Smart infrastructure	• Smart building • Smart home • Smart infrastructure management • Smart maintenance	[50–53]
Smart citizen and government	• Involvement of residents in the development of the city • Communication and exchange of data between the government, stakeholders, and residents • Services for residents • Sharing resources	[54–58]

planning [63]. However, resilience is also assessed in terms of adapting critical infrastructure networks to changing conditions and risks, organizational resilience, economic resilience, and community resilience [59].

All the research trends described above are complementary. Cities are developing sustainably and building resilience based on new technological solutions from the smart city field. The sustainable development goals call for inclusive, safe, sustainable, and resilient cities [63]. Thus, it can be concluded that the further development of these three concepts is interdependent, meaning that the applicable research streams are intertwined. This can even be seen in their defined dimensions, where the strands of development related to environment, mobility, infrastructure, economics, and society are repeated. One of the critical research areas is mobility, particularly the development of transport systems that provide a sustainable, reliable, and comfortable way for residents to travel. Therefore, the following section analyzes the impact of the studied urban development trends on public transport systems.

Table 4
Dimensions of the resilient city

Dimension	Research trends	Example sources
Environmental resilience	- Resilience of cities to natural hazards (floods, droughts, fires, earthquakes, heat) - Adaptation of infrastructure - Land reclamation	[64–67]
Social resilient	- Social capital - Vulnerability to epidemics and crises - Elimination of social inequality - Subjective poverty - Risk and vulnerability to a shortage of urban resources	[68–71]
Infrastructure resilience	- Integration of infrastructure in cities - External threats to urban infrastructure - Urban space planning - Public transport - Blue-Green Infrastructure - Early warning systems	[72–75]
Economic resilience	- Regional integration - Human capital - Economic disparities - Diversification of the local economy	[76–78]
Government and risk management	- Crisis scenarios - Adaptation policies - Risk monitoring and assessment tools - Risk management models	[59, 67, 79]

4. RESULTS – PUBLIC TRANSPORT

4.1. Sustainable public transport

Transport systems are a critical element of large cities, as they determine the mobility of their inhabitants and the level of emissions and noise in urban space. For this reason, the concept of sustainable development very strongly promotes a model of urban mobility based on public transport. Velasco and Gerike [80] even point out that public transport is one of the pillars of sustainable transport systems. They base their opinion on the fact that public transport (1) provides all residents with access to appropriate destinations and (2) is the most efficient in terms of cost, environmental impact, and space consumption.

The main research trends related to sustainable public transport include:

1. Research on reducing emissions and improving air quality in cities (examples of research [80–83]).

A critical problem of modern cities is the excessive share of individual transport, the leading emitter of air pollution in urban areas. For this reason, promoting public transport development is recognized as a leading strategy for improving

urban air quality, an important indicator of urban environmental quality. Policies and strategies for developing public transport, making it more comfortable to use, and encouraging residents to change their transport behavior are important directions for sustainable urban development.

2. Research on the integration of public transport and active mobility (micromobility) of citizens (example studies [84–87]). Active mobility of residents, involving walking or using personal transport devices (bicycles, scooters) is a crucial element of sustainable mobility. Therefore, it is necessary to develop infrastructure solutions and movement patterns for urban residents that promote active mobility in combination with public transport systems. Research indicates that integrating personal transport devices into public transport systems can increase accessibility and lead to changes in the transport behavior of residents, who will be more inclined to move away from car use.

3. Decarbonization of public transport (example studies [88–91]).

The development of public transport must reflect current trends related to sustainable cities. Therefore, an important research area is the need to decarbonize transport systems by investing in low- and zero-emission solutions, among other things. Therefore, much research is concerned with the electrification of bus fleets, the development of green energy tram systems, hydrogen solutions for public transport, and life-cycle cost models for these investments.

4. Research on transport equity through social accessibility (example studies [92–94]).

Public transport is a transport system that provides opportunities for residents of all social strata to move within the urban area. Social equity in public transport planning reduces the risk of social exclusion, which is understood as a limitation of the ability to perform daily activities at a normal level. The research examines issues relating to increasing the number of local transport hubs, the demand for travel by public transport, and the formulation of policies to create a more equitable transport system.

4.2. Smart public transport

Public transport is currently facing many challenges due to the changing needs of city dwellers. The most important challenges include ensuring the reliability of connections, comfort, safety, and timeliness of journeys. Cities are increasingly implementing various technological solutions to improve the quality and safety of the travel process to meet these challenges. The main research trends related to the application of digital technologies in improving public transport systems include:

1. Research on the development and implementation of intelligent transport systems (example studies [49, 95–97]).

The development of intelligent transport systems (ITS) is a significant research direction related to smart mobility. ITS encompasses a variety of applications that support the management of safe and efficient transport solutions, from traffic management to autonomous vehicles. Research in this area focuses on applying various technologies such as the Internet of Things, GPS systems, artificial intelligence, machine

learning, and digital twins to reduce congestion, minimize delays, and improve the effectiveness and efficiency of public transport systems. The most popular research in recent years has been applying big data and artificial intelligence to improve IT systems. It should be noted that the authors of published articles focus on issues relating to dynamic traffic signal control, fleet management, predictive analytics, optimizing operations, implementing smart schedules and smart stops, and improving the overall efficiency of the public transport network.

2. Mobility as a service – MaaS (example studies [98–100]).

MaaS is a digital solution-based service concept that aims to solve decision-making problems related to urban mobility. As such, research in this area is primarily concerned with the integration of different modes of transport in a single digital ecosystem, the ability to handle ticketing, reservations, and payments through a single app, optimization of door-to-door travel, personalization of journeys based on user preferences, and real-time and cross-system data. The collaborative aspects between transport system stakeholders and, above all, the possibility for them to communicate with each other using different digital platforms to improve the MaaS development process are also becoming a critical issue.

3. Electrification and intelligent energy management (example studies [88, 101]).

The requirements for implementing low- and zero-emission solutions in public transport systems are forcing changes regarding the management of the vehicle fleet and the power system. Electric vehicles require modifications to power systems, forcing changes in route planning processes, service operations, and investment in charging infrastructure. For this reason, research in this area focuses primarily on optimizing vehicle charging processes, integrating charging systems with renewable energy sources, and creating smart grids to improve energy supply and consumption management.

4.3. Resilient public transport

In research on resilient cities, public transport plays a critical role if city authorities want to ensure continuity of operation in the event of disruptions, rapid response to emerging crises, and flexible adaptation to climate and social change. Research shows that long-term reliability and continuity of transport systems will increasingly require consideration and planning for climate change and extreme weather events [102]. It is equally important to consider social and technological changes in the design and operation of transport systems. Therefore, mainstream research related to the design and operation of resilient public transport systems focuses on the following issues:

1. Resilience of public transport to natural disasters and climate change (exemplary research [102–105]).

Research in this area is typically concerned with modeling the impact of extreme weather conditions on selected public transport systems, various methods for assessing the resilience of transport systems to disasters such as earthquakes, floods, and extreme temperatures, as well as the design of transport networks resilient to climate change and natural disasters.

2. Crisis management and business continuity of public transport systems (example studies [106–109]).

Crisis management is primarily concerned with business continuity planning for transport systems during pandemics, blitzes, and, more recently, cyber-attacks. This research usually concerns the development of methods to assess the resilience of public transport systems to failures, cyber-attacks, urban pandemics, and emergency resource management concepts. Particularly during the COVID-19 pandemic, many researchers analyzed how urban transport systems adapted to the effects of the pandemic. Some publications deal with using public transport as an evacuation tool or as support for emergency logistics.

3. Adaptability and resilience of transport infrastructure (examples of research [110–112]).

This research strand focuses primarily on the design of modular and reconfigurable transport systems. Therefore, the development of temporary transport routes or stopping points is becoming a prominent issue, as well as the development of novel approaches to transport network design based, for example, on mobile stops. Adaptability and flexibility are also recognized as important resilience metrics defined for public transport systems.

4. Energy resilience of public transport (example studies [113, 114]).

Tram networks, as well as the introduction of electric buses, make public transport systems dependent on energy availability. Therefore, in this strand, researchers are looking for methods to reduce the dependence of the transport system on centralized energy sources and implement diversified forms that also use energy from renewable sources. An important aspect of building energy resilience is also the creation of energy storage facilities that can provide an alternative source in times of crisis. Research also focuses on methods (scenarios) for the operation of public transport vehicles during energy emergencies.

5. Integrating public transport with resilient urban planning (example studies [115–117]).

Public transport must interact with resilient urban planning. For this reason, many studies are concerned with linking transport design to the concept of 15-minute cities. The design of public spaces with access to resilient public transport systems is also important.

5. DISCUSSION

The literature review identifying the main research concepts on urban development indicates that all three analyzed trends are intensely symbiotic. This is confirmed both by the results of the narrative literature review, which identified the main research trends in each of the concepts analyzed, and by the research of other authors, which repeatedly shows strong links between the concepts [13, 14, 118]. A strong link exists between the concepts of smart and sustainable cities. This is mainly because the transformation of cities towards the smart concept strongly focuses on sustainability goals due to the overlapping development practices of smart and sustainable cities [119]. On the other hand, it

is also related to the fact that urban resilience is the most recent of the concepts analyzed, as evidenced by the systematic review presented in Section 3.1. However, this concept also shows a strong use of technology to make cities resilient [12].

All three concepts interact very strongly with aspects of residential mobility. Sustainability targets changes in residents' transport behavior to foster emission reductions and improve urban air quality. Therefore, sustainable mobility is one of the main research trends in this concept. Ongoing research is therefore directed towards developing public transport, which should be people's dominant mode of movement within a city, and its integration with micro-mobility. Smart mobility is also a key area that is being developed as part of the smart city. New technological solutions, which are constantly emerging, support planning urban journeys using public transport or personal transport devices and enable better coordination of public transport systems, improving their efficiency, performance, and punctuality. Public transport is also a crucial element in building urban resilience. Its efficient operation is a critical component of crisis management and ensuring the continuity of urban systems. For this reason, issues concerning creating and operating flexible transport infrastructures that quickly adapt to changing conditions are now an important part of research in this area.

As evidenced by the systematic literature review presented in Section 3.1, all three research concepts analyzed represent a developing research area, as evidenced by the growing number of related publications. Based on the analysis of the defined research trends in public transport and the observed technological changes, it is possible to formulate the main challenges and further developments that urban public transport will face in terms of its sustainability, resilience, and smart city:

- **Automation of urban transport systems.** The initial stages of transport automation are already observable, with examples such as the autonomous metro in Dubai demonstrating the feasibility of large-scale implementation. This process presents not only technological challenges but also social ones, as public concerns regarding the safety and reliability of autonomous vehicles remain significant. In its early phases, automation is expected to be adopted primarily in large metropolitan areas with strong technological and financial capabilities, as the deployment of pilot projects requires substantial investment and extensive research and innovation resources. Successful implementation further depends on well-developed digital infrastructure and stable transport networks, including integrated intelligent transport systems (ITS), dense sensor networks, and high-quality roadways and rail tracks. Medium-sized cities with established "smart city" policies may also become early testing grounds. Their less complex road networks and lower traffic intensity can facilitate the integration of automation technologies while reducing operational risks.
- **Recurring pandemics.** Many researchers have noted that pandemics and large-scale disease outbreaks are likely to occur more frequently than in the past. This raises the challenge of adapting public transport systems to meet heightened safety and hygiene requirements for travel. Continued development of contactless operations (e.g., proximity-based tick-

eting, mobile payments) will be essential, alongside the introduction of dynamic passenger load management systems. The importance of the "mobility as a service" (MaaS) model is expected to grow, enabling flexible integration of multiple transport modes. Declining public confidence in crowded vehicles is likely to promote the expansion of micromobility solutions (e.g., bicycles, e-scooters), particularly in small and medium-sized cities and in urban areas designed according to the "15-minute city" concept. In large metropolitan areas, pandemics will pose the greatest challenge, as the main alternative to public transport often remains private car use, exacerbating congestion and environmental impacts.

- **Recurring natural disasters and climate change.** Ongoing climate change exposes urban residents to extreme weather conditions, including heat waves, severe cold spells, sudden heavy rainfall, and intense winds capable of damaging transport and urban infrastructure. These events often cause temporary disruptions in transport services, significantly affecting daily mobility. This creates a pressing need to develop green urban infrastructure along transport corridors to ensure that recurring natural hazards do not undermine the resilience of public transport systems. Large cities are particularly vulnerable to such events, primarily due to the wide-ranging and high-intensity disruptions they cause. In these cases, research into the integration of early warning systems becomes crucial, while a key challenge lies in designing strategies to maintain network functionality under crisis conditions.
- **Increasing dependence on technology.** The concept of smart mobility is focused on leveraging information technologies to support the sustainable development and resilience of transport systems. However, the growing reliance on technology also increases the dependency of both users and transport operators on intelligent transport systems. A critical development priority is therefore to secure existing systems against various forms of external and internal cyber threats, while ensuring operational continuity. Large cities are particularly exposed to cyberattacks, given the potentially greater scale, visibility, and societal impact of successful breaches. Moreover, their transport systems are more complex and require a higher level of integration, leading to greater reliance on large-scale technological support to maintain efficiency and service quality. Consequently, it is essential to advance research into the development of contingency scenarios for situations in which access to digital solutions becomes limited or disrupted.
- **Regulatory implications.** Technological, social, and environmental changes necessitate both the modification of existing legal provisions and the integration of new regulations. This requires aligning urban mobility strategies with climate policy objectives, as well as embedding within them legal measures related to crisis management. Equally important is the development of regulations governing the collection, processing, and sharing of transport-related data, striking a balance between the implementation of innovative solutions and the protection of individual privacy. It should also be noted that the concepts under consideration often compel legislators to respond more rapidly than under conventional

legislative cycles. This, in turn, calls for the introduction of mechanisms enabling regulatory updates at intervals shorter than those typical of standard legal amendments.

To summarize the discussion so far, it is necessary to refer to the questions posed at the beginning of the research conducted. The results of the analysis have made it possible to provide comprehensive answers to all three research questions. Their summary is presented in Fig. 3.

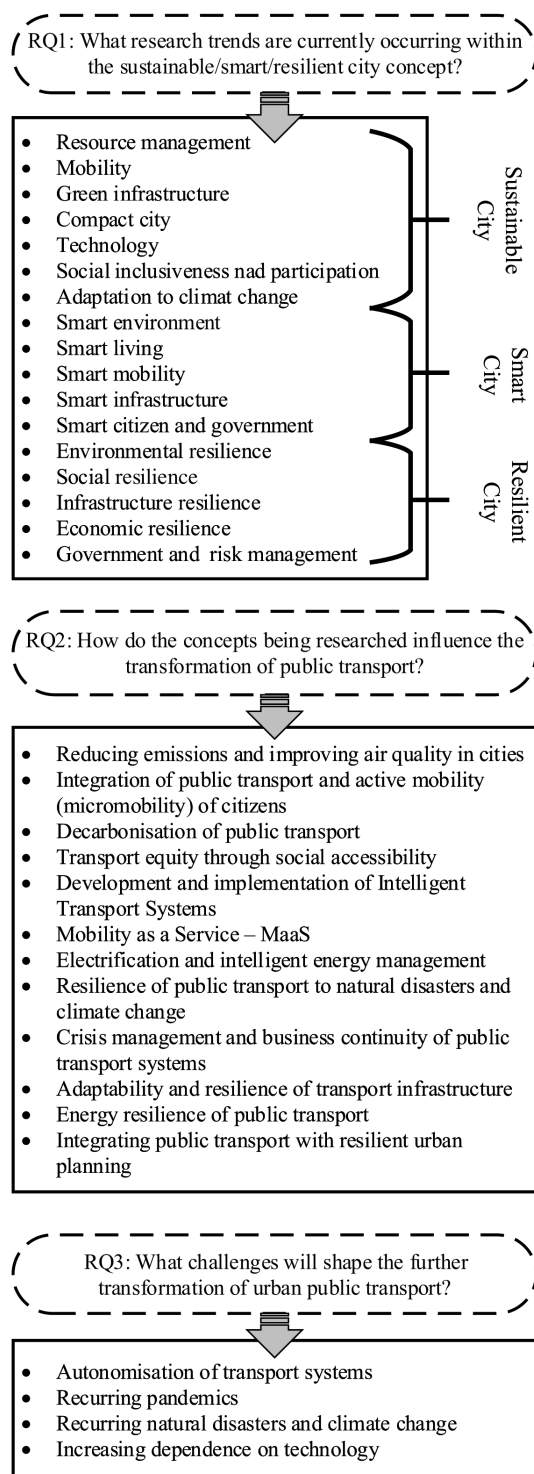


Fig. 3. Answers to research questions

6. CONCLUSIONS

The common subject area for the reviewed articles confirms the need for an integrated approach to all three research trends analyzed. Although each of these concepts can be analyzed separately, the research on them in most cases is combined in selected aspects. This is particularly evident in the area of transport. Building sustainable and resilient public transport systems nowadays seems impossible without adequate technological support. At the same time, resilient transport systems are solutions that use sustainable energy sources and consider climate change. Therefore, it makes sense now to conduct research into developing urban transport that is simultaneously sustainable, resilient, and intelligent.

The research results presented here are of interest to other researchers. First, they synthesize knowledge of the three currently dominant development concepts. In addition, they indicate their impact on the transformation of contemporary public transport systems, which may inspire further research in these areas. It should also be noted that the defined challenges and proposed areas of further research related to public transport can provide impetus for other researchers and also provide a hint for urban public transport organizers. The progress observed in research on sustainable and resilient public transport systems must be reflected in the implementation of appropriate solutions and procedures. Therefore, the presented research results can also inspire municipalities and urban public transport companies.

The analyses presented in this study are subject to certain limitations. Research on changes in urban mobility was conducted primarily through a narrative review, which, while grounded in an initial systematic review, relied mainly on review articles and publications with high citation indices, as outlined in Section 3. This methodological choice may have resulted in the omission of certain aspects of urban mobility from the reported findings. Consequently, a proposed direction for future research is to broaden the analysis to include studies with lower citation indices, which may nonetheless offer valuable insights and contribute meaningfully to the advancement of the examined concepts for the development of contemporary cities.

The presented results reflect the complexity of research currently required to create sustainable and resilient cities based on technological developments. All these aspects are research areas within the Center for Sustainable Development of Wrocław University of Science and Technology. Public transport systems are only a fragment of the urban fabric, the transformation of which influences, but is also dependent on, the development of other urban systems. Therefore, further areas of the authors' research will be identifying the relationships linking transport systems with other urban systems, analyzing their interactions, and the need for their coordination to develop sustainable and resilient cities smartly.

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