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Review

Synergies and Potential of Industry 4.0 and Automated Vehicles in Smart City Infrastructure

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Abstract: The integration of Industry 4.0 and automated vehicles into the smart cities concept is a topical issue in the urbanization of cities and technological innovation within cities. As it is a relatively modern issue, many aspects of this field have not yet been explored; as a consequence, this paper is concerned with the search for synergies between Industry 4.0 and automated vehicles in smart city infrastructures. There is a lack of contributions in this field that summarize these synergies in a single article and address a wide range of aspects, including transport, energy, communication, and citizen participation. As the field lacks a complete and clear summary of what is already known, which would help multiple stakeholders, the authors decided to conduct this review. The article elucidates the above-stated aspects through a clear and in-depth literature review, which is complemented by specific examples from practice. Of course, the article also includes a description of the synergy potential and the impact on the inhabitants, the environment, and, last but not least, on the overall city life. The main hypothesis of this article is that the integration of Industry 4.0 technologies and automated vehicles within smart city infrastructure will result in significant improvements in transportation efficiency, resource utilization, and overall urban sustainability. The article discusses the positives and negatives of such integration, highlighting, on the one hand, the benefits in terms of reducing environmental impact and improving citizens' quality of life, but on the other hand, also highlighting the various ethical, legal, and social issues that such integrations may bring. Several methods have been used within the article, namely analysis, synthesis, comparison, and historical interpretation. The final discussion highlights the benefits, as well as the challenges, that such integration faces and must deal with if it is to be successful. It can be concluded that the synergistic potential of automated vehicles and Industry 4.0 in smart city infrastructure is enormous and that such integration offers promising solutions for enhancing transportation efficiency, energy management, and overall urban sustainability. It is also highlighted in the article that, in order to reap the benefits of such synergies, a wide-ranging collaboration of policymakers, industry stakeholders, and urban planners is needed.

Keywords: Industry 4.0; automated vehicles; smart cities

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1. Introduction

The 21st century is a century of change in urban landscapes, fueled by exponential population growth and technological advancements. Cities are transforming from densely built-up areas into intricate ecosystems known as smart cities. These interconnected urban environments leverage the power of data and information technology to optimize infrastructure, services, and resource management, fostering a more sustainable and livable future [1].

Industry 4.0, the ongoing automation and data exchange revolutionizing manufacturing and industrial processes, are basic elements of smart cities. This fourth industrial revolution fosters intelligent and interconnected systems, creating the way for greater efficiency, flexibility, and environmental sustainability. However, the smart city integration requires a second, equally impactful movement: Automated Vehicles (Hereinafter referred to as "AVs"). These self-driving cars, trucks, and other transportation systems hold immense potential to revolutionize urban mobility. Studies suggest that AVs can dramatically reduce traffic congestion, a big problem in modern cities [2]. With their ability to adhere to precise lane positioning and communication protocols, AVs can significantly improve traffic flow, leading to shorter commute times and reducing the emissions of toxic exhaust components. Furthermore, AVs hold the potential to enhance safety by eliminating human error, a leading cause of traffic accidents [3].

The core of this synergy lies in the exchange of real-time data. Data generated by AVs in traffic can be integrated with Industry 4.0 principles to optimize logistics operations and dynamically adjust factory production schedules based on real-time demand fluctuations. This continuous flow of information creates the way for a more responsive and efficient urban ecosystem, as emphasized in the study [4].

This article analyzes what specific benefits can be expected in the context of combining the above elements in modern smart cities. Our work focuses on the interplay between Industry 4.0 and automated vehicles within smart city infrastructure and their potential impact on transport, production, and sustainability. As presented in the abstract, the main hypothesis is that the integration of AVs and Industry 4.0 in smart city Infrastructure has the potential to result in significant improvements in transportation efficiency, resource utilization, and overall urban sustainability.

At the same time, however, it should be noted that despite all the positives, such integration faces many challenges. These challenges include, for example, data security, privacy issues, social, economic, ethical, and legal aspects—since automated vehicles and Industry 4.0 machines collect a huge amount of data and, without good security, there is a high risk of misuse of this data. Additionally, the compatibility of existing infrastructure poses a significant problem. Integrating AVs with existing traffic networks will require investment and technological innovation. Finally, the development of regulatory frameworks is critical to address liability issues in the event of accidents involving AVs [5].

At the beginning of each chapter, the current state of knowledge is theoretically described, with reference to the most relevant authors and their key publications that touch on this issue. Controversies and divergent hypotheses that appear in the literature are highlighted.

Our main goal is to provide a clear view of the potential that the combination of Industry 4.0 and automated vehicles offers for creating more efficient, sustainable, and intelligent smart cities. The findings suggest that combining elements of Industry 4.0 with automated vehicles offers promising solutions for improving transport efficiency, energy management, and the overall sustainability of cities. By critically analyzing existing research and exploring controversial hypotheses, the opportunities and obstacles associated with integrating Industry 4.0 and AVs in smart cities are highlighted. This work wants to provide valuable insights for policymakers, urban planners, and researchers to guide the development of efficient, sustainable, and future-proof urban environments.

In conclusion, the key findings from our analysis and proposed potential avenues for future research in this field are outlined. Hopefully, our research will be helpful not just for professionals in the field but also for anyone intrigued by the evolution of urban environments.

2. Materials and Methods

In this article, the integration of Industry 4.0 technologies and automated vehicles within smart city infrastructure is analyzed. To achieve this goal, different methods and approaches that allowed us to analyze the topic with a sufficient level of detail were used.

In order to explain the steps of the research conducted, we have summarized them in the following Figure 1 with a description of each step. The research was conducted, and the manuscript was written through a systematic process that involved several key steps.

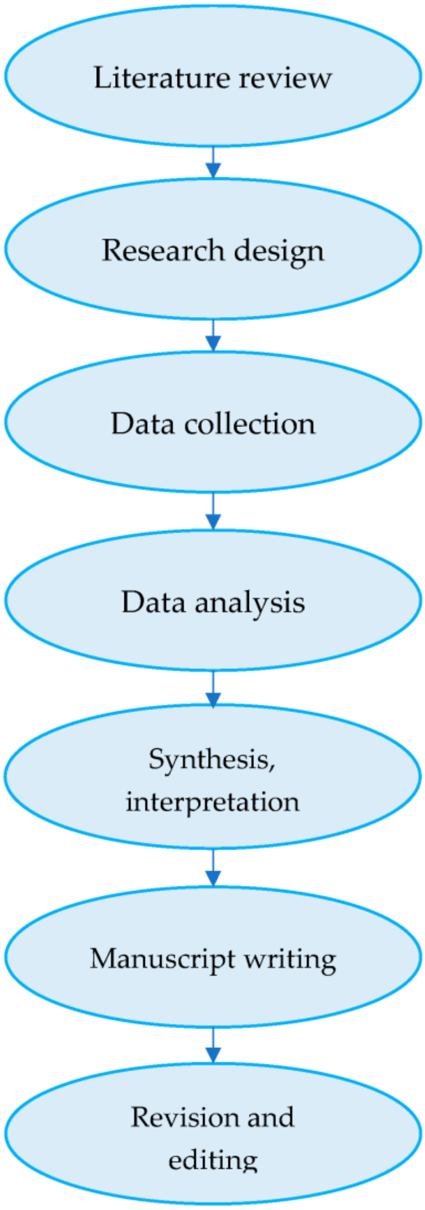

Figure 1. Steps of research. Source: Own processing.

(a) Literature review—the process began with an extensive review of existing literature on the integration of Industry 4.0 technologies and automated vehicles in smart cities. This involved searching scholarly databases, reports, and case studies. The literature review aimed to gather a comprehensive understanding of the current state of knowledge, identify gaps, and inform the research questions and objectives.

(b) Research design—based on the insights gained from the literature review, the research design was formulated. This included defining the scope and objectives of the study, determining the methodology, and outlining the structure of the manuscript. The research design aimed to ensure that the study addressed the research questions effectively and followed a systematic approach to data collection and analysis.

(c) Data collection—the next step involved collecting data relevant to the research objectives. This included gathering information from scholarly articles, government reports, industry publications, and other sources. Data collection methods included keyword searches, citation tracking, and consultation with subject matter experts to identify relevant literature.

(d) Data analysis—once the data were collected, they were analyzed to extract key findings, themes, and patterns. This involved organizing the data, coding information based on predefined categories or themes, and synthesizing the results. Data analysis aimed to identify trends, gaps, and areas of consensus or contention in the literature.
(e) Synthesis and interpretation—the synthesized findings were then interpreted in the context of the research objectives and existing knowledge in the field. This involved drawing connections between different studies, identifying overarching themes or trends, and critically evaluating the evidence. The synthesis process aimed to generate new insights and perspectives on the integration of Industry 4.0 technologies and automated vehicles in smart cities.
(f) Manuscript writing—with the synthesized findings and interpretations in hand, the manuscript was written following a structured format. This typically included sections such as an introduction, literature review, methodology, results, discussion, conclusions, and recommendations. The manuscript writing process involved crafting clear, concise, and coherent prose that effectively communicated the research findings and their implications.
(g) Revision and editing—after the initial draft of the manuscript was completed, it underwent multiple rounds of revision and editing. This involved refining the language, clarifying arguments, addressing feedback from co-authors or reviewers, and ensuring consistency and accuracy throughout the text. The revision process aimed to improve the quality and readability of the manuscript before submission for publication.

The methodology used in the article belongs to the descriptive or qualitative approach. This methodology involves a review of the existing literature and a description of the findings without the need to conduct specific experimental procedures or quantitative analyses. Instead, it relies on the synthesis of information from a variety of sources to provide a comprehensive overview of the subject matter [6].

A multifaceted approach was used, combining a literature review with a selection of case studies to explore the potential of integrating Industry 4.0 and Automated Vehicles (AVs) within smart city infrastructure. This approach has also been supplemented by familiar methods of analysis, synthesis, comparison, statistical methods, and historical interpretation [7].

The method of analysis is a research technique used to systematically break down and examine composite data, information, or phenomena into its component parts in order to understand their structure, relationships, and meanings. The main steps of this method, which are also presented in the paper, are as follows. The first step is to determine which data or materials will be analyzed. This can be monographs, interviews, case law, legislation, media, or other sources of information. Then, the material to be analyzed is divided into single parts or elements based on criteria defined by the researcher. The next step is to classify the elements into categories or groups based on their similarity or importance. This process allows the analyzed data to be organized and structured. Once categorized and classified, the analyzed data are interpreted and evaluated to understand its meaning, relationships, and implications. This step involves a deeper look at the relationships between the elements analyzed and their meaning within the overall context. Based on the analysis, conclusions are drawn and results are interpreted. These conclusions can be used to support hypotheses, clarify relationships, or reveal new insights into the issue under study. The analysis method allowed us to analyze in detail the current trends and developments in the field of Industry 4.0 and automated vehicles. Articles, literature studies, and case studies from various sources were analyzed, which provided us with a comprehensive view of the issue, and, thanks to such an analysis, the main aspects that could potentially have a positive/negative impact on such integration were identified [8].

Following the analysis, synthesis was used to integrate and reconcile information, opinions, or knowledge from different sources in order to create a new and more comprehensive view of a given topic. The main steps of the synthesis method applied in the paper are as follows.

(a) The authors gathered and analyzed relevant information from several sources, including literature on smart cities, Industry 4.0, automated vehicles, and technological innovations in urbanization.
(b) After collecting the information, the authors analyzed and classified it according to different criteria, such as transport efficiency, sustainability, economic growth, and citizen participation. This process allowed us to identify the main ideas and trends in the integration of Industry 4.0 and automated vehicles in smart cities.
(c) Based on the analysis of the information, the authors integrated and harmonized different aspects and findings from the literature to identify patterns, connections, and differences between them. This process enabled the development of an overall view of the topic and an understanding of its broader context.
(d) The authors developed new insights and concepts on the synergies and potentials of Industry 4.0 and smart cities by integrating and reconciling information from different sources. These new insights have contributed to further understanding and clarification of the problematic areas.
(e) Finally, the authors validated and evaluated the synthesized findings to determine their reliability, relevance, and significance within the study area. This step allowed an assessment of the quality of the synthesized information and its contribution to knowledge [9].

The well-known method of comparison, through which authors compared different approaches, legal regulations, case studies, and opinions, was used, and thus, authors were able to evaluate the intersection of these sub-models and find the ideal smart cities model and the greatest opportunities in terms of integration. Specifically, a qualitative and quantitative comparison method was used. In the qualitative comparison, the authors focused on the understanding of the individual texts and the observation of the current state of the art in this field, which allowed the authors to qualitatively compare the different elements of smart cities, looking for their synergies. Also, qualitative analysis was used to compare Barcelona and Singapore as leading smart cities. This comparison was also complemented by a quantitative comparison, which is also complemented by specific mathematical figures and data. In fact, all graphs presented in this article contain quantitative data that are compared, for example, year-on-year, but also within specific periods between each other. This combination of quantitative and qualitative comparisons has allowed authors to gain a comprehensive view of the issue and to conduct a broad and clear literature review in this area [10].

The authors examined the historical context and evolution of Industry 4.0 and automated vehicle technologies to understand their emergence, evolution, and current status. This historical perspective provided us with an important framework for understanding current trends and future perspectives. In some parts of our research, the authors used statistical methods to analyze and interpret data collected from different sources. These methods allowed us to quantify and evaluate the importance of different factors influencing the integration of Industry 4.0 and automated vehicles into smart city infrastructure [11].

An extensive literature review was conducted to establish a foundational understanding of existing research on smart cities, Industry 4.0, and AVs. Academic databases such as Google Scholar, Web of Science, and Scopus were searched using a combination of keywords including “smart city”, “Industry 4.0”, “Automated Vehicles”, “urban mobility”, “data analytics”, and “sustainability.” The inclusion criteria were peer-reviewed articles, conference proceedings, or books published within the past ten years that addressed the aforementioned topics. However, it is always necessary to work critically with relevant data from a variety of sources when analyzing this issue, as not all data from large database sources and large journals may always be relevant [12].

The theoretical basis was obtained from studying a large amount of relevant literature. This theoretical background allowed us to focus on the key elements and the synergistic potential of such integration, while it is important to stress that such a symbiosis can only work thanks to an interconnected infrastructure based on a wide spectrum sharing of data and information. As part of the literature review, the authors also looked at the underlying principles within Industry 4.0, which include and will be described in the next parts of the article, such as automation, data exchange, and the use of intelligent machines within manufacturing and industrial processes. Finally, the literature on AVs was examined, focusing on their potential impact on urban mobility, traffic flow optimization, and safety improvements.

By critically reviewing the current literature and current research, the authors have not only provided a starting point for our paper and research but have also identified gaps in this integration and potential places where it could be further improved.

The authors have also complemented the theoretical background with a variety of case studies from the field that represent real-world experiences where people can both see and learn from the best. As examples, Barcelona and Singapore are explored below. These cities are directly implementing the above elements in practice, and so, based on their experience, researchers can learn from their mistakes so they are not made again in the future while also revealing weaknesses (such as privacy and data protection) that need to be addressed in the long term so that this integration can work without complications. The authors have mainly drawn data for our case studies from official city government reports, industry publications, news articles from reputable sources, and academic journals focused on urban planning and technology [13].

Data extraction was carried out carefully with a focus on details. Through a thematic analysis approach, key themes were found, providing a detailed understanding of the practical implications of incorporating Industry 4.0 and AVs in smart cities. This analysis concentrated on retrieving details concerning the following.

(a) The specific Industry 4.0 technologies implemented within the city (e.g., intelligent transportation systems).
(b) The types of AV technologies and their safety (e.g., self-driving cars, autonomous buses, connected logistics vehicles, legislation).
(c) The data collection and management strategies employed within the smart city infrastructure.
(d) The challenges encountered during implementation, such as infrastructure compatibility issues, data security concerns, etc.

This study recognizes specific constraints. The variety of case studies selected gives a glimpse of current initiatives but may not cover all smart city developments happening worldwide. Furthermore, the ever-changing technology and urban planning landscape indicate that research results may require ongoing review and adjustment due to the evolution of these sectors.

Even with these drawbacks, this study provides valuable perspectives on the possibilities of combining Industry 4.0 and AVs in smart cities. Future studies can expand on this base by delving deeper into particular technological developments.

3. Results

3.1. Automated Vehicles—General

Since the beginning of road transport, there has always been someone behind the wheel of a car. Over time, together with the rapid development of technology, studies have suggested the possibility of self-driving cars. Vehicle automation has its advantages, such as information sharing with smart cities, but there are also disadvantages to be considered, particularly the liability issues and, last but not least, the cyber-security issues that come with it. As this is an emerging sector in the transport industry, the sector can also be described as a challenge not only for computer scientists and cyber security engineers but also for the legal field and legislators, as the level of answering cyber security questions is at an early stage and, thus, many of them are unanswered. People deal with cybersecurity on a daily basis with our devices, such as mobile phones, tablets, and computers, which are exposed to cyber threats and attacks on a daily basis. Due to the prolonged use of such devices, more risk mitigation practices are being put in place to enhance security. However, in the case of autonomous vehicles, these are just in the early stages of regulation, as evidenced by the recent first legislative acts regulating the area at various levels. Safety must be seen as the most fundamental and most important aspect of autonomous vehicles, whether it is the safety in traffic itself, the safety of passengers, the safety of the surroundings, or the cybersecurity of the vehicle and the information it shares with smart cities [14].

This is where the clash of interests between the smart cities concept and the concept of automated vehicles comes into play. The smart cities concept foresees a wide sharing of information between the different elements. As an example, a situation where automated vehicles would share information with a particular smart city about its location, speed, vehicle occupancy, and destination, and the smart city would calculate the best route with respect to traffic using an advanced computer and thus be able to manage traffic and navigate through traffic jams, phantom jams, and ensure traffic flow. Also, smart cities would be able to adjust traffic lights based on the data from cars, considering the possibility of traffic jams. If a smart city receives information from an automated vehicle stuck in a traffic jam, it would be able to give that direction a kilometer longer to ensure traffic flow. For example, the emergency services would also be able to operate in this way. Thus, a smart city would identify information from the vehicle and adjust traffic accordingly. For example, the emergency services could have a green light at all traffic lights, which means that they would not have to brake before every intersection, worrying whether all vehicles would let them through. This is the ideal situation from a smart city point of view, but on the other side, there is cyber security [15]. Such widely shared information between vehicles, traffic lights, and other road users puts the safety of the occupants of individual vehicles at high risk. The fact that information is exchanged in cyberspace poses the greatest threat in terms of hacker attacks. Data obtained in this way can even be misused in transnational organized crime [16].

The number of cyber-attacks continues to increase, as confirmed by Table 1 below, which shows the top ten data leaks in 2023 and the amount of data leaked. Over 3.5 billion different datasets have been stolen as a result of the biggest data leaks in 2023. Big hacking attacks are also faced by well-known companies that have access to huge amounts of data from different users, often secret data, such as SAP, which had over 95 million different datasets stolen in November 2023. In this context, the individual reasons and consequences of the leaked data should also be mentioned. The most common are forms of hacker attacks on technological infrastructure, inadequate network security, and the human factor that failed. Such failures have disastrous consequences since billions of datasets were leaked in 2023, and the data are often subject to privacy protection since they are, for example, personal data, health data, business data, confidential data, and much more. The concerns and risks associated with information sharing between automated vehicles and smart cities are entirely justified, and it will be a major challenge for businesses that will implement these modern-day advances to be wary of such leaks [17].

As this is a relatively new technological and scientific field, there is relatively little legal regulation in this area. In the following sections, the authors discuss the differences between automated and autonomous vehicles, the categorizations of these vehicles, how the European Union law regulates this area, and last but not least, the authors describe the synergies and potential between automated vehicles and smart cities [25].

Table 1. Top ten data breaches in 2023 Source: ITGovernance. Available online: https://www.itgovernance.co.uk/blog/list-of-data-breaches-and-cyber-attacks-in-2023 (accessed on 5 March 2024) [17].

	Organization Name	Sector	Location	Known Records Breached	Month of Public Disclosure	Consequences	The Reason for the Leak	Size (gb)
1	DarkBeam	Cyber security	UK	>3,800,000,000	September	identity theft and unauthorized access to sensitive accounts	data visualization interface unprotected	2900
2	Real Estate Wealth Network	Construction/ real estate	USA	1,523,776,691	December	information on property owners, sellers, investors, including name, physical address, phone number, provider, and what was downloaded from the database	insufficient protection of cyberspace	1160
3	Indian Council of Medical Research (ICMR)	Healthcare	India	815,000,000	October	patient records—medical diagnoses	massive ransomware attack on the All India Institute of Medical Science	620
4	Kid Security	IT services/ software	Kazakhstan	>300,000,000	November	user activity logs, including 21,000 telephone numbers and 31,000 email addresses	the open instance has been hit by the 'Readme' bot and was partially destroyed	228
5	Twitter (X)	IT services/ software	USA	>220,000,000	January	email addresses linked to more than 200 million Twitter profiles	a bug in Twitter's systems	167
6	TuneFab	IT services/ software	Hong Kong	>151,000,000	December	records with users' IP addresses, userIDs, emails, and device info	misconfiguration on MongoDB, a document-oriented database platform, that left TuneFab's data passwordless and publicly accessible	115
7	Dori Media Group	Media	Israel	>100 TB	December	confidential company data	hackers attack on the weak point of security	99
8	Tigo	Telecoms	Hong Kong	>100,000,000	July	full access to encrypted devices and all related data	ransomware attack	76
9	SAP SE Bulgaria	IT services/software	Bulgaria	95,592,696	November	sensitive data, such as passwords, tokens, or keys	hackers attack on the weak point of security	73
10	Luxottica Group	Manufacturing	Italy	70,000,000	May	personal information of customers, including names, emails, phone numbers, addresses, and dates of birth	security incident at a third-party vendor	53

References: Available online: https://www.cshub.com/data/news/darkbeam-data-leak (accessed on 5 March 2024) [18], https://cybernews.com/security/kidsecurity-parental-control-data-leak/ (accessed on 5 March 2024) [19], https://www.itgovernance.co.uk/blog/criminal-hackers-leak-email-addresses-of-220-million-twitter-users (accessed on 5 March 2024) [20], https://cybernews.com/news/spotify-music-converter-puts-users-at-risk/ (accessed on 5 March 2024) [21], https://www.databreaches.net/vido-and-chatting-app-leaks-more-than-100-million-user-messages/ (accessed on 5 March 2024) [22], https://www.aquasec.com/blog/the-ticking-supply-chain-attack-bomb-of-exposed-kubernetes-secrets/ (accessed on 5 March 2024) [23], https://www.bleepingcomputer.com/news/security/luxottica-confirms-2021-data-breach-after-info-of-70m-leaks-online/ (accessed on 5 March 2024) [24].

3.2. The Difference between Automated and Autonomous Vehicles

Automated vehicle technologies enable the transfer of control and decision-making functions from humans to computers or artificial intelligence. The digitization and automation of vehicle driving will transform road transport in a way that is being seen as a revolution in mobility. If human error is the most common cause of road accidents, authors can consider automatically computer-controlled driving to be safer. The scientific or design direction has a vision for road transport that also has the potential to be more efficient, more accessible, and more environmentally friendly, and such digital development also directly helps economic growth in the European Union [26].

Following this, it is essential to define the difference between an automated vehicle and an autonomous vehicle. In common practice, it may appear that the two terms are interchangeable, but this is not actually the case. An automated vehicle can be understood as a motor vehicle, whether a car, truck, or bus, that has technology available to assist the driver so that elements of the driving task can be transferred to a computer system. On the other hand, an autonomous vehicle is a fully automated vehicle equipped with technologies capable of performing all driving functions without any human intervention. It is also important to specify a connected vehicle, which is a vehicle that is connected to a network or a motor vehicle that is equipped with devices to communicate with other vehicles or infrastructure via the Internet [27].

In addition to the above definition, it can also be found in General Security Regulation (EU) 2019/2144. The Regulation defines an automated vehicle as “a motor vehicle designed and constructed to be able to move autonomously for a certain period of time without the continuous supervision of the driver, but where the intervention of the driver is always foreseen or required”. It defines a fully automated vehicle as “a motor vehicle designed and constructed to be able to move without the supervision of a driver”. It should be noted that it will be important for cybersecurity to define which vehicles are subject to potential threats and also what cybersecurity is and what its subjects and objects are [28].

Act No. 429/2022 Coll. amending and supplementing certain acts in connection with the development of automated vehicles is also a major contribution to the issue. For the purposes of this Act, the term automated vehicle is understood to mean both an automated vehicle as defined in the aforementioned Regulation and “another motor vehicle designed and constructed to be able to move independently for a certain period of time without the continuous supervision of the driver, but where driver intervention is assumed or required”. A fully automated vehicle, on the other hand, is again considered by law to be a fully automated vehicle as defined by the regulation or “another motor vehicle designed and constructed to be capable of autonomous movement”. However, the main essence of automated vehicles and fully automated vehicles is to be an automated driving system (“ADS”), which the Act also defines as “a vehicle control system that uses hardware and software to provide dynamic control of the vehicle on a continuous basis” [29].

It is also necessary to define in which parts of automated vehicles artificial intelligence is located or in which segments of autonomous driving it is actually used. If we focus on the sources from which artificial intelligence will draw its inputs in automated vehicles and autonomous driving, we are talking about multiple cameras placed in different places in the car, radars that emit electromagnetic waves and detect their reflection from an object capable of reflecting these waves, lidars, or devices with a sensor or group of sensors that are capable of mapping nearby or distant objects and surfaces. Among other things, artificial intelligence also has the ability to draw data from GPS or other global positioning systems. Based on the above inputs, the AI can then perform several types of tasks that are tied to the aforementioned sensors or share this information with smart cities [30].

3.3. Categorization of Vehicle Automation Levels

The automation levels determine how the different aspects of the dynamic control of the vehicle are divided between the human and the car, depending on the different aspects of the control. Each has its own specific characteristics (e.g., highway merging, high-speed driving, low-speed driving in traffic congestion, and others). Categorization of vehicle automation levels consists of six levels of vehicle driving automation, starting with level 0 for the lowest recognized category and ending with level 5 for the highest category [31].

Level zero represents the most common vehicles in today’s traffic, where the driver controls the vehicle, and no autonomous system is present, even though the car has enhanced warning or intervention systems, such as blind spot monitoring, which alerts the driver but does not further intervene in the steering.

The first stage is called driver assistance, which is a driver assistance system that performs steering or acceleration/deceleration depending on the driving mode, using information about the driving environment and expecting the driver to perform all other aspects of dynamic driving. This is also defined as driver assistance systems, such as lane keeping or active cruise control, which can accelerate and decelerate the vehicle according to a set distance from the vehicle in front.

If both systems are present in the car and able to work together at the same time, they fulfill the prerequisite for the second level of categorization, which is called partial automation. It should be added that in the zero, first, and second stages, it is assumed that the surroundings are monitored by a human driver who is driving the vehicle and is ready to intervene and take control at any moment.

The third stage is called conditional automation and consists of the vehicle being able to accelerate, decelerate, and steer up to a certain speed, while the driver must be able to take control of the vehicle if necessary, but until such a need arises, the vehicle takes care of monitoring the surroundings.

The fourth level is called high automation and is an improvement of the previous level, but the difference is that this kind of car can cope in most situations without the need for human intervention.

The fifth level, the highest possible category of vehicle automation, is called full or complete automation, which means fully autonomous driving of the vehicle without any human driver activity. In the highest three levels of automation, the car itself, and not the human, monitors the surroundings [32].

Figure 2 presents a comparison of the share of autonomous vehicle sales of levels 2–4 in total vehicle sales in 2025 and 2030 by level of automation. In 2025, the share of total sales of autonomous vehicles of "Level 2—Entry" will be approximately 47% of all vehicle sales; in 2030, this figure will decrease to 39%, but at the same time, sales of vehicles with a higher level of autonomy will increase. In 2025, sales of autonomous vehicles in the "Level 2—advanced" category are expected to account for 12% of total sales, so in 2030, this figure will rise to 17%. Equally, there will be an increase in Level 3 vehicles, which will see their share of total sales rise from 4% to 5%. The most significant growth, however, can be seen in "Level 4—highly-autonomous vehicles", which will see an increase from 0% to 3% between 2025 and 2030. Again, these statistics only prove that the growth in sales of autonomous vehicles cannot be stopped, and thus, everybody needs to adapt to this trend and seize the opportunity to integrate and exploit the synergistic potential offered by the combination of smart cities and Autonomous Vehicles as much as possible [33].

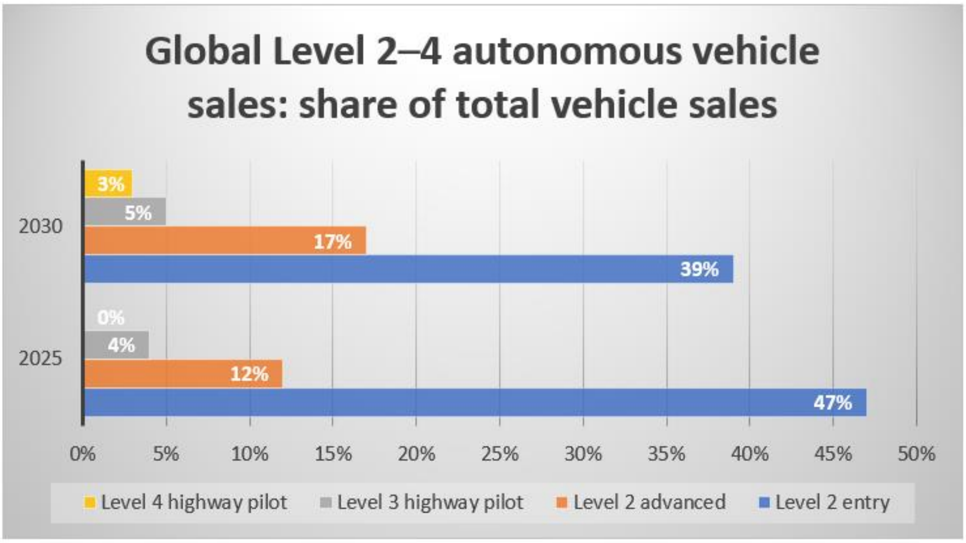

Figure 2. Levels 2–4 autonomous vehicle sales as a share of total vehicle sales in 2025 and 2030, by automation level. Own processing according to Statista data. Available online: https://www.statista.com/statistics/1230101/level-2-autonomous-vehicle-sales-worldwide-as-a-share-of-total-vehicle-shares-by-autonomous-vehicle-level/ (accessed on 8 March 2024) [33].

3.4. Cybersecurity Legislation for Automated Vehicles—Directive NIS 2

The official title of Network and Information System Directive 2 (NIS Directive 2, the number after the name indicates the serial number of the Directive) is given in the references. In the context of interpretation, this title may be interpreted as the Directive on the protection of network and information systems; it is intended to be a response to the application practice and conclusions of the European Commission, which points out that the objective of the NIS Directive has not been met. The NIS Directive was insufficiently linked to the sectoral requirements. With the NIS 2 Directive comes a fundamental change in the regulation of automated vehicles, in particular, because NIS 2 will now also apply to the manufacture of motor vehicles and vehicle manufacturers themselves, compared to the NIS Directive. The entities subject to the NIS 2 Directive can be divided into two categories: key actors and important actors. As far as vehicles are concerned, the NIS 2 Directive will apply not only to manufacturers of motor vehicles themselves but also to manufacturers of electrical and electronic equipment for motor vehicles [34].

Under Chapter 4, which addresses cyber risk management measures and reporting obligations, the NIS 2 Directive obliges Member States to ensure that "the governing bodies of key and significant entities shall approve the cyber risk management measures taken by those entities to comply with Article 21, oversee its implementation and may be held liable if entities breach that Article". Those measures are based on an all-risk approach designed to protect networks and information systems and the physical environment of those systems from incidents and include at least:

(a) Principles of risk analysis and information system security;
(b) Incident handling;
(c) Business continuity, such as backup and disaster recovery management and crisis management;
(d) Supply chain security, including security aspects relating to the relationship between the entities and their direct suppliers or service providers;
(e) Security in the acquisition, development, and maintenance of network and information systems, including vulnerability management and vulnerability disclosure;
(f) Policies and procedures for assessing the effectiveness of cyber risk management measures [35].

Compared to the previous NIS Directive, the definition of 'incident' has been changed to mean "an event threatening the availability, authenticity, integrity or confidentiality of data stored, transmitted or processed or of services provided or accessed through networks and information systems". In addition to the definition of an incident, the Regulation also recognizes the so-called Significant Incident. In order to determine which incident is considered significant, it must be fulfilled that: "(a) it has caused or has the capacity to cause a significant operational disruption of services or financial loss to the affected entity, (b) it has affected or has the capacity to affect other natural or legal persons by causing them significant pecuniary or non-pecuniary damage, (c) it has caused or has the capacity to cause significant pecuniary or non-pecuniary damage, (d) it has caused or has the capacity to cause significant pecuniary damage to other natural or legal persons" [36].

Manufacturers of automated vehicles and fully automated vehicles will also have an obligation to report incidents under NIS Directive 2. Manufacturers of automated vehicles will be considered as relevant entities in that they can be classified as a type of entity in the manufacturing sector and the sub-sector manufacturing of motor vehicles, semi-trailers, and trailers within the meaning of Annex II of the NIS 2 Directive, while they can also be classified as medium-sized and large enterprises, which implies that manufacturers of automated vehicles will have to implement security measures. However, the operation of an automated vehicle cannot be considered as a service provided by entities in the manufacturing and motor vehicle manufacturing subsectors; thus, if a cyber threat, for example, in the form of a cyber-attack, were directed at an automated driving system or other system of a vehicle, the manufacturer of that vehicle would not be obliged to report such an incident under the NIS 2 Directive. However, the authors anticipate that in the longer term, there will be an amendment to the Directive, which will also require such manufacturers to share such information. As this is one of the first legislative efforts in the field of automated vehicles, it does not envisage cyber threats associated with smart cities at all, and therefore, authors also expect that, in a potential amendment of the regulation, the sections on cybersecurity of smart cities and data sharing between smart cities and vehicles will be incorporated into this regulation as well. On the other hand, it has to be said that the Directive responds to the current needs of society, and since currently, most vehicles are not autonomous at all, there has been no need to address and regulate the security of data shared between smart cities and autonomous vehicles until now [37].

3.5. Synergies and Potential between Automated Vehicles and Smart Cities

Automated vehicles and smart cities represent two interconnected technologies with huge potential for transforming transport and urban life. Automated vehicles, which can drive themselves without driver intervention, ensure increased safety, fluidity, and efficiency of transport. Smart cities, which use information and communication technologies to optimize urban systems, can further exploit these benefits of automated vehicles for the benefit of citizens in a number of areas [38]. The areas of interpenetration between smart cities and automated vehicles and their advantages/disadvantages are listed below.

More efficient transport in smart cities, thanks to automated vehicles, represents a fundamental change in the way traffic is managed and how transport networks are used. Automated vehicles can communicate with each other and with the central transport system, allowing more dynamic adaptation of routes and speeds of individual vehicles. With such communication, vehicles can optimize the flow of traffic between each other based on current traffic and road conditions [39].

Smart cities can also use data on vehicle movements and traffic to drive traffic lights and other traffic devices and signs. These systems dynamically adjust traffic lights to prioritize vehicle movements based on the current road situation, minimizing time spent in congestion and improving traffic flow and safety. Analytical tools using traffic data from automated vehicles can predict congestion and identify critical points in the traffic network. Based on this data, smart cities can take action to prevent congestion and improve traffic flow. Based on traffic and vehicle movement data, smart cities plan and implement improvements to transport infrastructure. This can include widening roads, creating new lanes, optimizing parking spaces, and promoting public transport to increase the efficiency of overall transport [40].

Through the above measures, the potential of automated vehicles can be exploited to the maximum and, thanks to such a connection, they can together contribute to more efficient and faster transport in cities, which will avoid traffic jams and improve the overall travel experience of individual city residents and tourists. At the same time, it should be said that speeding up traffic and relieving congestion will also ensure lower carbon emissions and thus improve the air in cities overall.

At the same time, thanks to sensors and communication units, automated vehicles can communicate with each other. However, communication does not only take place on a horizontal level between cars but also with traffic signs, traffic lights, and surrounding buildings. Such inter-vehicle communication ensures a very rapid exchange of data and information on various road traffic elements, such as current road conditions, including traffic information and weather conditions. As mentioned above, these vehicles are equipped with advanced sensors and technologies that allow them to quickly detect potentially dangerous situations on the road, such as nearby vehicles, pedestrians, or obstacles. Thanks to computer units that allow a very rapid assessment of the situation and, at the same time, interface with other vehicles, these vehicles are able to minimize the risk of accidents and take preventive measures to minimize the risk of road accidents. It is essential to recall that automated vehicles analyze the behavior and movements of other road users based on historical data and current conditions. This analysis allows vehicles to anticipate potentially dangerous situations and, most importantly, it allows them to learn from past situations and, thanks to the things learned, adapt their behavior to minimize the risk of collisions and accidents in the future [41].

Automated vehicles not only bring faster traffic and higher levels of safety to smart cities but can also be used for parking optimization. The efficient use of parking spaces has a direct impact on traffic flow, quality of life for residents, and the environment. Smart cities are equipped with sensors that monitor the availability of parking spaces in public car parks and on streets. These sensors collect a lot of data and exchange it with cars and the smart city itself. The information is, for example, about which parking spaces are available and which are occupied, and this information is then shared with autonomous vehicles, which can search for the appropriate parking space accordingly. It should be added that thanks to such an intelligent parking system, it is possible for the cities to also make more money for the budget because intelligent parking systems can also adjust parking prices based on supply and demand. This means that, for example, at the busiest times, parking prices will be more expensive, forcing people to look for cheaper spaces, for example, outside the center, and forcing them to use transport or park only briefly. Of course, even such rules would recognize exceptions in the form of free parking spaces for the disabled and so on. Moreover, intelligent parking systems analyze parking usage data and predict future parking demand based on history and trends. This data can help cities, especially when planning future infrastructure. For example, they can take into account the need to build more free catchment car parks and strengthen public transport to relieve parking congestion in city centers. This will allow commuters to combine different modes of transport according to their needs and preferences. Optimizing parking in smart cities contributes to more efficient use of public spaces, reduces traffic in search of parking spaces, and improves the overall traffic flow. These systems also increase driver convenience and reduce the negative impact of car traffic on the environment and quality of life in the city [42].

Following the above, it is inevitable that the synergistic potential of this combination will manifest itself in the end, mainly in the form of reduced emissions and pollution in smart cities. This will ensure more sustainable and healthier living environments for their residents. Automated vehicles, integrated into intelligent transport networks that optimize vehicle flow, ensure that vehicles move around the city efficiently and quickly. This reduces the amount of time vehicles spend in traffic and also reduces emissions. Smart cities contain a number of sensors that monitor air quality. They collect this data from different parts of the city, then analyze and evaluate it, and with this data, smart cities can redirect traffic where appropriate as part of traffic optimization and long-term sustainability. By collecting data on a regular basis and from a large number of users, smart cities are able to use this data to create personalized transport solutions for residents. These solutions can include route recommendations, travel times, and information on available transport services. Such recommendations would take into account current traffic, preferred modes of transport, travel times, and other factors, improving the efficiency and convenience of travel. Based on data from automated vehicles, smart cities can also predict and optimize travel times for individual residents. These optimized times can include recommendations for optimal departure times, travel during less congested times, and other strategies to minimize time spent in traffic [43].

Figure 3 confirms our assertions, where it is evident that this autonomous vehicle market is growing; where it is worth approximately USD 41.1 billion this year, it will already be worth over USD 114.5 billion in 2029. This trend shows that it is essential to deepen the integration of systems between smart cities and autonomous vehicles, and it is important that this trend is captured because it has the potential not only in terms of safer, more efficient, and greener transport in smart cities, but it can also boost the economy because this market is expected to grow several times more [44].

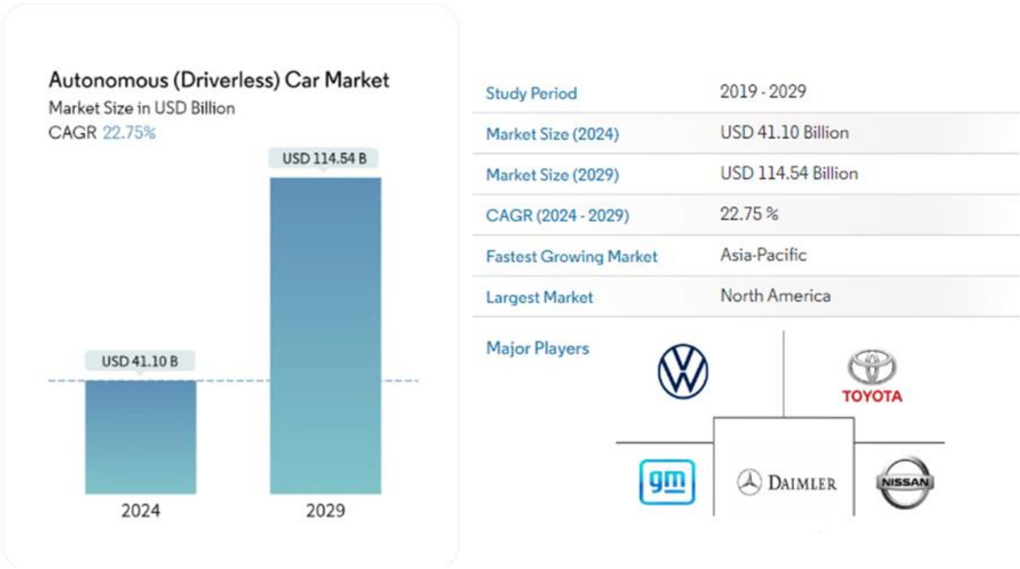

Figure 3. Autonomous (Driverless) Car Market. Source: MordorIntelligence. Available online: https://www.mordorintelligence.com/industry-reports/autonomous-driverless-cars-market-potential-estimation (accessed on 9 March 2024) [44].

3.6. Smart Cities and Autonomous Vehicles in Practice

Pilot projects to integrate self-driving cars and smart cities are already underway in cities around the world; well-known examples include:

(1) Singapore;
(2) Barcelona.

The first of these cities is Singapore. According to several metrics and several prestigious measurements, Singapore is one of the most progressive and innovative cities in the world. The measurements show that Singapore has come to the top of the rankings by effectively utilizing technology for urban planning. Singapore started investing in smart infrastructure a long time ago, and this is why it can be considered a leading example of how technology projects in smart cities can improve efficiency, sustainability, and the quality of life for its residents. It is also known that Singaporeans are some of the happiest and most content people with their leadership. The smart city program in Singapore is called Smart Nation and aims to incorporate digital technologies into the daily routines of citizens and enhance the provision of public services. The incorporation of automated vehicles and Industry 4.0 into the city's infrastructure is one of the elementary elements of this program. Singapore has long been grappling with the modern trend of increasing vehicles in urban areas. Therefore, Singapore seeks to improve transport options for citizens while reducing the amount of congestion in cities by introducing a system of automated vehicles. Residents and the leadership of this city realize that using these vehicles can help decrease traffic, increase the number of parking spaces, and enhance road safety. Singapore's smart city efforts do not stop at AVs but they are making significant investments in smart city technology, including sensors, IoT, data analytics, and artificial intelligence, in order to improve and automate city management and achieve greater efficiency. These technologies enable cities to supervise, control, and improve different areas of city life like transportation, energy, garbage disposal, public safety, and other areas [45].

Barcelona is the second city analyzed. It is located in Spain and is known as a very progressive, innovative, and technology-driven city that puts a strong emphasis on sustainable urban planning and strives for the long-term wellbeing of residents. Thanks to large investments in smart city components, Barcelona obtained second place overall in smart cities. The above investments were mainly directed towards the purchase of sensors and data to enhance different parts of the city's infrastructure and services. One of Barcelona's primary goals is to improve transportation efficiency. As part of the effort to improve transport, a number of sensors have been installed to collect data on traffic movement, pinpoint congestion areas, and apply smart traffic solutions like dynamic traffic light systems or information boards displaying current traffic updates. The aim of these measures is to make vehicle movements smoother, safer, more efficient, faster, and more sustainable in the long term. Parking is inextricably linked to vehicle movements. Barcelona is looking to improve parking efficiency by installing sensors in car parks that track parking spot availability and notify drivers of open spots through mobile applications. This parking app system with broad data sharing increases driver satisfaction, decreases traffic from parking searches, and enhances city traffic flow. As the authors said above, all of these measures ultimately help long-term sustainability and improve energy efficiency. Buildings have embedded sensors and monitoring systems to track energy usage and pinpoint sections with high consumption. City officials can create plans to reduce energy usage and improve efficiency using this information [46].

Above, the authors have described the agenda of two of the most well-known and progressive smart cities around the world. These cities are characterized by high levels of automation, digitization, and integration of the smart cities concept with elements such as autonomous vehicles and Industry 4.0. As can be seen from the Figure 4, these cities are well above average, especially in the areas of data management, citizen feedback, public awareness, housing and energy, and public safety. Of course, there are specific areas in which each city excels and in which it is weaker, but over the long term, these cities stay above average. Again, this is proof that integrating smart cities with its core elements can deliver the desired results. Figure 4 designed to plot 18 factors translated into values over multiple quantitative variables. Blue line is about the city and orange line is the average value for the six selected cities [47].

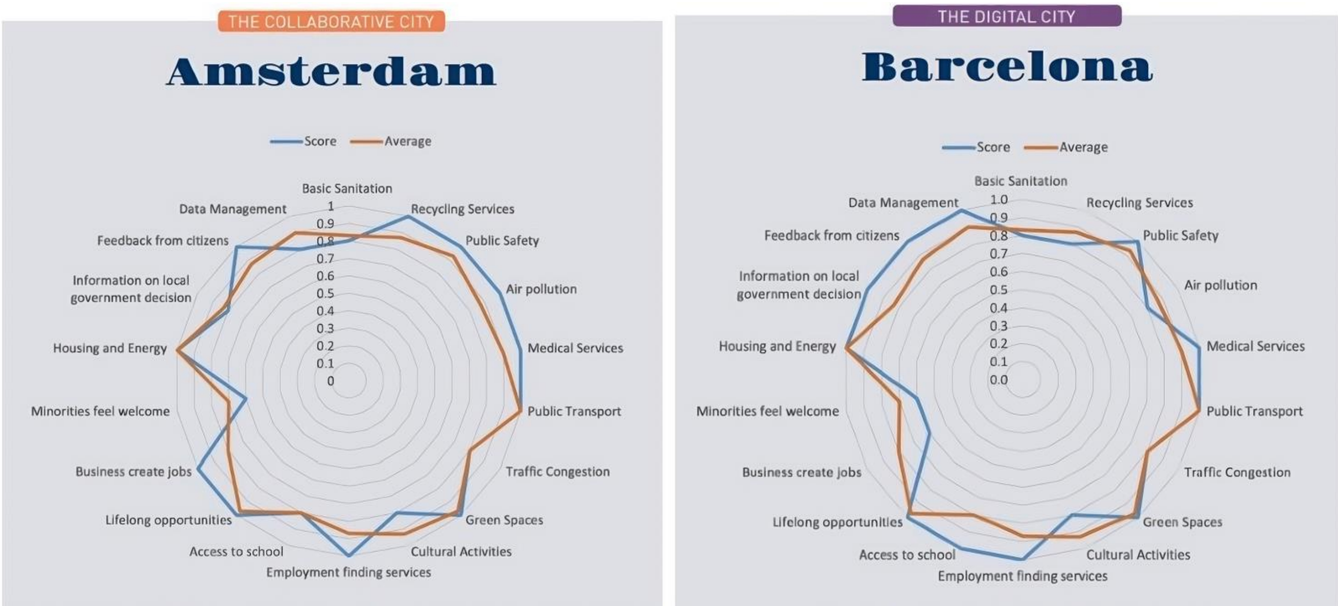

Figure 4. Smart Cities—The sustainable program of six leading cities. Source: HEC Paris. Available online: https://www.hec.edu/en/smart-cities-sustainable-program-six-leading-cities (accessed on 10 March 2024) [47].

Automated vehicles and smart cities represent a reliable penetration in the effort to achieve sustainable, efficient, and friendly transport for residents and visitors. Their synergies and potential are evident in many areas, including more efficient transport, improved road safety, reduced emissions and pollution, better use of public spaces, and the provision of personalized transport solutions.

The integration of automated vehicles into intelligent transport networks enables cities to better manage traffic, minimize congestion, and optimize vehicle flow. This improves traffic flow and reduces time spent in traffic, contributing to a better quality of life for citizens.

In addition, automated vehicles are able to react more quickly to risky situations and cooperate with the infrastructure, thereby improving road safety and minimizing the risk of traffic accidents.

Personalized transport solutions created based on data from automated vehicles provide individuals with the opportunity to use transport more efficiently and conveniently, contributing to a better travel experience and increasing overall mobility in the city.

It is very difficult to find accurate statistics that would indicate the exact number of autonomous vehicles (level 5) within the cities of Barcelona and Singapore. This is mainly due to the fact that cars move dynamically in space and time and, therefore, do not stay in one place. Thus, it is practically impossible to accurately record the number of such vehicles. Another reason is individual legislation, which, for example, within the European Union significantly affects the possibility of driving with a fully autonomous vehicle. Therefore, in this article, authors mainly refer to official sources and studies, especially the statements of the representatives of these cities, since official data are not available. Within the available data, it can be stated that Barcelona at Level 3 AV Testing with permits takes place on selected roads. Commercial uses for the public are still limited. Within Barcelona at Level 4/5 AVs, technology testing and development are underway, but Barcelona is the center for testing autonomous vehicles. Within Singapore Level 3 AVs, 10 licenses have been granted to operate autonomous taxis in 2023. Pilot programs with autonomous buses and vans are underway. At the level of 4/5 AVs: In 2022, the first fully autonomous taxi service project was launched. Autonomous trucks are being tested on highways. Singapore has ambitious plans to develop autonomous transport. However, what can be compared between these two cities is the increase in market size between 2024 and 2031. This comparison is illustrated in Figure 5. In 2024, the market size in Singapore is approximately USD 692.7 Mn; in 2030, it is assumed that the market size will be approximately USD 1865.9 Mn—this is a massive increase in market size [48]. According to the available data, the market size in Barcelona in 2024 is approximately USD 453.8 million, and in 2030, the market size is expected to reach USD 1303.8 million [49].

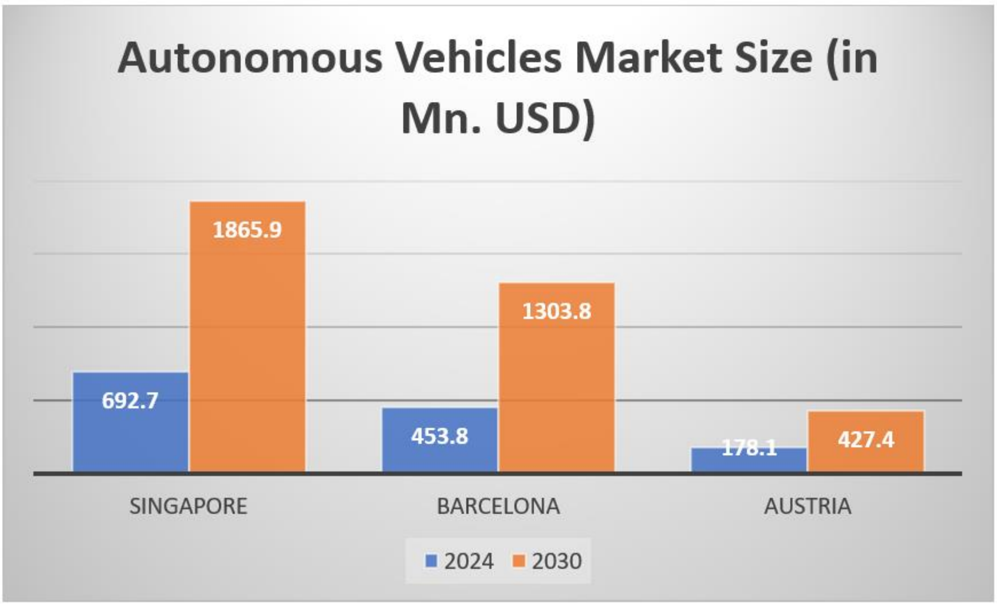

Figure 5. Autonomous/self-driving cars market (2024–2030). Own processing according to research data. Available online: https://www.6wresearch.com/industry-report/austria-autonomous-self-driving-cars-market (accessed on 15 March 2024) [50].

In order to compare how these cities are ahead of the competition in terms of the number of automated vehicles, the authors added in Figure 5 also Austria, which is considered to be very advanced in the field of automated vehicles, electric vehicles, and ecology, in general, where it can be seen that in 2024, their market size is USD 178.1 Mn and in 2030, the market size will be USD 427.4 Mn [50].

On the basis of this comparison, it can be concluded that Barcelona and Singapore are leaders in this area; however, the market size in 2030 will, of course, also depend a lot on the policies of individual states, and these are only estimated values. In any case, in 2024, the statistics rank them among the leading smart cities in this area. In this respect, it should be emphasized that while Barcelona and Singapore are leading smart cities, other governments are also gradually allocating more resources to the development of Smart Cities. An example is Italy and its GHOST program, funded by the Italian Ministry of Education, whose main objective is to focus attention on and progressively improve smart city governance. As the authors point out, at least the cities of Cagliari and Florence are benefiting from this program and are adapting urban strategies and planning based on data and data generated through smart city governance. In this way, they are able to adapt to their needs, for example, in the tourism sector, and maximize the benefits and profits for the city while giving tourists an optimal experience [51]. The development of the smart cities concept within Italian cities is also confirmed by other studies that highlight the development not only in the field of smart city governance but also in the development of smart transport, which includes smart public transport, cycle paths, bike sharing, and car sharing [52]. As can be seen from the analysis in question, both Barcelona and Singapore are leading smart cities, but Italian cities are by no means lagging behind either.

Combined, automated vehicles and smart cities provide dynamic and innovative solutions towards a more sustainable, safer, and more efficient urban environment for all its inhabitants [53]. However, authors should not forget the challenges that are associated with this integration, such as employee acceptance of digital transformation in smart cities and the ability of employees to adapt to it [54].

3.7. Industry 4.0

Industry 4.0 is a reaction to the overall development of the industry. Having experienced three industrial revolutions, we are now in the midst of a fourth industrial revolution [55]—hence, the appropriately titled Industry 4.0. Nevertheless, the authors will give a brief overview of the initial three industrial revolutions before delving into Industry 4.0, followed by an examination of the potential synergy between Industry 4.0 and smart cities in the upcoming chapter.

The first Industrial Revolution started at the end of the eighteenth century in Europe, Great Britain, and the United States of America (hereinafter referred to as "USA"). This industrial revolution was characterized by a shift from manual production, which took a very long time, to machine production using water-powered and steam-powered machinery. It was a major change in the history of industry, as machines, not just people, gradually started to be involved in production. In the early 19th century came the second industrial revolution. This was characterized by the invention and emergence of key inventions needed to speed up production in factories. Such inventions include, for example, airplanes, fertilizers, belt manufacture, and petrol engines. Perhaps the most significant characteristic of the second industrial revolution was assembly line production. When the assembly line was combined with electric drive and other inventions of the period, so-called mass production with an efficient division of labor began. The third industrial revolution dates back to the 1970s and is characterized by partial automation using memory-programmable elements and computers. In fact, this revolution has already made it possible to automate the entire production process. This is the case, for example, of robots in car factories, which carry out certain tasks instead of humans. That is to say, the automation of production through electronic systems, information technology, and computer-controlled production.

At the same time, this industrial revolution also included digital systems, which made it possible to optimize the entire production process [56].

On the basis of this historical excursion, the world is now coming to Industrial Revolution 4.0, which has been underway since around 2010 and is expected to last for around 30 more years. The Figure 6 graphically illustrates the content of each industrial revolution and describes what was characteristic of that revolution [57].

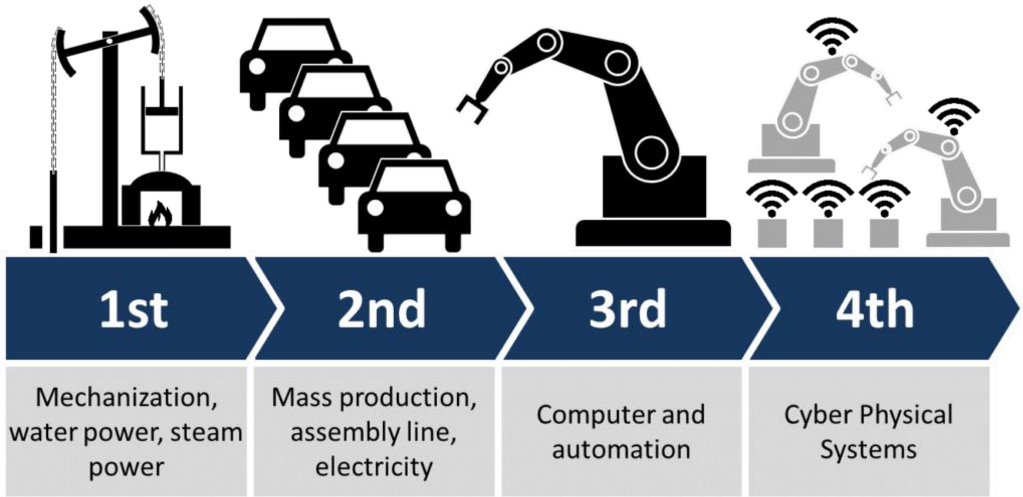

Figure 6. How does Industry 4.0 differ from the previous generation? Source: Renaix. Available online: https://www.renaix.com/industry-4-0-the-fourth-industrial-revolution/ (accessed on 11 March 2024) [57].

Industry 4.0 is characterized by massive digitization and automation of production. Based on this technological trend, individual factories are changing and adapting, giving rise to factories based on automated cyber–physical systems that carry out activities previously completed by humans.

The basic principles of Industry 4.0 include the following.

(a) Modularity—systems must be as modular as possible and capable of autonomous recovery based on situation recognition;
(b) Real-time working;
(c) Service orientation;
(d) Decentralization—decision making is autonomous across subsystems;
(e) Virtualization—systems can be interfaced with virtual models;
(f) Interoperability—systems and people are able to communicate with each other via the Internet [58].

The core components of Industry 4.0 include cyber–physical systems, Internet of Things (Hereinafter referred to as “IoT”), Internet of Services, cloud computing, big data, product lifecycle system, digital manufacturing, digital twin, system integration, industrial IoT, autonomous robotics, 3D printing, smart factory, and augmented reality. Cyber-physical systems combine cyber (software) and physical (hardware) elements to enable real-time process integration and control. The Internet of Things is a set of interconnected devices that collect and exchange data over the Internet. In Industry 4.0, it is used to monitor and control manufacturing processes and equipment. It is the use of the Internet to provide various services such as cloud computing, online storage, and other digital services that are used in Industry 4.0 to optimize processes and manage business operations. Cloud computing provides access to computing resources (such as computing power, storage, and applications) via the Internet. In Industry 4.0, it enables fast and flexible big data processing, data storage, and the use of software applications remotely. Big data is huge volumes of data that are collected and analyzed from different sources. In Industry 4.0, big data is used to improve decision-making processes, predict trends, and optimize manufacturing operations. The product lifecycle system encompasses the planning, development, production, delivery, and management of products throughout their lifecycle. In Industry 4.0, it is optimized using digital technologies and data. Digital manufacturing uses digital technologies such as 3D printing, CNC machines (CNC machines are PC-controlled manufacturing machines responsible for producing goods), and robotics to create products and components. These technologies enable more flexible and efficient manufacturing. A digital twin is a digital replica of a physical object, process, or system. In Industry 4.0, digital twins are used to model, simulate, and monitor manufacturing processes and equipment. System integration ensures that different components and systems in an industrial environment work together and communicate with each other seamlessly. Industrial IoT is the application of IoT in an industrial environment, which helps in monitoring, controlling, and optimizing manufacturing processes and equipment. Autonomous robotics involves the use of robots and machines with artificial intelligence and sensors to perform tasks without human intervention. Three-dimensional printing is the technology of creating three-dimensional objects layer by layer. In Industry 4.0, it is used to produce prototypes, components, and even final products. A smart factory is a manufacturing plant that uses advanced digital technologies to automate and optimize production processes and equipment. Artificial reality is a technology that allows digital information and virtual objects to be overlaid with the real world through real-time imaging. In Industry 4.0, it is used for productivity improvement, employee training, and other applications [59].

Industry 4.0, as mentioned above, is a concept that transforms traditional manufacturing and industrial processes through digital technologies and innovation.

Industry 4.0 technologies enable the following.

(a) Increased efficiency and flexibility—digital technologies enable faster production and more flexible responses to market changes and customer demands.
(b) Personalized manufacturing—technologies such as 3D printing and digital manufacturing processes make it possible to produce personalized products and components without increasing costs.
(c) Predictive Maintenance—IoT and big data enable real-time monitoring of equipment health and prediction of equipment failure, minimizing unplanned production downtime.
(d) Improved quality and innovation—digital technologies enable accurate monitoring and control of manufacturing processes, leading to improved product quality and fostering innovation.
(e) Reduced costs and increased competitiveness—more efficient use of resources and automation of processes can lead to reduced production costs and increased business competitiveness [60].

Industry 4.0 is also accompanied by challenges such as ensuring cyber security, the need to retrain the workforce, and issues relating to ethics and fairness in relation to the use of technology. However, the proper management and implementation of technologies and processes associated with Industry 4.0 can bring significant benefits to industrial enterprises, economies, and smart cities alike. The authors describe the benefits of Industry 4.0 for smart cities below [61].

A similar trend to autonomous vehicles can be seen in Industry 4.0, where market share is growing yearly on every continent. This situation is documented in Figure 7, where a progressive increase in Industry 4.0 market size can be seen. It is noteworthy that by 2030, this market will double within Europe, Asia, and North America. Therefore, if modern cities want to make the most of the potential of both autonomous vehicles and Industry 4.0, it is imperative to capture the trend and look to integrate these elements into their infrastructures. The authors have provided specific examples of the integration of these elements in several sections of this article. Therefore, if cities want to make the most of this market capitalization in 2030, it is essential to take action now [62].

Figure 7. Industry 4.0 market share, size, trends, industry analysis report, by technology source: Polaris market research analysis. Available online: https://www.polarismarketresearch.com/industry-analysis/industry-4-market (accessed on 11 March 2024) [62].

3.8. Analysis of Industry 4.0 Elements and Their Use in Smart Cities

3.8.1. Digitization and Harnessing the Potential of New Technologies

Digitization and harnessing the potential of new technologies in Industry 4.0 give an insight into the transformation of industries and the way manufacturing processes are carried out. As mentioned above, the first of the analyzed elements of Industry 4.0 is the digitization and exploitation of the potential of new technologies in Industry 4.0 and also in smart cities.

Industry 4.0 involves digital transformation, which means the transition to digital technologies and processes in the industrial environment. This means that traditional mechanical and manual processes are replaced by automated systems that use sensors, IoT, artificial intelligence, and other digital tools to improve the efficiency and accuracy of manufacturing operations. IoT plays a key role in Industry 4.0, enabling communication and interaction between physical devices and software systems. This collection of sensors and connected devices provides manufacturing companies with vital data to monitor the health and efficiency of their process systems. Industry 4.0 is characterized by a high level of robotization and automation of production processes. Robotic systems are becoming increasingly sophisticated and capable of performing a wide range of tasks, increasing productivity, and reducing labor costs. Analytical tools and artificial intelligence are key components of Industry 4.0. These technologies enable manufacturing companies to analyze vast amounts of data and extract valuable insights that they can use to optimize their processes and decision making. With digitization and automation, mass personalization and individual production in the industry are also becoming possible. Thanks to flexible production processes and technologies, such as 3D printing and manufacturing, companies can adapt to individual customer requirements. The digital transformation of the industry is also having an impact on workflows and employee needs. Employees need to acquire new digital skills and adapt to new technological environments and production processes. Digital transformation can also contribute to environmental sustainability by enabling more efficient use of resources, minimizing waste and emissions, and promoting the use of renewable energies [63].

The analysis of digitalization and the exploitation of the potential of new technologies in Industry 4.0 in the context of smart cities offers insights into the integration of modern technological innovations into urban environments to improve the quality of life of residents and the efficiency of public services. Digital transformation in Industry 4.0 brings smart solutions for urban infrastructure. Sensors, IoT devices, and analytics tools can be integrated into various infrastructure elements such as transport networks, public lighting, waste management, and water systems, enabling better monitoring and management of these systems. In the context of smart cities, digitalization and automation in Industry 4.0 can lead to innovations in transport and mobility. Autonomous vehicles, intelligent transport systems, and shared transport services improve traffic flow, reduce congestion, and minimize emissions in urban areas. The use of new technologies in Industry 4.0 can contribute to increased energy efficiency in smart cities. Intelligent energy grids, distributed energy sources, and consumption management can help minimize energy waste and increase the share of renewable energy sources in the city. Digital technologies and IoT devices can be used to create smart buildings and urban solutions in smart cities. These solutions can improve building efficiency, resource management, safety, and occupant comfort. The integration of new technologies in Industry 4.0 into smart cities can contribute to improved public safety. Monitoring, tracking, and prediction systems can help city authorities respond more quickly to accidents, crimes, and other crisis situations. Digitization and new technologies in Industry 4.0 can also support the participation of citizens in decision-making processes and city governance. Smartphone apps, information-sharing platforms, and public consultation forums can enable citizens to actively participate in the development of their city [64].

3.8.2. Internet of Things

The Internet of Things in Industry 4.0 is the concept of connecting physical devices, machines, and other objects to the Internet to collect data, monitor, control, and automate manufacturing processes and other industrial operations. In this context, IoT enables the creation of an intelligent and connected industrial environment that increases the efficiency, flexibility, and safety of production. The principle of IoT is that physical devices are equipped with sensors, chips, and internet connectivity, allowing them to collect data and communicate with the network and other devices. These devices can share data about their status, environment, and activities through wireless communication and cloud platforms [65].

In the industrial environment, IoT will find applications in various fields, such as the following.

(a) Monitoring and diagnostics—sensors connected to production equipment can collect data on their operation and status, allowing their performance to be monitored and potential faults to be predicted.
(b) Control and automation—IoT enables remote control and automation of manufacturing processes based on real data and analytics. This increases flexibility and efficiency in production and enables rapid response to changes in the environment.
(c) Logistics and supply chain—IoT can be used to track and manage the movement of materials and products in the supply chain, improving its efficiency and transparency.
(d) Energy Efficiency—IoT sensors and analytics tools can help monitor and optimize energy consumption in industrial facilities and infrastructure, helping to reduce costs and environmental impact.
(e) Service and Maintenance—IoT enables the creation of predictive maintenance models based on the collection of equipment performance data. This means that service work can be performed in a timely manner and downtime is minimized [66].

In essence, IoT in Industry 4.0 introduces a new way of managing, monitoring, and optimizing production and industrial operations by connecting physical devices to the Internet and creating intelligent and connected industrial ecosystems.

In the context of smart cities, the Internet of Things is a key element that enables the intelligent management and optimization of various aspects of urban life. An example is smart transport. IoT devices can be integrated into transport networks and vehicles, allowing traffic to be monitored, road data to be shared, and traffic lights and traffic systems to be managed. This contributes to optimizing traffic, minimizing congestion, and improving the mobility of citizens. Sensors attached to parking spaces can monitor their availability and inform drivers about available parking spaces using mobile apps. These sensors reduce traffic in search of parking and improve the use of public spaces. LED lights (Light Emitting Diode) with integrated sensors can be used to monitor light intensity, temperature, and other factors in the urban environment. This data can be used to automatically adjust the lighting according to needs and increase energy efficiency. Sensors located in different parts of the city can monitor pollutant levels and other environmental factors. This data can be analyzed to manage emissions and support measures to improve air quality. Containers equipped with sensors can inform city authorities of their fill levels, allowing for the planning of more efficient collection routes and minimizing environmental pollution. IoT devices can be integrated into buildings and infrastructure to monitor energy consumption, air quality, and other parameters. This enables more efficient building management and reduces environmental impact [67].

All these IoT applications in the context of smart cities contribute to improving the efficiency of public services, enhancing the quality of life of citizens, and promoting the sustainable development of urban areas. Their effectiveness lies in connecting physical objects to the internet and using data for intelligent decision making and management.

3.8.3. Infrastructure as a Service (IaaS)/Cloud Computing

Infrastructure as a Service (hereinafter referred to as "IaaS") is a cloud computing model that allows organizations to rent, manage, and use virtual IT (Information Technology) infrastructure resources over the Internet. This model provides flexibility and efficiency in the use of hardware, software, and network resources without the need to invest in physical facilities and their maintenance. IaaS provides virtualized resources such as virtual servers, storage, and network processes. These resources are managed by the cloud service provider and are accessible over the Internet. Users can customize their resource usage according to their current needs. This means they can easily increase or decrease capacity according to demand, minimizing costs and ensuring sufficient application performance. IaaS services are often billed on a per-use basis, which means organizations only pay for the resources they use. This funding model enables more efficient use of resources and reduces costs. IaaS service providers are responsible for provisioning and managing the infrastructure, which means users do not have to worry about maintenance and updates to the physical hardware. Users have access to a wide range of technologies and tools available in the cloud, including analytics tools, database systems, and development environments [68].

In summary, Infrastructure as a Service (IaaS) provides organizations with a flexible and scalable solution for managing their IT infrastructure. It helps organizations improve efficiency, reduce costs, and improve the performance of their IT systems.

In the context of smart cities, infrastructure as a service (IaaS) and cloud computing play a key role in delivering digital services and managing smart infrastructure. The following are some specific aspects of how IaaS and cloud computing support the development of smart cities.

Cloud computing enables central storage and management of data, which is key to the efficient functioning of smart cities. City authorities can use cloud storage to share and store data on traffic, the environment, public safety, and other aspects of urban life. IaaS enables the implementation of smart e-government solutions, which include lighting management, traffic management, waste management, and other aspects of the urban environment. Cloud computing provides a platform for managing these systems from a central location using data and analytics. Cloud computing provides a flexible and scalable infrastructure for connecting and managing large numbers of Internet of Things devices and sensors. These devices collect data on the state and functioning of urban infrastructure, such as air quality, noise levels, traffic conditions, etc. Cloud computing enables the integration of different systems and applications within smart cities. This ensures better interoperability and the possibility of creating complex solutions that take into account different aspects of urban infrastructure. Cloud computing provides an agile environment for the development, testing, and implementation of new applications and services within smart cities. This enables rapid innovation and contributes to the dynamism and flexibility of smart city projects [69].

In summary, infrastructure as a service and cloud computing are key elements for the development of smart cities, enabling central management, efficient data management, implementation of intelligent solutions and supporting agile development of new applications and services. These technologies contribute to a better quality of life for citizens and to the sustainable development of urban infrastructure.

3.9. Synergies and Potential between Industry 4.0 and Smart Cities

Industry 4.0 and the smart cities concept are initiatives that are shaping modern cities and their economies. Their synergy brings significant opportunities for innovation, efficiency, and sustainability in the urban environment, but they also bring various challenges, for example, in the form of personal data protection and liability for damage in the field of the Internet of Things [70].

The core elements of Industry 4.0 are smart manufacturing and smart logistics. These two elements enable the transformation of smart cities into mature cities. These developments bring new opportunities to optimize and speed up production processes and logistics operations, enable better control of the production process, and increase overall efficiency and adaptability to change. Thanks to these technologies, it is possible to fully automate the production process through robots and automated systems that can perform a myriad of operations with minimal human intervention, increasing accuracy and overall productivity. Robots have sensors, IoT devices, and analytics tools installed in them. The data collected from these sensors provides us with important information about equipment performance, quality, and status, enabling rapid response to potential problems and optimization of manufacturing operations. Integrating these smart technologies into the manufacturing process provides us with tracking, control, and optimization of the flow of materials and products, and at the same time, within smart cities, it is also possible to optimize the quantity of goods and other products delivered based on demand. It is, therefore, possible to forecast demand, minimize inventories, and optimize supply, leading to lower costs and greater efficiency. As machines operate not only in factories but also in ordinary cities (e.g., waste treatment machines, city lighting, etc.), these sensors can help cities to diagnose early, detect faults, eliminate defects, and optimize resource use. For example, sensors in garbage bins can indicate how full the bin is and then adjust waste import/export accordingly. This increases the efficiency of waste collection and is also more environmentally friendly, as garbage pickup will not have to drive to bins that are empty. Also inextricably linked to Industry 4.0 is the concept of predictive maintenance, which makes it possible to anticipate and prevent equipment failures by analyzing data and monitoring their condition. With take-it-or-leave-it maintenance, production downtime, and unplanned repairs can be minimized, reducing operating costs and increasing equipment availability, whether in factories or smart cities [71].

As the authors stated about autonomous vehicles, they contribute to a more sustainable environment in the context of smart cities; the same is true for the integration of Industry 4.0 into smart cities. Industry 4.0 brings higher levels of energy efficiency and sustainability to smart cities, which ultimately minimize environmental impact. Industry 4.0 brings new technological tools and innovations to smart cities, giving them the ability to use available resources efficiently. The digital transformation in industry makes it possible to optimize processes and minimize energy losses, and this energy optimization can be applied equally in smart cities. Intelligent control systems and analytical tools help to identify areas where energy efficiency can be improved and energy consumption reduced. Industry 4.0 technologies enable smart cities to monitor emissions and environmental indicators in real time and, therefore, enable smart cities to better manage their energy systems. Smart cities are also trying to shift the focus of their activities and maximize their consumption of renewable energy sources. Industry 4.0 is very important in this respect as it supports the development of new technologies such as solar panels, wind turbines, and batteries for energy storage. These technologies allow cities to diversify their energy sources and reduce their dependence on fossil fuels [72].

Integrating new technologies and innovations into smart cities increases the competitiveness of their economies internationally and makes them attractive to investors and a highly skilled workforce. It is such modern solutions in cities that make them attractive to foreign investors, and foreign investment massively boosts domestic economies, so it is essential to try as much as possible to implement Industry 4.0 into smart cities. Industry 4.0 and smart cities are creating new jobs in areas like digital technology, smart infrastructures, data analytics, and artificial intelligence, and these jobs require skills and expertise, contributing to increasing the productivity and competitiveness of the workforce [73].

The above aspects demonstrate the potential and benefits that can arise from the synergistic interaction between Industry 4.0 and smart cities. Their joint efforts can lead to the creation of smarter, more efficient, and sustainable urban pro-environments where citizens can live and work with greater comfort and quality of life.

The above statement could work in practice, as shown in the Figure 8. It can be seen that the basis is data sharing between the different elements, and this ensures the smooth running of traffic in the city. This is facilitated not only by data from autonomous vehicles but also by Industry 4.0 technologies. If all the elements can be successfully incorporated, smart cities in the future may look like the following [74].

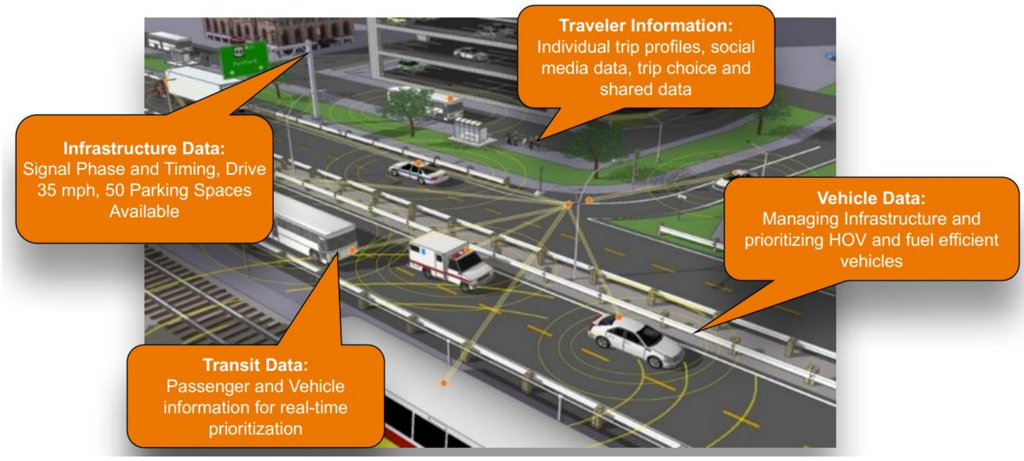

Figure 8. Traffic management and control based on big data, AI, AV and Industry 4.0. Source: AUVSI. Available online: https://thedocs.worldbank.org/en/doc/147471501515848530-0190022017/render/KOTIWB2017MyJ2Moderator.pdf (accessed on 12 March 2024) [74].

4. Discussion

As this article shows, the synergy between Industry 4.0 and smart cities offers significant opportunities for innovation, economic growth, and sustainable development, especially as the integration of modern technologies brings new dimensions to the urban environment and takes cities to the next level, enabling more efficient use of resources, improving the quality of life of citizens and strengthening the competitiveness of cities in the global marketplace, and last but not least, strengthening the economy of the city and of the whole country. With a stronger economy and more financial capital comes new investment, while at the same time, the city opens the door to investment in research and development and support for start-ups. At the same time, however, the risks and challenges that this integration brings must also be addressed, and these include issues around data security, ethical issues, and social inclusion to ensure that all city residents have access to the opportunities and benefits that technological development brings. Working together, Industry 4.0 and smart cities can create dynamic and sustainable urban environments that will serve as a model for future generations and contribute to overall societal well-being and development, which brings us to the fact that the main hypothesis was that this integration will lead to significant improvements in transport efficiency, resource use, and overall city sustainability. The authors consider this hypothesis confirmed, as they have presented a large body of evidence that shows that, despite certain challenges that this integration has to face, the benefits still outweigh the costs.

Automated vehicles bring a new dimension to smart cities in the form of improvements in transport efficiency, as technologies that incorporate automated vehicles are able to interact with smart cities and Industry 4.0 on a wide scale, creating a great opportunity to change the way transport is managed and performed in urban environments. With better coordination of traffic flows and minicongestion mitigation, smoother traffic flow will be achieved, and cars will be enabled to optimize roads through GPS connected to smart cities, which ultimately improves the movement of inhabitants, reduces the stress associated with congestion, and improves the overall sustainability and quality of life in cities. Following on from the above, it is important to highlight that smooth movement, reduced emissions, and a congestion-free city have a positive impact on the environment. With fewer vehicles in queues, greenhouse gas emissions are reduced, while it is true that this environmental aspect is important for sustainable urban development and biodiversity conservation [75].

Improved transport, with all of its associated benefits, such as a better environment, new investments, and a stronger economy, are key benefits of integrating Industry 4.0 technologies and automated vehicles into smart cities.

Another very important finding and conclusion is that this integration has the potential to increase resource efficiency in smart cities, with increased resource efficiency also ensuring a more sustainable urban environment and economy. The integration of Industry 4.0 technologies into smart cities brings new tools and opportunities for better management and use of energy and other resources, for example, in the energy sector, but not only. Smart sensors and analytical tools allow cities to monitor energy consumption in real time and identify areas of waste, with this information enabling more efficient energy management strategies to be put in place, leading to savings and optimized resource use. However, sustainability is no longer only linked to the above benefits. Industry 4.0 technologies in smart cities are a key tool for the transition to renewable energy sources. As an example, smart control systems allow solar and wind resources to be better integrated into the energy grid and managed efficiently, not only increasing the share of renewable energy in the urban grid but also reducing greenhouse gas emissions and dependence on fossil fuels.

These improvements result not only in environmental sustainability but also in economic benefits because the city itself (reduced energy consumption also means less energy distribution and management costs, which can have a long-term positive impact on public finances and the city budget) and its citizens benefit from lower energy costs and increased resource efficiency. On the other hand, low energy costs are attractive for investors and start-ups, and this attracts new investments to the region, and with that comes new jobs and a reduced unemployment rate.

Another important conclusion is that when we look at this integration comprehensively, it has huge potential for the overall sustainability of the city, a key part of which is the integration of Industry 4.0 technologies into smart cities. One of the most important factors affecting the overall sustainability in the city is the issue of efficient, clean and smooth transport, where there are conscious citizens who do not only travel by car but also by public transport and when they need to use a car they use automated electric vehicles because these vehicles contribute to reducing greenhouse gas emissions and other pollutants associated with traditional internal combustion engines. Their use also reduces noise and improves air quality in urban areas, which has a direct positive impact on the health of the population.

Better managed energy systems are another example of how Industry 4.0 technologies are contributing to improving the sustainability of cities, as the intelligent control systems that are part of Industry 4.0 and smart cities themselves enable more efficient use of energy in buildings, public lighting and other components of a city's infrastructure, and this use of technology not only reduces energy consumption but also the costs associated with operation and maintenance.

Smart cities should use smart technologies to better integrate solar, wind, and other renewable energy sources into their energy grids, as such an approach not only reduces dependence on fossil fuels but also strengthens the energy independence and stability of the city [76].

It is also essential to present future authors and researchers with directions on what future research can take. It is important to take into account the dynamics of technological developments and societal changes that affect the integration of Industry 4.0 technologies and automated vehicles into smart cities, specifically pointing out that these trends require constant analysis and monitoring in order to understand their further evolution and their impact on the urban environment and society as a whole.

One possible direction for future research is to look more deeply into the social and economic aspects of the integration of Industry 4.0 technologies and automated vehicles into smart cities. In this paper, the authors did not explore how these technologies affect the lives of the inhabitants, their working environment, and the economic prosperity of the city and, as a result, the socio-economic impacts that can have a significant impact on the overall operation of smart cities and on such integration have not been analyzed in this paper, and at the same time may be a factor that significantly slows down the whole process of integration.

Furthermore, it is also necessary to analyze the ethical and legal aspects of integrating Industry 4.0 technologies and automated vehicles into smart cities because, based on the findings and conclusions of this paper, the authors have discovered issues related to the protection of citizens' privacy, fair access to technological innovations, and, last but not least, the protection of data and data that will be shared between smart cities, automated vehicles, and Industry 4.0. In addition, legal aspects such as the regulation of the use of automated vehicles, liability in the event of accidents or incidents involving them, or the dissuasion of individuals from exercising their legal rights, need to be addressed in more detail in the context of the integration of automated vehicles and Industry 4.0 into the smart city infrastructure [77].

Another important aspect of future research directions is to study the impact of industry integration 4.0 technologies and automated vehicles in smart cities on the labor market and social inclusion, as this aspect has been outlined only very marginally, without any deeper analysis, and it will be important to examine how these technologies affect jobs, skills, and qualifications of the workforce, and what measures need to be taken to ensure that every citizen has access to opportunities and benefits. The authors know that, on the one hand, such integration has a strong potential to create new jobs, but at the same time, it will also destroy a huge number of jobs and leave many people unemployed. Therefore, a discussion on future research directions is key to understanding and managing the impacts of technological innovation on society, the legal system, the economy, and the urban environment. Future studies should address these important issues and contribute to the dealignment of sustainable, equitable, and inclusive smart cities.

In the context of the above, it should be remembered that by 1975, there were only three megacities in the world (New York, Tokyo, and Mexico City). Today, there are 21 such cities. The basic definition of a megacity is that it must have more than 10 million permanent inhabitants. At the same time, the world's 600 largest cities generate up to 60% of the world's total gross domestic product. As the Figure 9 shows, by 2040, up to 65% of the population will live in cities. Cities as they are today, are not sustainable considering the amount of people living in them; therefore, it is imperative to integrate autonomous vehicles and Industry 4.0 into our cities as much as possible to make them smart cities of the highest level as soon as possible so that residents can live in a safe, clean, economically strong, and long-term sustainable city [78].

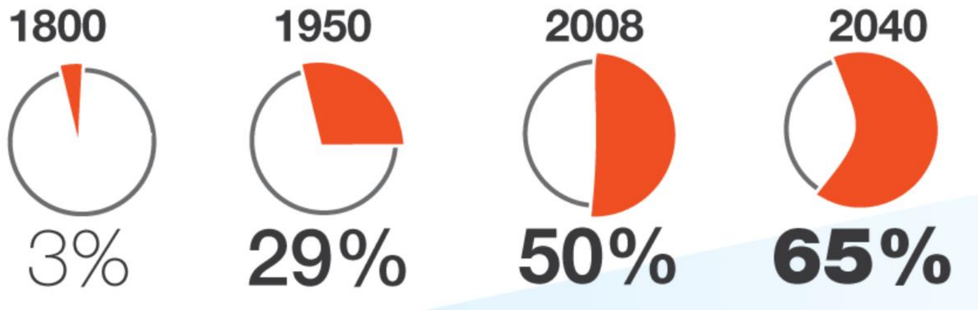

Figure 9. Percent of population living in cities over years. Source: Postscapes. Available online: https://www.postscapes.com/anatomy-of-a-smart-city/ (accessed on 12 March 2024) [78].

5. Conclusions

In the Conclusions, the authors would like to briefly summarize the findings and results that were presented in the Discussion, summarize the benefits and spin-offs of this literature review, and emphasize the novelty of this research. Based on the analysis of the synergies and potential for integrating Industry 4.0 technologies and automated vehicles within the smart city infrastructure, several important conclusions can be drawn.

The first conclusion is that the integration of Industry 4.0 technologies and automated vehicles has a huge potential to transform the urban environment and the way of life of citizens. It is clear that the results of this work clearly show that these technologies can improve transport efficiency, resource use, and the overall sustainability of the city, thus confirming the main hypothesis the authors have set out. To make the conclusion more specific and detailed, it is necessary to look deeper into the specific ways in which the integration of Industry 4.0 technologies and automated vehicles can transform the urban environment and the lives of citizens.

1. Transport Efficiency: The integration of Industry 4.0 technologies, such as real-time data analytics and IoT connectivity, with automated vehicles, has the potential to significantly improve transport efficiency in smart cities. This includes optimized traffic flow, reduced congestion, and enhanced mobility options for citizens. For example, autonomous vehicle fleets can dynamically adjust routes based on traffic patterns, leading to smoother and faster journeys for commuters.
2. Resource Utilization: The adoption of Industry 4.0 technologies enables more efficient use of resources within smart cities. Smart sensors and monitoring systems can optimize energy consumption, waste management, and water usage, leading to reduced resource wastage and lower environmental impact. Additionally, automated vehicles can contribute to resource conservation by reducing fuel consumption and emissions compared to traditional vehicles.
3. Sustainability: By leveraging Industry 4.0 technologies and automated vehicles, smart cities can enhance their overall sustainability. For instance, the implementation of smart grid systems and renewable energy sources can help reduce carbon emissions and dependency on fossil fuels. Moreover, the integration of automated vehicles into public transportation networks can encourage modal shifts away from private car ownership, further reducing pollution and promoting sustainable urban mobility.
4. Quality of Life: The improved transport efficiency, resource utilization, and sustainability facilitated by Industry 4.0 technologies and automated vehicles directly contribute to enhancing the quality of life for citizens. Reduced travel times, cleaner air, and more reliable public services all lead to a safer, healthier, and more enjoyable urban living experience. Additionally, the convenience and accessibility offered by smart transportation systems can improve social inclusion and equity by providing better mobility options for all residents, regardless of their socioeconomic status.

By focusing on these specific aspects, the conclusions highlight the tangible benefits that the integration of Industry 4.0 technologies and automated vehicles can bring to smart cities, aligning with the main hypothesis of the study and providing a clearer understanding of its implications for urban development and citizen well-being.

The second conclusion is that the successful exploitation of this potential requires close collaboration between the public sector, the private sector, academic institutions, and residents because, without such cooperation, it will not be possible to fully realize all the benefits that Industry 4.0 technologies and automated vehicles bring. To provide a more specific and detailed description of the second conclusion, the key stakeholders involved in collaboration should be elaborated on, and the specific areas where their cooperation is crucial for fully realizing the benefits of Industry 4.0 technologies and automated vehicles should be outlined.

1. Public Sector Involvement: Government entities play a central role in setting policies, regulations, and standards that shape the integration of Industry 4.0 technologies and automated vehicles into urban environments. They are responsible for developing smart city initiatives, allocating resources for infrastructure upgrades, and ensuring the safety and reliability of smart transportation systems. Collaboration with the public sector is essential for creating an enabling environment that fosters innovation, supports research and development, and addresses regulatory challenges.
2. Private Sector Engagement: Private companies, including technology firms, automotive manufacturers, and service providers, drive innovation and investment in Industry 4.0 technologies and automated vehicles. Their expertise in developing cutting-edge solutions, such as AI algorithms, sensor technologies, and autonomous vehicle platforms, is critical for advancing state-of-the-art smart city infrastructure. Collaboration with the private sector enables access to advanced technologies, fosters entrepreneurship, and stimulates economic growth through job creation and industry partnerships.
3. Academic Institutions and Research Organizations: Academic institutions and research organizations play a vital role in advancing knowledge and understanding of Industry 4.0 technologies and their applications in smart cities. Through research collaborations, technology transfer initiatives, and educational programs, they contribute to the development of innovative solutions, talent development, and capacity building in the field. Collaboration with academia enhances the quality of research and fosters interdisciplinary approaches to addressing complex urban challenges.
4. Community Engagement and Citizen Participation: Residents are key stakeholders in smart city initiatives, as they are the ultimate beneficiaries and users of urban infrastructure and services. Their input, feedback, and engagement are essential for ensuring that smart city projects meet the needs and preferences of diverse communities. Collaboration with residents through participatory planning processes, citizen science initiatives, and community forums promotes transparency, inclusivity, and social equity in decision making and governance [79].

By emphasizing the importance of collaboration among these stakeholders, the conclusion highlights the interconnected nature of smart city development and underscores the need for coordinated efforts to unlock the full potential of Industry 4.0 technologies and automated vehicles in urban environments.

The third conclusion is that although this integration has enormous synergistic potential and many benefits, it is essential to pay particular attention to the ethical and legal issues associated with the integration of these technologies into the urban environment because, even in the context of existing and effective European Union regulations, it is essential to ensure the protection of citizens' privacy, fair access to technological innovations, and transparent decision-making processes. To provide a more specific and detailed description of the third conclusion, the authors must analyze ethical and legal considerations associated with the integration of Industry 4.0 technologies and automated vehicles into the urban environment.

1. Privacy Concerns: The deployment of IoT sensors, surveillance cameras, and data analytics tools in smart cities raises significant privacy concerns. Citizens' personal data, including their movements, behaviors, and interactions, may be collected, stored, and analyzed by various entities. It is crucial to establish robust data protection regulations and privacy policies to safeguard individuals' privacy rights and prevent unauthorized access or misuse of sensitive information.
2. Equitable Access to Technology: The adoption of Industry 4.0 technologies and automated vehicles should prioritize equitable access and ensure that all segments of the population, including marginalized communities and vulnerable groups, can benefit from technological advancements. Efforts should be made to bridge the digital divide, address socio-economic disparities, and promote inclusive development to prevent the exacerbation of existing inequalities.
3. Transparency and Accountability: Transparent decision-making processes and accountability mechanisms are essential to build trust and legitimacy in smart city governance. Citizens should have access to information about the implementation and operation of Industry 4.0 technologies and automated systems, including data collection practices, algorithmic decision-making processes, and system performance metrics. Public authorities and private entities should be held accountable for their actions and decisions that impact the urban environment and citizens' well-being.
4. Ethical Considerations: The integration of autonomous vehicles and AI-driven systems into urban environments raises ethical dilemmas related to safety, liability, and human–machine interactions. Ethical frameworks and guidelines should be developed to address issues such as algorithmic bias, decision making in critical situations, and the ethical use of personal data. Stakeholders must engage in ethical discussions and consider the societal implications of technology deployment to ensure that smart city initiatives align with ethical principles and values [80].

By highlighting these specific ethical and legal challenges, the conclusion underscores the importance of proactive measures to address them in the integration of Industry 4.0 technologies and automated vehicles into the urban environment. It emphasizes the need for comprehensive regulatory frameworks, ethical guidelines, and public engagement strategies to mitigate risks and promote responsible innovation in smart city development.

The authors can also conclude that the main hypothesis of this paper has been confirmed, as the authors are of the opinion that the integration of Industry 4.0 technologies and automated vehicles within smart city infrastructure will result in significant improvements in transportation efficiency, resource utilization, and overall urban sustainability.

This literature review brings several benefits and spin-offs to the current state of knowledge of this issue. The aforementioned article adds significantly to our understanding of how Industry 4.0 and automated vehicles are integrated into smart cities in a number of ways. The authors have integrated knowledge from many sources and carried out a methodical analysis of the literature that is currently in existence. This method made it possible to present a thorough summary of the ways that Industry 4.0 and smart cities complement one another. The review delineates the principal themes and factors that impact the assimilation of Industry 4.0 technology and automated vehicles inside metropolitan settings. These results can be used as a springboard for additional investigation and learning in the area of urbanization and smart cities. The advantages and difficulties of integrating Industry 4.0 and automated vehicles into smart cities are covered by the writers of this paper. This critical viewpoint makes it possible to comprehend the advantages and disadvantages of this technology revolution in urban settings. Since the article outlines the major advantages of incorporating Industry 4.0 technologies into smart cities, it can be used as background knowledge by those making decisions about urbanization to help them create policies and plans for urban growth.

The synthesis of available data and the aforementioned conclusions point to a number of avenues for future research on the integration of Industry 4.0 and automated vehicles into smart cities.

1. A closer examination of the technical components: future research should concentrate more on the technology and technical issues of incorporating automated vehicles and Industry 4.0 into smart cities. On the one hand, it is important to analyze automated vehicles, but the potential of these vehicles also lies in so-called connected automated vehicles. So not only will the vehicles drive automatically and share information with the city, but they will also share this information with each other in an anonymized form to ensure that personal data is protected and, on the other hand, to ensure maximum use of these vehicles. As some authors state, "Connectivity is the key to promoting autonomous and sustainable mobility". Investigating developments in sensors, artificial intelligence, IoT, connectivity, and other related technologies that support smart urbanization is part of this [81].
2. Social and economic aspects: further research should focus on the social and economic implications of integrating Industry 4.0 and automated vehicles into smart cities. This includes an analysis of the impact on the labor market, social inclusion, equal opportunities, and the improvement of the quality of life of citizens.
3. Ethical and legal issues: It is also important to examine the ethical and legal issues related to the use of automated vehicles and Industry 4.0 technologies in urban environments. This includes issues related to privacy, security, liability, and regulation of these technologies.
4. Innovations in policies and regulations: further research should also focus on innovations in policies and regulations that support the integration of Industry 4.0 and automated vehicles in smart cities. This includes creating supportive legislative frameworks, policies, and initiatives that promote technological innovation and sustainable development in urban environments.
5. Comprehensive impact assessment: Further research should include a comprehensive assessment of the impact of the integration of Industry 4.0 and automated vehicles into smart cities on different aspects of urban life. This includes an assessment of the environmental, social, economic, and technological implications of this integration [82].

The manuscript provides significant findings that have important implications for the development of technology integration in cities because this literature review highlights the very strong transformative potential of integrating Industry 4.0 technologies and automated vehicles into smart city infrastructure. This transformative potential stems from the synergistic interactions between Industry 4.0 technologies, characterized by advanced automation, data exchange, and artificial intelligence, and the deployment of automated vehicles within the smart city landscape. The integration of Industry 4.0 technologies and automated vehicles holds the promise of revolutionizing urban landscapes by redefining traditional notions of mobility, efficiency, and sustainability. Through the advanced integration of smart technologies, urban infrastructure becomes more responsive, adaptive, and efficient, facilitating enhanced resource utilization and optimized service delivery. Automated vehicles, equipped with advanced sensors, connectivity, and autonomous capabilities, play a pivotal role in reshaping transportation systems, offering safer, more efficient, and environmentally sustainable mobility solutions. Moreover, by harnessing the power of real-time data analytics, predictive modeling, and AI-driven algorithms, the integration of Industry 4.0 technologies and automated vehicles enables dynamic optimization of urban operations, ranging from traffic management to energy distribution. This optimization not only enhances operational efficiency but also fosters a more sustainable urban ecosystem by minimizing energy consumption, reducing traffic congestion, and mitigating environmental impact.

Thanks to a comprehensive view of this integration, the article describes how modern smart cities should look and enriches this issue with practical examples from practice that either confirm or create room for a broader understanding of the individual findings. By taking into account various factors, such as transport efficiency, resource use, and citizen engagement, the findings offer insights into the multifaceted nature of urban development and the strong synergistic potential between technology and urbanization. By employing a systematic literature review methodology, the research provides a rigorous analysis of existing knowledge in this area. By synthesizing different sources and identifying gaps in the literature, these findings contribute to a better scientific understanding and provide a solid foundation for future research and policy initiatives. As mentioned above, future research may address, for example, a closer examination of the technical issues of smart cities, social and economic aspects, and ethical and legal issues, or future research may evolve towards the analysis of a particular smart city. Our future research will build on this article and the related literature and will analyze the Slovak capital city, Bratislava, in terms of smart city criteria. Drawing on insights from multiple disciplines, including urban planning, transportation engineering, and information technology, the study offers interdisciplinary perspectives on urban innovation. By bridging disciplinary boundaries, the findings foster collaboration and dialogue between researchers, policymakers, and industry stakeholders, facilitating the development of innovative solutions to urban challenges.

However, this research not only focuses on the theoretical analysis of this issue but also offers practical implications for urban policymakers, planners, and industry practitioners. It is important to say that it is these practical examples that allow city authorities to try to adapt their cities in today's times because the investments they make today can be capitalized in the future in the form of obtaining much higher investments and associated positive factors, such as a decrease in unemployment, growth in city performance, and so on. All of these findings are backed by relevant data from databases, so it is not just about theoretical assumptions, it is about the real development of this market, which brings a huge amount of opportunity. If cities can be inspired by our research, it will ultimately bring huge opportunities for cities to develop.

In summary, this article represents significant advancements in our understanding of the integration of Industry 4.0 and automated vehicles in smart cities. It gives a thorough summary, examines the advantages and difficulties, and presents a critical evaluation that can be used as a foundation for more study and tactical choices in this area. Finally, the authors would like to stress the importance of continuing research in this area, as there is still much room for improvement.

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