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Metaverse Meets Smart Cities—Applications, Benefits, and Challenges

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Abstract: The metaverse aims to merge the virtual and real worlds. The target is to generate a virtual community where social components play a crucial role and combine different areas such as entertainment, work, shopping, and services. This idea is explicitly appealing in the context of smart cities. The metaverse offers digitalization approaches and can strengthen citizens' social community. While the existing literature covers the exemplary potential of smart city metaverse applications, this study aims to provide a comprehensive overview of the potential and already implemented metaverse applications in the context of cities and municipalities. In addition, challenges related to these applications are identified. The study combines literature reviews and expert interviews to ensure a broad overview. Forty-eight smart city metaverse applications from eleven areas were identified, and actual projects from eleven cities demonstrate the current state of development. Still, further research should evaluate the benefits of the various applications and find strategies to overcome the identified challenges.

Keywords: metaverse; smart city; smart municipality; applications

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1. Introduction

The metaverse aims to merge the virtual world with the real world. The target is to generate a web of virtual communities where social components play a crucial role and combine different areas such as entertainment, work, shopping, and services [1]. The metaverse is not a new concept. Neal Stephenson explained the metaverse in his 1992 novel "*Snow Crash*" [2]. The metaverse is an accumulation of various topics that have become increasingly popular in recent years due to technical and social developments [3]. Applications have existed for many years, particularly in gaming, where virtual worlds and avatars interact with digital objects. Due to the current transformation of Web 2.0 to Web 3.0, the metaverse is increasingly focused, as it implements essential elements such as decentralization and openness from the ground up [4]. This is reflected in the interest of the economy, as large companies and governments are investing huge sums in the development of the metaverse. For example, the Republic of Korea invested around 185 million US dollars in 2022 to build a metaverse ecosystem and metaverse infrastructure that is reliable for users and local companies [5]. Social change is contributing to the development of the metaverse, as the COVID-19 pandemic has highlighted the need for virtual applications and their connection to the physical world, as well as the opportunities that digital life offers [6]. For example, regardless of location, users can view digital twins in virtual reality environments with business partners worldwide or experience virtual, interactive festivals and events in their favorite computer game [7]. The interest in the metaverse is also reflected in the growing interest of large tech companies. In October 2021, for example, the social media company Facebook changed its name to Meta [8]. The steadily increasing number of users [3] indicates the acceptance and development of the medium. Gaming and gaming applications make up the majority of metaverse applications available on the market to

date [9]. Virtual retail spaces are also popular with significant brands [10]. Components such as avatars, digital objects, goods, and interaction and communication options play a vital role in the applications. Services, social meeting places, digital currencies, works of art, properties, buildings, and other 3D models, which are, in part, digital images of reality, are integrated into the virtual worlds to expand the range of functions [3]. Technological progress is constantly producing innovations and technologies that enable the development of innovative applications in the context of the metaverse. Increasingly powerful computer architectures, optimized operating systems, intelligent programs, and artificial intelligence enable developments that make the intersection of virtual and physical worlds increasingly real. Machine learning and artificial intelligence are currently enabling cross-industry technical advances. For example, direct voice communication with computer-controlled avatars is possible through the automated processing of human speech. Automatically generating content and optimizing applications and models is becoming increasingly easy [11].

One area in which the metaverse has great potential is the area of cities and municipalities. A smart city is often defined as leveraging information and communication technologies to increase the quality of life, resource efficiency, and sustainability [12–14]. Cities have been transforming in recent years, driven by the wave of digitalization and the coronavirus crisis, which led to the digitalization of processes and automation of procedures. Smart cities use data enriched with experience and information to make various areas smarter and derive insights [15]. While many large cities have already implemented smart city applications, small- and medium-sized cities and municipalities are currently undergoing digital transformation. Digitization measures are being implemented in municipal and urban structures, and established processes are being revised [16]. The metaverse offers approaches to digitalization and can strengthen citizens' social community. This creates the first contact points between the metaverse and smart city applications. The concept of smart cities is based on data and technologies that record a wide range of conditions in the city, making them more efficient and livable. IoT sensors, in particular, are used to provide access to the data sources. The data collected forms the basis for processing with AI and data science methods and generates data-based insights. The existing data are an ideal basis for use in the metaverse, as interfaces are available and a comprehensive infrastructure is established [17]. The metaverse supplements the smart city with essential components, such as virtual participation in urban planning processes, to enable citizens' involvement. For example, the German city of Aalen plans a virtual town hall meeting to foster direct communication between citizens, administration, and politics [18]. Furthermore, smart city metaverse applications can make life much easier by integrating virtual citizen services, remote workplaces, real-time traffic and transportation information, and education and health services. By closely connecting the real and virtual worlds, cities can respond more effectively to challenges such as traffic management, environmental protection, and energy efficiency [4]. However, there are ethical and social issues to consider, such as data protection, the security of virtual spaces, and potential social inequality in access to technologies [19]. Nevertheless, the potential applications of the metaverse in the smart city sector offer a promising opportunity to transform cities and shape people's lives in new, innovative ways.

As the metaverse can be used in many areas and affects different areas of people's lives, it is essential to identify how it can be used effectively in the urban environment. This gives rise to the following research questions:

What potential use cases does the metaverse offer in the smart city sector, and what applications and benefits are there?

Which challenges do smart city metaverse applications inherit?

By answering these research questions, the study contributes a comprehensive overview of potential and already implemented metaverse applications in the context of cities and municipalities. This indicates which applications have already been implemented and which are still waiting to be realized. In addition, challenges related to these applications

are identified. Thus, the paper provides researchers and practitioners with a guide to smart city metaverse applications. It identifies potential benefits and challenges and indicates which stakeholders in a municipality are affected. Furthermore, the study indicates which smart city metaverse applications are specifically popular, i.e., which applications have already been implemented frequently.

The remaining paper is structured as follows: Section 2 presents the metaverse technology stack. The current state of research on the metaverse in the smart city context is described and analyzed in Section 3 to provide context for this paper. The Section 4 presents the research methodology used and the material generated. This includes explaining the steps and techniques used to collect and analyze the data. Section 5 presents the research outcomes, including potential metaverse applications in the smart city context and concrete examples from real-world practice. The challenges for the smart city metaverse are identified. The findings are then discussed in Section 6, examining advantages and disadvantages and possible solutions. Finally, Section 7 summarizes the paper's conclusions and provides an outlook on future developments.

2. Metaverse Technology Stack

The metaverse requires various technical components to operate. These can be described in different models. The term technology stack combines computer science and software development terms to describe a collection of technologies, frameworks, and tools [20]. It shows which components are necessary and how they work together to create a specific application or platform. In the context of the metaverse, the technology stack refers to the various technologies used to support the virtual ecosystem of the metaverse and enable the activities within it [21]. In this study, we mainly build on a technology stack introduced by Lee et al. [1], with additions based on an article by Kaya Kuru [22]. Our depiction of the relevant layers is presented in Figure 1.

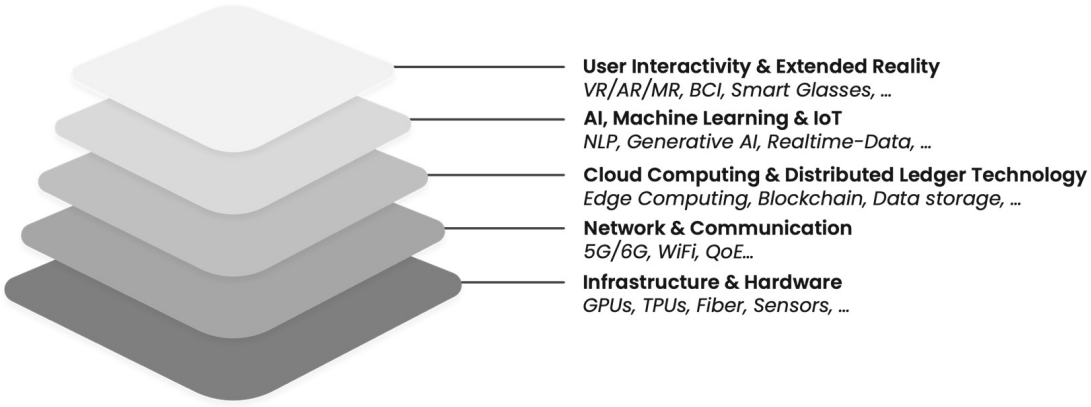

Figure 1. Metaverse technology stack layer (own presentation based on the contents of [1,22]).

The individual components of the stack are explained below:

- Infrastructure and Hardware: The metaverse's infrastructure and hardware comprise the physical layer required to operate and interact with virtual worlds. This includes powerful servers, network connections, and specialized technology, such as high-performance computing cores like Graphics processing units (GPUs) or Tensor processing units (TPUs). to enable reliable and low-latency experiences [19].
- Network and Communication: Networks and reliable data protocols that enable high data quality are required to provide enormous amounts of data with low latency. Wireless networks play a vital role here, as they significantly increase the quality of experience (QoE) compared to wired networks due to freedom of movement and availability. In addition to the data rate and throughput, the networks' scalability plays a key role in enabling low latency [8].

- Cloud Computing and Distributed Ledger Technology: Distributed Ledger Technology (DLT) in the metaverse refers to technologies such as blockchain that enable decentralized data management. DLT secures digital assets, authenticates users, and creates a trusted environment for transactions within the metaverse [22].
- AI, Machine Learning, and IoT: Artificial intelligence and machine learning are crucial elements in the metaverse, as they enable dynamic and interactive design of the virtual worlds. AI enables personalized experiences, intelligent avatars, and non-player characters (NPCs) with real-time translation over natural language processing (NLP), and it adapts the virtual environment to user behavior. However, the provision of real-time data via efficient IoT sensors also enhances a feeling of immersion by creating real-life conditions [1].
- User Interactivity and Extended Reality: People can use different types of interfaces to interact with the metaverse environment. These include intuitive input devices such as hand and gesture recognition, data glasses for immersion in virtual worlds, and spatial computing applications that enable people to move freely in the virtual world and interact with digital objects [23].
- To demonstrate the interaction of the individual layers and the need for interaction, an example application from the smart city context is explained: various technologies from the metaverse stack are required to provide a metaverse citizen platform for digital events. The infrastructure and hardware include potent servers, GPUs, and TPUs to ensure a smooth experience at digital events. Wireless networks enable improved freedom of movement and availability for participants, while cloud computing and distributed ledger technology ensure the security of digital assets and transactions. AI and machine learning provide personalized experiences and interactive virtual environments, while IoT sensors provide real-time data to enhance immersion. Intuitive input devices and augmented reality options allow users to interact freely in the virtual world and experience digital events in an immersive way.

3. Related Work

A comprehensive qualitative literature and internet search was conducted to identify related works to this study. The literature databases Google Scholar, Scopus, and Web of Science were searched, each with the search terms “Smart City Metaverse”, “Urban Metaverse”, “Municipality Metaverse”, “Metaverse City Applications”, and “Metaverse Risks Challenges”. We found that five search results particularly addressed the applications and challenges in the context of the metaverse in combination with the smart city. These studies were then selected for a more detailed review and comparison.

In their study, Allam et al. examine how digital platforms are shaping urban life, focusing on the emergence of the metaverse as a virtual city concept. They explore the potential impact on urban planning, services, and social dynamics, highlighting both opportunities and concerns for policymakers and researchers [4].

Yaqoob et al. highlight the growing global trend towards the metaverse and its potential to revolutionize smart cities through immersive digital spaces. They discuss the benefits, technologies, and research challenges associated with utilizing the metaverse for innovative smart city applications and outline future research directions for its integration [24].

An article by Chen Zefeng et al. discusses the connection between the concept of the smart city and the rise of the metaverse. The authors emphasize the opportunities that the metaverse offers for promoting smart cities. They introduce the future vision and applications of smart cities based on the metaverse. In addition, they explain the technologies for smart cities in the metaverse and existing solutions. Despite the potential of the metaverse, some concerns and unresolved problems are also discussed [19].

Jie Wang and Gabriella Medvegy address various influencing factors, such as the listing of Roblox on NASDAQ and the introduction of the “metaverse city” Seoul, thereby shedding light on the metaverse in different contexts. The article compares various research trends in connection with the metaverse to possible integration into smart cities [25].

An article by Kaya Kuru deals with the connection between virtual worlds and the metaverse from the urban quality-of-life perspective. Specifically, the paper analyzes ways the metaverse can be integrated into the smart city ecosystem to improve quality of life [22].

Although these studies deal with relevant aspects, they only cover partial areas and do not provide a comprehensive presentation of the areas of application and challenges of the metaverse in the context of the smart city. Furthermore, the challenges are not explicitly assessed in connection with the possibilities of the smart city but are considered in a purely abstract manner. This means that there is still a research gap concerning a comprehensive and practice-oriented consideration of the potential of the metaverse for the smart city. It is considered timely and valuable to fill this gap by collecting a comprehensive overview of smart city metaverse applications and challenges.

4. Materials and Methods

The study focuses on evaluating the metaverse's application potential in the smart city context. A systematic approach has been applied, combining different research methods, particularly qualitative and inductive approaches. This research aims to develop a comprehensive understanding of the metaverse's areas of application and identify concrete potential applications. The insights gained were validated through real-world examples and considered in terms of potential smart city applications and their technological requirements.

The first phase of the research involved extensive qualitative literature and internet research to create a list of relevant application areas in the context of the metaverse. The literature research was carried out to provide a comprehensive basis for understanding the current knowledge about the smart city metaverse and identify potential applications. The online literature databases Google Scholar, Scopus, and Web of Science were searched with the search terms "Smart City Metaverse", "Urban Metaverse", "Municipality Metaverse", "Metaverse City Applications", and "Metaverse Risks Challenges". The search included peer-reviewed journal articles, as well as articles in books and conference contributions, in order to consider a wide range of relevant sources.

The first ten results per search term were analyzed to ensure a balance between completeness and manageability of the literature review. Of the 146 suggested articles, 112 unique results remained after removing the duplicates. Upon closer examination of these results, 19 studies were relevant to the research focus. Special attention was paid to current publications published within the last five years and with a high number of citations to ensure that the information collected is up to date and has a significant impact on the scientific community.

To identify already existing applications in the urban environment, in addition to the scientific sources, various online sources were used to identify an extensive portfolio of different applications. The non-scientific online sources were researched via the search engine Google with the search terms "Metaverse application city", "Metaverse application smart city", "Metaverse smart city", "Metaverse citizen", and "Metaverse real application". Results were only considered if at least three independent sources equally described them. In addition to the literature research, three expert interviews were conducted to complete and compare the identified applications and challenges. For this purpose, three experts from different industries who are publicly active in the field of the metaverse were chosen. The first expert is a research executive at a university metaverse lab. Expert two supervises metaverse industry projects as head of development. The third expert is the chief marketing officer at a company that deals with blockchain, NFTs, and 3D models for the metaverse. The experts were intentionally selected from different industries to cover different perspectives and requirements.

The research methods provided a thorough approach to studying the smart city metaverse and its applications. An extensive search of literature databases and consideration of recent publications within the last five years ensured that the information gathered was up to date and significantly influenced the scientific community. Including non-scientific sources via online search engines complemented the literature search to capture a compre-

hensive portfolio of different applications. Interviews with experts from different industries provided practical insights and enabled the consideration of different perspectives and requirements. The results from the literature review and expert opinions were combined to create a complete picture of the potential applications and challenges associated with the smart city metaverse. These methods were chosen to capture a broad range of information and provide a sound basis for the scientific work.

5. Results

The results gathered with the methods explained in Section 4 are presented in the following section. Firstly, potential applications were collected from the literature and internet research. Forty-eight smart city applications are accumulated and explained in Section 5.1. Then, in Section 5.2, the involved stakeholders and their individual benefits are presented. Section 5.3 explains real-world examples of smart city metaverse applications from eleven cities worldwide. These examples are mapped to the applications from the first section, indicating how often specific applications have been implemented as of today. Section 5.4 finally presents critical challenges extracted from literature research and expert interviews.

5.1. Potential Applications in the Smart City

Table 1 provides an overview of fields of metaverse applications in a smart city context and the corresponding applications. In addition, it addresses the stakeholders responsible for providing the metaverse infrastructure and the individual components, as well as those who benefit significantly from the applications. Further details on each field are provided below. Section 5.2 addresses the stakeholders in metaverse applications.

Table 1. Smart city metaverse applications.

Field of Application	Application	Stakeholders
City Planning & Simulation	Urban planning	Administration, planning offices, public authorities
	Risk planning	Administration, public authorities
	Digital City Twin	Administration, industry, building yard
	Environmental monitoring and management	Administration, legislator
	Planning tool for renewable energies and potential savings	Administration, citizens, authorities
Administration & Optimization	Monitoring of Smart Buildings	Administration, property manager
	Tracking the use of resources and consumption optimization	Administration, building yard
Citizen Services & Participation	Digital administration services	Administration, citizens
	Digital forms	Administration, citizens
	Virtual customer centers	Administration, citizens
	Digital citizen ID	Administration, citizens
	Citizen participation and virtual voting	Administration, citizens, politics
	Provision of city-related real-time information	Citizens, tourists
	Provision of information on measures and funding opportunities	Citizens, industry, clubs

Table 1. *Cont.*

Field of Application	Application	Stakeholders
Entertainment & Life Quality	Virtual events and exhibitions	Citizens, tourists
	Social meeting places	Citizens
	Support for local clubs, voluntary work, and charitable projects	Citizens, clubs, non-governmental organisations (NGOs)
	Inclusive and barrier-free offers	Citizens
Education & Universities	Virtual classrooms	Students, teachers
	Virtual education and training of adults	Citizens, industry, job center
	Interactive learning media	Students, teachers, citizens
	Research environment and meeting place for experts	Students, teachers, experts
Healthcare	Telemedicine	Doctors, patients, health insurance companies
	Preventive courses and training	Doctors, patients, health insurance companies
	Expert exchange	Doctors, medical staff
	Remote monitoring of health parameters	Health insurance companies, citizens, doctors
Tourism	Virtual city tours	Citizens, tourists, retail
	Virtual sights	Citizens, tourists
	City Marketing	Administration, citizens
Public Authorities	Real-time status and response options	Administration, public authorities
	Realistic training environment	Public authorities
	Monitoring compliance with laws and safety standards	Public authorities
	Optimization of workflows and processes	Administration, public authorities
Transportation, Infrastructure & Grids	Status Visualization	Administration, citizens
	Planning and forecasting of capacity utilization	Administration, citizens, public authorities
	Development of smart grids in the water, electricity, gas and internet sectors	Administration, energy providers, city services
Economy	Payment platform	Administration, banks, industry
	Digital properties	Administration, citizens
	Digital products	Administration, industry
	Digital jobs and placement of the unemployed	Industry, job center
Retail & Industry	Virtual shopping centers and retail platforms	Retail, industry, citizens
	Marketing platform for local businesses	Retail, industry
	Provision of digital workplace offerings	Administration, industry, citizens
	Provision of a platform for SMEs to simulate and optimize production and logistics	Industry
Governance & Policy Making	Platform for strategic decision-making	Politics, administration
	Simulation of legislative procedures	Politics, administration

Table 1. *Cont.*

Field of Application	Application	Stakeholders
Cultural Heritage Preservation	Presentation of local cultural assets	Administration, clubs, citizens, tourists
	Community offerings for the preservation of culture and customs	Administration, clubs, citizens

City Planning and Simulation: The application of the metaverse in a smart city opens up new horizons for advanced urban planning and simulation tools that enable a comprehensive digital representation of the urban environment. Using sophisticated algorithms and real-time data integration, stakeholders are immersed in highly detailed virtual environments that accurately reflect the complexity of the physical urban landscape. These urban planning simulations in the metaverse facilitate joint decision-making between administrations, planning offices, and public institutions. By simulating different urban development scenarios and risk assessments, stakeholders can evaluate the potential impact of proposed changes on infrastructure, the environment, and community wellbeing [25]. The city's digital twin provides a dynamic platform for continuously monitoring and managing environmental parameters to ensure sustainable growth and resilience. Stakeholders use these simulations to optimize the use of renewable energy, minimize resource consumption, and increase efficiency. The integration of predictive analytics and scenario planning allows administrators to anticipate future energy needs and strategically allocate resources to maximize savings and minimize environmental impact [25]. This collaborative approach encourages innovation and data-driven decision-making, leading to more resilient and sustainable urban development. From the expert interviews, it became clear that planning components can have particular benefits regarding the more efficient use of resources, better quality of life for citizens, and a more robust infrastructure for the future.

Administration and Optimization: The metaverse application provides a comprehensive platform for management and optimization tools that can improve various aspects of city operations. By leveraging real-time data streams and predictive analytics, these tools provide administrators and real estate managers with valuable insights to increase efficiency, reduce costs, and promote sustainability. Virtual representations of buildings and infrastructure allow stakeholders to monitor resource usage, identify inefficiencies, and develop targeted optimization strategies [24]. Interactive dashboards and simulation models allow administrators to explore different scenarios and assess the potential impact of operational changes on energy consumption, waste management, and overall performance. Furthermore, these tools facilitate seamless communication and collaboration between stakeholders, making it possible to optimize resource allocation and improve management processes [26]. According to the experts interviewed, cities can achieve greater transparency, accountability, and responsiveness in managing their resources and delivering services to citizens by harnessing the power of the metaverse. This ultimately leads to more effective and efficient city administration and citizens' greater sense of wellbeing.

Citizen Services and Participation: The metaverse opens up new possibilities for digitizing various citizen services that were previously analog, making the work of administrations and citizens alike easier. Virtual customer centers, digital forms, and interactive platforms enable citizens to access information, submit applications, and participate in decision-making processes anytime and anywhere [22]. Digital citizen ID cards ensure secure authentication and enable access to personalized services. Virtual voting platforms allow citizens to express their opinions and actively contribute to shaping the future of their community. Real-time information ensures that citizens are always informed about city-related news, events, and opportunities, fostering a sense of belonging and civic pride. Using the metaverse to improve citizen services and participation, cities can create more inclusive and responsive governance structures based on transparency, accountability, and public engagement [4]. This digital transformation empowers citizens to actively participate in shaping their urban environment, ultimately leading to more resilient, equitable,

and sustainable cities. The benefits of such development are directly tangible for both the administration and the citizens and contribute to a vibrant and livable city [22].

Entertainment and Life Quality: Citizen satisfaction is a fundamental characteristic of a city, and the metaverse offers ways to increase it. Entertainment and quality-of-life initiatives are crucial in improving overall wellbeing. Through virtual events, exhibitions, and social meeting places, citizens can socialize, have cultural experiences, and participate in leisure activities without physical limitations. Virtual reality technology enables citizens to immerse themselves in a diverse cultural offering, visit historical sites, and interact with local artists and performers from anywhere globally [19]. Inclusive and accessible virtual environments ensure that everyone, regardless of physical ability or location, can access and enjoy these experiences. Furthermore, the metaverse offers opportunities to support local associations, volunteer work, and charitable projects, allowing citizens to contribute to their community significantly. These initiatives foster a sense of belonging, connectedness, and common purpose, contributing to the smart city's overall quality of life and social cohesion [4]. The experts also confirmed this during the interviews. Promoting entertainment and cultural offerings in the metaverse also helps to make urban life more dynamic, diverse, and lively, thereby improving the wellbeing of citizens in the long term.

Education and Universities: Educational institutions and universities face the challenge of widening access to education and promoting collaboration between students, teachers, and researchers. The metaverse offers a solution using virtual environments to create innovative learning opportunities [25]. Virtual classrooms enable interactive learning experiences that are independent of physical boundaries. This allows students to participate in lectures, discussions, and group activities from anywhere worldwide. This flexibility opens up new opportunities for learning and encourages collaboration across geographical distances. For adult learners, virtual education and training programs offer personalized learning paths based on individual career goals and interests. Interactive learning media such as simulations, virtual labs, and educational games promote critical thinking, problem-solving skills, and creativity. Experts can share knowledge, exchange ideas, and collaborate on interdisciplinary projects in metaverse research environments. These collaborative spaces promote innovation and accelerate progress in various fields. By breaking down traditional barriers to education and research, the metaverse democratizes access to knowledge and accelerates innovation. Ultimately, this contributes to a more educated and knowledgeable workforce equipped to meet modern workplace demands [4].

Healthcare: In the healthcare sector, the metaverse opens up new opportunities for digital healthcare services such as telemedicine, prevention programs, and remote monitoring solutions that can be seamlessly integrated into virtual applications. Virtual clinics and telemedicine platforms connect patients with healthcare providers and enable remote consultations, diagnoses, and treatment plans without physical appointments [22]. Preventive programs use advanced data analytics and behavioral analysis to promote healthy lifestyles, develop personalized health interventions, and prevent the onset of chronic diseases. One of the experts described this opportunity in the interview, saying that by integrating remote health monitoring devices, vital signs and health data can be recorded in real time, allowing healthcare providers to continuously monitor the health of their patients and proactively intervene when necessary. This was also confirmed by the publication of Yaqoob et al. [24]. The metaverse facilitates collaboration and knowledge sharing between healthcare professionals through virtual conferences, seminars, and expert networks. Using these technologies, cities can improve access to healthcare services, reduce health inequalities, and support individuals in taking control of their health and wellbeing. This ultimately contributes to a healthier and more resilient community by making healthcare more effective and accessible [27].

Tourism: According to the experts interviewed, the tourism industry, in particular, will play a key role in future applications and will benefit significantly from them, as the virtual experience of travel destinations, sights, and cultural attractions from the comfort of their own homes will provide users with an easy way to travel. Virtual city tours offer

interactive experiences with historical context, cultural insights, and exclusive behind-the-scenes looks at landmarks and attractions. Virtual reality technology allows visitors to experience destinations in a highly realistic and immersive manner, engaging all the senses and creating unforgettable experiences. Virtual tourism platforms offer curated itineraries, interactive maps, and guided tours catering to various interests and preferences [22]. In addition, the metaverse is a powerful marketing tool for cities, allowing them to showcase their unique offerings, attract visitors, and promote tourism-related businesses and services. Using virtual tourism initiatives, cities can expand their reach, diversify their tourism offerings, and improve the visitor experience. This contributes to economic development and allows people from different parts of the world to discover and experience new cultures without physically traveling [4].

Public Authorities: The metaverse provides government agencies with advanced technologies and data-driven insights to optimize city operations, improve service delivery, and streamline administrative processes. Real-time monitoring and response systems provide the administration with up-to-date information on the status and performance of the city, so that emerging issues can be identified and citizens' needs can be responded to quickly [19]. Virtual training environments allow agencies to simulate various scenarios, train personnel, and refine emergency protocols in a safe and controlled environment. Tools to monitor compliance with laws, regulations, and safety standards ensure accountability and transparency in city operations. In addition, the metaverse facilitates collaboration and knowledge sharing between agencies by enabling the exchange of best practices, sharing of resources, and coordination of actions between departments and agencies. By harnessing the power of the metaverse, cities can improve the efficiency, effectiveness, and responsiveness of public services, ultimately improving the quality of life for residents. Integrating these technologies into the public sector helps modernize administration and promote efficient, transparent, and citizen-centric governance [28].

Transportation, Infrastructure, and Grids: Seamless integration of traffic, infrastructure, and networks in virtual environments provide stakeholders with real-time insights and predictive analytics to optimize urban mobility, infrastructure, and resource management [25]. Status visualization tools provide interactive maps, dashboards, and data visualizations that enable stakeholders to monitor traffic routes, infrastructure projects, and network operations in real time. According to one industry expert interviewed, predictive modeling and forecasting capabilities enable managers to anticipate demand, optimize capacity utilization, and plan infrastructure investments to accommodate future growth and changing mobility patterns. Virtual representations of smart grids facilitate the integration of renewable energy sources, optimize energy distribution, and improve the grid's overall reliability and resilience. In addition, the metaverse serves as a platform for testing and evaluating new transportation technologies, infrastructure concepts, and network management strategies in simulated environments. By harnessing the power of the metaverse, cities can create more efficient, sustainable, and resilient transportation and infrastructure systems that meet the needs of citizens and promote economic growth and development. Integrating these technologies and analytical tools into urban planning and infrastructure management helps improve mobility, use resources more efficiently, and enhance the quality of life for residents [24].

Economy: The metaverse has the potential to reshape local economies through digital platforms, virtual marketplaces, and innovative business models, which can have a positive impact on economic growth, entrepreneurship, and job creation. Virtual payment platforms enable secure and seamless transactions that allow businesses and consumers to conduct commerce across virtual and physical environments. Digital products and services open new business opportunities to monetize digital assets, expand reach, and improve customer loyalty [24]. Virtual employment services connect employers with qualified workers, facilitating talent recruitment and workforce development initiatives. In addition, the metaverse provides a fertile environment for innovation and entrepreneurship. It enables start-ups and SMEs to experiment with new business ideas, test market demand, and scale

their activities in virtual environments. By harnessing the power of the metaverse, cities can boost economic activity, foster innovation, and create new opportunities for prosperity and growth. Integrating these digital platforms into local economies can create a more dynamic and resilient economic landscape that benefits businesses and consumers [25].

Retail and Industry: Virtual environments enable retailers and industry to create realistic shopping experiences, promote products, offer customer services, and optimize production and logistics processes. Virtual malls and retail platforms offer consumers a highly interactive and personalized shopping experience [22]. They can explore products, interact with brands, and shop from anywhere in the world. Marketing platforms for local businesses provide retailers and manufacturers with a digital shop window to showcase their products, target specific customer segments, and drive sales. Virtual simulations enable small- and medium-sized enterprises to optimize production processes, streamline the supply chain, and minimize costs while maximizing efficiency and competitiveness. The metaverse also serves as a testing ground for new retail concepts, industrial designs, and business models. It allows stakeholders to experiment with innovative ideas and technologies in simulated environments [24]. The interviews revealed that integrating virtual retail and industry initiatives supports cities and local businesses, boosts economic growth, and creates a vibrant and resilient urban economy. Integrating these digital platforms into retail and industry helps increase efficiency, improve customer experience, and strengthen competitiveness. According to the interviewees, enormous markets are already emerging, especially in the fashion industry.

Governance and Policymaking: The metaverse offers a unique opportunity to improve governance and policymaking through digital platforms, simulation tools, and data-driven insights. It enables stakeholders to collaborate, analyze, and implement effective policies and strategies to address urban challenges. Virtual platforms for strategic decision-making provide policymakers with interactive dashboards, scenario modeling tools, and simulation environments. These enable them to explore policy options, assess their potential impacts, and make informed decisions [29]. Simulation tools allow stakeholders to simulate legislative processes, test policy proposals, and evaluate their effectiveness in addressing complex urban challenges. Using advanced analytics and artificial intelligence, cities can identify trends, anticipate future scenarios, and develop proactive policies and strategies that promote sustainability, resilience, and equitable growth [6]. The metaverse also serves as a platform for civic engagement, public participation, and transparency. It allows citizens to contribute to policymaking, hold elected officials accountable, and advocate for their interests and priorities. By utilizing the metaverse, cities can create more inclusive, responsive, and effective governance structures that empower citizens, foster trust, and improve the overall quality of life for residents. Integrating these technologies into policymaking can lead to more transparent, participatory, and efficient governance responsive to citizens' needs and concerns [29].

Cultural Heritage Preservation: Through virtual spaces, heritage preservation initiatives can protect and promote the rich cultural heritage of cities. Virtual presentations of local cultural assets offer immersive experiences that allow citizens and visitors to explore historic sites, artifacts, and traditions in unprecedented detail. Community-based cultural and heritage preservation offerings provide citizens with platforms to share stories, memories, and traditions, fostering a sense of belonging and connection to their cultural heritage. Cities can preserve and pass on their cultural heritage to future generations through digital archives, interactive exhibitions, and educational programs to ensure its continued relevance and appreciation [22]. In addition, the metaverse serves as a platform for cultural exchange, collaboration, and innovation. It enables artists, historians, and community leaders to celebrate diversity, foster dialog, and explore new ways to preserve and communicate cultural heritage [30]. By embracing virtual heritage preservation initiatives, cities can enrich their cultural landscape, promote social cohesion, and strengthen their identity as vibrant and inclusive cultural centers [31].

5.2. Stakeholders and Their Benefits

In a smart city metaverse application, many stakeholders benefit from the application but are also involved in developing and providing the necessary infrastructure. Key stakeholders and how they can specifically benefit from the metaverse in the smart city are presented below:

City administration and planning offices: A city administration is a municipal institution responsible for managing and planning urban measures and resources, public buildings, and various services and is the point of contact for municipal matters [4]. Through metaverse applications, the city administration benefits specifically from a versatile and immersive planning tool, providing online offers and services. However, closer contact with citizens and the opportunity to organize and provide digital events and platforms also contribute to citizen loyalty. Using a smart city metaverse application contributes significantly to efficient urban development and improving citizen services [26].

Citizens: Cities' inhabitants play a decisive role in urban life. Through the metaverse, they benefit from personalized services, improved access to information, active participation in urban decision-making processes, and a new virtual world with entertainment opportunities and experiences in various industries. Digital job creation and the preservation of local cultures are further advantages [4].

Retail: Retail stores and retailers offering goods and services can tap into new revenue streams and strengthen customer loyalty in the metaverse. By creating virtual shopping experiences, they can offer their customers an innovative and interactive shopping experience that goes beyond the boundaries of traditional brick-and-mortar stores. In addition, they can integrate digital payment options to simplify the purchasing process and increase customer flexibility. These customizations allow retailers to expand their reach and reach new audiences while strengthening customer loyalty [24].

Industry: Industry includes companies and manufacturers from various sectors. In the context of a smart city metaverse application, the industry benefits from new business opportunities, such as providing technologies and services for the city's digital infrastructure. However, the industry also drives development and can act as a service provider [24].

Building yard: Municipal building yards are responsible for the physical implementation and design of urban structures [4]. As part of a smart city metaverse application, municipal building yards benefit from a number of specific advantages. The metaverse enables them to plan and implement projects more efficiently. They can also optimize resources and use consumables in a resource-saving manner. In addition, the metaverse enables better coordination between different construction projects, thus contributing to a more effective use of human resources and machinery.

Energy suppliers: Energy suppliers, whether municipal utilities or private companies responsible for electricity, water, energy supply, and grid infrastructure, benefit from smart city metaverse applications in various ways. They can optimize the city's energy infrastructure and monitor and reduce energy consumption. The metaverse enables more precise analysis and forecasting of energy demand, more efficient resource distribution, and the integration of renewable energies into the supply network [24].

Tourists: Visitors to a city who contribute to its cultural and economic life can benefit from personalized travel experiences, virtual city tours, and improved access to tourist offers in the metaverse. The metaverse allows them to virtually explore the city, visit cultural attractions, and enjoy interactive experiences that go beyond traditional tourism offerings [4].

Healthcare: The healthcare sector, consisting of doctors, hospitals, medical staff, and health insurers, can improve healthcare in the metaverse by offering telemedicine, remote patient monitoring, and digital health services. This allows them to benefit from a reduced workload and better patient health. The metaverse opens up new possibilities for patient care, enables remote access to medical services, and promotes efficiency in the healthcare system [27].

Clubs and NGOs: Associations, clubs, and non-governmental organizations committed to social, cultural, or environmental issues in the city can use platforms in the metaverse to present their projects, collect donations, and promote their causes. The metaverse gives them a wider reach and allows them to interact more effectively with the community, which can lead to greater support for their initiatives [22].

Pupils, teachers, students, and professors: Educational institutions play a central role in educating the population and promoting innovation. In the metaverse, they can use virtual learning environments to make teaching content more interactive and improve access to education for all. Through the metaverse, educational institutions can also introduce new teaching methods and technologies that make learning more effective and accessible [4].

Legislature: The legislature is responsible for creating and enforcing laws and regulations. As part of a smart city metaverse application, they help create a legal framework that ensures the regulated and safe operation of the metaverse. This allows them to ensure the protection of civil rights, security, and data protection in the virtual space. They can also promote innovation and set standards that steer the development of the metaverse in a positive direction. By creating a clear legal framework, they also create trust among users and promote the long-term acceptance and use of the metaverse [29].

Banks: Financial institutions play an essential role in financing projects and investments. In the metaverse, they can contribute to urban development by offering financing options for innovative technologies and infrastructure projects. By providing financing for metaverse projects, banks can not only expand their business but also promote technology, innovation, and economic growth in smart cities, which could also open up new business opportunities for them [24].

Public Authorities: Public authorities play a crucial role in administrating and enforcing laws and providing public services. In the metaverse, they can benefit from various advantages. They can use realistic training environments to train their employees more effectively. They can optimize processes and reduce bureaucratic hurdles by introducing more efficient measures. Their ability to respond in real time enables citizens to receive faster assistance and support. The metaverse also helps increase the transparency of the government apparatus by providing insights into decision-making processes and administrative procedures. In addition, authorities can run simulations to analyze the potential impact of policies or infrastructure projects before they are implemented in the real world [28].

Politics: Politicians play a central role in shaping the political landscape and developing guidelines for urban development. In the metaverse, they can create added value through various measures. On the one hand, they can promote citizen participation by providing platforms for discussion and feedback that enable citizens to participate actively in political decision-making processes. In addition, politicians can test innovative policy approaches and measures in the virtual space before implementing them in the real world. The metaverse also offers the opportunity to drive the digitalization of the public sector by introducing digital administrative services and establishing more efficient communication channels between the various levels of government [29].

Job centers: Employment offices are essential in supporting job seekers in their job search and further training. In the metaverse, they can expand and improve these functions. By organizing virtual job fairs, employment offices can provide a platform for job seekers and companies to network and explore potential employment opportunities. In addition, they can offer training and education programs in virtual environments to improve job seekers' skills and increase their employability. For disadvantaged populations in particular, the metaverse can facilitate access to jobs by providing opportunities for flexible work arrangements and remote work that can overcome geographical barriers [4].

5.3. Real-World Metaverse Applications in the Smart City

Table 2 lists exemplary smart city metaverse applications and records whether they are pure metaverse developments or only fulfill some components and attributes. The ap-

plications are explained in further detail in the following paragraphs, including references to the respective sources.

Table 2. Overview of current metaverse smart city applications corresponding to Table 1.

City/State/District	Platform	Metaverse	Smart City Metaverse Applications Already Implemented
Seoul, Republic of Korea	Metaverse Seoul	Yes	Digital administration services, virtual city tours *
Helsinki, Finland	Zoan	Partial	Urban planning, digital administration services, virtual events and exhibitions, virtual city tours, virtual shopping centers and retail platforms
Catalonia, Spain	CatVers	Yes	Social meeting places
Barbados	Decentraland	Yes	Digital administration services, digital properties
London, United Kingdom	-	Partial	Urban planning, virtual city tours, virtual sights, presentation of local cultural assets
New York City, USA	-	Partial	Status visualization (transport), planning and forecasting of capacity utilization (transport)
Santa Monica, USA	FlickPlay	Yes	Digital administration services, virtual city tours, marketing platform for local businesses
Shanghai, China	-	Partial	Digital administration services, digital products, digital jobs, and placement of unemployed
Singapore	-	Partial	Risk planning, digital city twin, environmental monitoring and management, tracking the use of resources and consumption optimization, digital administration services, provision of city-related real-time information
Dubai, UAE	-	Partial	Provision of city-related real-time information, status visualization (transport)
Benidorm, Spain	Steam	Yes	Virtual city tours, virtual sights, city marketing

* Other applications are planned but not yet implemented.

Seoul—Republic of Korea: The South Korean city of Seoul is the first city in the world to venture into the metaverse. Under the name "Metaverse Seoul", which is part of the comprehensive plan called "Seoul Vision 2030", residents are offered various services in a specially developed metaverse in addition to virtual exploration of the city. The project is divided into three phases. In the first phase, which started in spring 2023, users can explore the city with the help of avatars and ask questions about their personal tax affairs or receive assistance with various civic issues. The other phases will be completed by 2026, during which further services will be introduced. This includes the vision that citizens can interact with the city's infrastructure by combining virtual and physical reality. Various target components are described in Seoul Vision 2030. The services are divided into seven areas: Economy, Education, Communication, Culture, Urban Development, Administration, and Taxation. The platform offers various functions that developers can use to develop applications for the abovementioned areas [32]. For this purpose, functions are provided that enable the management of citizen data, tax accounting, education, citizen complaint management, culture, and tourism. The Seoul metaverse has created new opportunities for residents and visitors to experience and interact with the city without being physically present [33]. In addition to digitalizing citizen services and tourism, the city wants to use modern technologies to solve challenges such as poor air quality and improve the healthcare system. Seoul was awarded a prize for its innovation efforts and was named Smart City 2022 [32].

Helsinki—Finland: Virtual Helsinki is a digital replica of Helsinki's city center, launched in 2018. Developed initially as a digital twin, the application allows users to experience the city's famous sights virtually without being physically present. Virtual Helsinki is available for various VR devices and as a 360 video for mobile devices, providing visitors with an

interactive and immersive experience. Based on the digital twin, constant components have been added that increasingly transform it into a metaverse [34]. In addition to exploring different parts of the city, there are virtual activities such as concerts and exhibitions, shopping opportunities, services, simulation options, and virtual citizenship. In the future, virtual citizens can have digital homes, run businesses, and participate in activities such as concerts, art exhibitions, and virtual games to get closer to the metaverse avatars [35]. Virtual Helsinki is part of Helsinki's digital strategy and demonstrates the city's commitment to digital innovation and sustainable solutions. Helsinki has been recognized for its innovation and smart tourism offerings [34].

Catalonia—Spain: The northeastern Spanish region of Catalonia is working on the development of a metaverse called CatVers, a virtual platform with free access that was launched with the support of the regional government and the Barcelona Chamber of Commerce. The Catalan version of the metaverse will focus on the culture and identity of Catalans and will offer a virtual space for society. However, the platform is limited exclusively to the Catalan language, making access to this metaverse significantly more difficult for many users [31].

Barbados: The Caribbean Island state of Barbados, located northeast of Venezuela, signed contracts with Decentraland to open the first embassy in the metaverse. In addition to Decentraland, agreements have been signed with other metaverse providers offering digital properties, such as Somnium Space and SuperWorld. According to the Ministry of Foreign Affairs and Foreign Trade, the projects aim to identify investment opportunities in digital land, establish virtual embassies and consulates, and develop and provide services such as "e-Visa". Work is also actively underway in developing a "teleporter", which will enable interoperability for users, i.e., transporting avatars between the different worlds. The metaverse embassy offers a unique diplomatic opportunity to develop relationships with other countries, provide citizens access to services internationally, and promote cultural diplomacy [36].

London—Great Britain: The city of London works according to the Greater London Authority's London Plan, which provides an urban planning framework and regulations for new construction projects. Construction projects can be planned quickly and cost-effectively with the help of a 3D digital platform, which displays a large, detailed, and interactive model of the capital. Factors such as the layout, building density, environmental impact, and other components are considered [37]. An alternative application also enables impressive, location-based AR experiences based on high-resolution map models and scanned landmarks [38].

New York—USA: Columbia University is conducting a three-year project to develop a digital twin of significant intersections and locations in New York City. To this end, data from various sensors are being examined and used with the help of machine learning to optimize traffic flow and reduce congestion. The aim is to predict traffic conditions and implement intelligent traffic management. There will also be an app that makes the data available to road users, highlights road closures and accidents, and warns pedestrians of potential dangers at junctions [39].

Santa Monica—USA: Santa Monica provides an app similar to the augmented reality (AR) game Pokémon Go. A virtual AR application is combined with the physical world on the cell phone's screen via the smartphone's camera. The app's target is to collect various tokens to unlock content and collectibles. In contrast to the mobile game Pokémon Go, the digital economy is promoted here, as local trade transactions can take place. The relationship between citizens and their urban environment is also strengthened as they discover new urban areas and offers while searching for tokens [40].

Shanghai—China: Like the Chinese government, Shanghai plans to use the metaverse for administration and regulation. The city also intends to promote metaverse companies. The Shanghai government plans to establish a metaverse industry, expected to be worth 52 billion US dollars by 2025 [41].

Singapore: Singapore was one of the first cities to use a digital twin. The twin, Virtual Singapore, has been available since 2014 and accesses data from various sources. These include geometric, geospatial, topological, demographic, movement, and climate data. This allows models and large-scale simulations of the city to be created and the effects of urbanization on the city to be researched. Thus, solutions for optimizing logistics, administration, environmental and disaster management, infrastructure, internal security, and citizen service optimization are enabled [42].

Dubai—UAE: Dubai's Road and Transport Authority uses augmented reality to visualize a digital twin of the Dubai Metro rail network. The aim is to evaluate and analyze the metro's condition based on historical and current data. The aim is to detect critical changes at an early stage to minimize the railroads' downtime [43].

Benidorm—Spain: Under the name BenidormLand, the Spanish city of Benidorm is launching a platform to help promote tourism. It is based on a metaverse platform that depicts Benidorm virtually and supplements it with objects and avatars. The platform is an advertising tool to inspire potential tourists to make future trips and present the offer. Benidorm is a pioneer in digital tourism and the world's first certified digital tourism destination [44].

5.4. Challenges of the Smart City Metaverse

To minimize the impact on people and the environment, key challenges need to be taken into account when setting up and operating the metaverse. Additional challenges for municipal and urban applications arise due to citizens' concerns, sometimes poorly developed infrastructure, and social changes.

One interviewed expert particularly pointed out the trust that people have to place in virtual worlds. This usually represents a significant challenge for developing a smart city metaverse. According to the expert, many citizens have concerns about cybersecurity and data protection, as the increasing use of sensors and digital networking increases the risk of cyberattacks and the potential misuse of personal data. For example, citizens must be convinced to provide their personal data for digital identities. Face recognition, biometric IDs, and user-specific analyses are often debated, as critics claim privacy is not guaranteed [22]. One of the experts said that the use of new, modern technologies in society is also often viewed critically. Due to a lack of experience, the reliability of the technologies is questioned, and they are linked to health concerns. For example, the general public views new technologies critically, as there are no long-term studies on their harmlessness to health [17].

One interviewed industry insider drew particular attention to the challenges arising from the potential discrimination of people by artificial intelligence and algorithms, which are familiar from previous developments. Automated decision-making processes can reinforce existing biases and inequalities, as the algorithms are trained on historical data that may already contain biases. This leads to the risk of certain groups being disadvantaged due to gender, ethnicity, or other social characteristics. The challenge is to ensure that the algorithms developed are fair and transparent to prevent discrimination. Developing guidelines and standards for ethical design and the responsible use of AI in the metaverse is crucial to ensure an inclusive and equitable virtual environment for all users [45].

One of the experts also pointed to the spread of fake news as another significant challenge in the metaverse. The dynamic and immersive nature of the metaverse creates a fertile breeding ground for the rapid spread of manipulated or misleading information [46]. Fake news can easily be overlooked and perceived as authentic content in a virtual environment where the boundaries between reality and the digital world are blurred. The potential impact on user behavior and opinions in the metaverse is significant, as misinformation can undermine trust, cause social unrest, and influence political decisions [47]. Therefore, developers in the metaverse must proactively implement mechanisms to verify the authenticity of information and curb the spread of fake news. At the same time, users should be

taught to recognize and deal with disinformation to enable informed and critical use of the metaverse [48].

Literature research also revealed that a reliable infrastructure is required to operate the metaverse, which is not available to the same extent in all cities and regions. As a result, the performance of the applications varies depending on the location. In addition, the infrastructure, such as mobile networks, data networks, and energy supply, must be constantly expanded, maintained, and serviced, representing a considerable expense for municipal operations and the financial budget [24]. The enormous energy consumption required to operate the infrastructure and use the interfaces must be provided by the energy suppliers and guaranteed by the networks. This requires the consumption of local resources. Further resources are required to set up applications with hardware components such as digital twins, traffic monitoring systems, and control elements [22].

The social impact will be felt in cities where there are a large number of users. The shift of life to the virtual world is automatically associated with fewer citizens, visitors, and customers in the physical world. This means that facilities, stores, leisure facilities, offices, and other services are no longer worthwhile and must cease operations, which has a detrimental effect on the economic structure of smart cities. In addition, social and cultural exchange is neglected, leading to the alienation of citizens and the loss of local culture [22]. It is, therefore, essential to ensure that all members of the community benefit from developments in smart cities and that cultures and traditions have a place in the metaverse. Smart cities in the metaverse must also ensure that citizens have access to the metaverse, regardless of their economic and social status. The purchase of hardware and the costs of use are a hurdle for the poorer population and can lead to the exclusion of this social group [22]. There is also a need for counseling and services for those affected by illnesses that can be traced back to excessive use of computer media. Conscious and healthy usage behavior is essential to ensure the metaverse prevails as a medium and does not adversely affect users' lives [46].

In the development process, cities must define precise legal requirements and measures that create a legal framework for operation. The operation of the metaverse must neither violate existing laws nor be an area for unethical and inappropriate behavior [49].

6. Discussion

The metaverse is still in its infancy [3,50]. This is due to the fact that many technologies required for mass adoption have not reached a sufficient performance level up to now [50]. Still, in the context of a smart city, a multitude of applications are envisioned that aim to provide significant benefits for various stakeholders, as presented in Sections 5.1 and 5.2.

Section 5.3 shows the first attempts to leverage the metaverse in the context of cities and municipalities. Many applications, e.g., digital twins for city infrastructure, virtual tourism, or citizen services, have already been implemented. However, many of these examples are currently under development or somewhat experimental.

Comparing the envisioned 48 smart city metaverse applications from Table 1 with the already realized smart city metaverse examples from Table 2 shows that only 20 potential applications have been implemented. Metaverse-based digital administration services are included in six of the eleven city metaverse examples, making this application the most implemented, followed by tourism-related applications. While other applications from Table 1, e.g., city planning and simulation, are included in several examples, other fields, such as governance and policymaking, have not been addressed. Fields of application such as healthcare and education seem to not be in the actual focus of city metaverse initiatives, although they are undergoing research and development driven by other parties [51,52].

Thus, the expected benefits of metaverse applications in citizen services are apparent. Enabling citizens to access information or submit requests in an interactive, metaverse-enabled manner from anywhere reduces time and effort for citizens and the administration. Similarly, leveraging metaverse-enabled immersive experiences in tourism seems to come with obvious benefits. Independent of location and individual limitations, users can

experience the attractions and sights of a city. This might enable new business models and increase the attractiveness of the respective city to tourists. In the city planning and simulation field, which is addressed by some of the example cities in Section 5.3, the expected benefits are, for example, better quality of planning and decision processes due to the possibility of experiencing the outcomes in an immersive way in advance. While these examples from various fields of application have already been explored, other applications are still waiting to be implemented. In order to identify those metaverse applications that are beneficial for a specific city, it is mandatory to gain more experience, collect more data, and understand the specific needs of a city's stakeholders.

As laid out in Section 5.4, the smart city metaverse comes with challenges that must also be mastered. This is the necessary precondition for an overall beneficial and sustainable metaverse application. Different stakeholders are capable of or responsible for taking preventive measures, depending on the type of challenge or risk. Topics like data protection, security, or fake news, for example, are specifically influenced by the operator of a metaverse platform, whether this is a city itself or a third-party vendor. At the same time, legislation sets the boundaries for platform operators. On the other hand, cities have specific responsibilities when it comes to providing appropriate infrastructure or fighting inequalities, for example, by offering interface devices at low cost to low-income households.

Figure 2 graphically compares the opportunities and potential with the risks and impacts that can arise and occur when using metaverse applications in the smart city sector. It is essential to balance these two aspects.

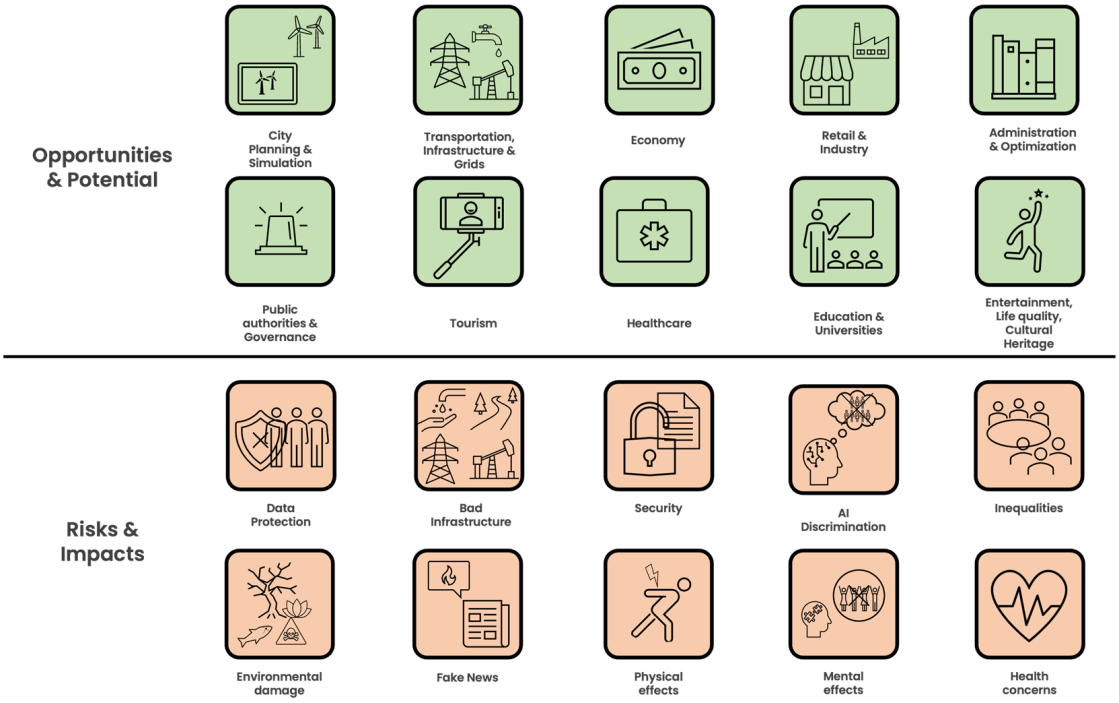

Figure 2. Metaverse opportunities and potential vs. risks and impacts.

7. Conclusions

The study provides an overview of potential metaverse applications and their benefits within the smart city context. Furthermore, it provides an overview of which applications have already been implemented and used by cities worldwide. This also indicates the fields of application where no practical experience exists. Coping with the risks and challenges of the metaverse requires theoretical research, but gathering experience with real-world applications is necessary too. In order to fully understand and leverage the benefits of the metaverse, more actual use cases need to be implemented, and more data must be collected. In these endeavors to explore smart city metaverse applications, municipalities,

industry, and research have to collaborate closely. Research needs to focus on generalizing learnings from implemented applications and transferring them to and from other domains. Municipalities need to understand the potential benefits of the metaverse and the necessity of timely providing the appropriate infrastructure, for example, broadband internet connections or 3D geodata.

The fields of applications and the city examples identified in this study represent the current status as of writing, which will continue to expand. Future research should evaluate how the applications can be implemented in practice and which ones offer efficient advantages and added value. It is also important to research how a compliant platform that is accessible to all users and can be used in an urban environment can be created, overcoming the identified challenges.

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References

1. Lee, L.-H.; Braud, T.; Zhou, P.; Lin, A.W. All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda. *arXiv* **2021**, arXiv:2110.05352.
2. Stephenson, N. *Snow Crash*; Bantam Paperback Edition; Bantam Books: New York, NY, USA, 1993; ISBN 055308853X.
3. Ball, M. *The Metaverse: And How It Will Revolutionize Everything*; Liveright: New York, NY, USA, 2022.
4. Allam, Z.; Sharifi, A.; Bibri, S.E.; Jones, D.S.; Krogstie, J. The Metaverse as a Virtual Form of Smart Cities: Opportunities and Challenges for Environmental, Economic, and Social Sustainability in Urban Futures. *Smart Cities* **2022**, *5*, 771–801. [CrossRef]
5. Kshetri, N. National Metaverse Strategies. *Computer* **2023**, *56*, 137–142. [CrossRef]
6. Bibri, S.E.; Allam, Z. The Metaverse as a Virtual Form of Data-Driven Smart Urbanism: On Post-Pandemic Governance through the Prism of the Logic of Surveillance Capitalism. *Smart Cities* **2022**, *5*, 715–727. [CrossRef]
7. Orsolits, H.; Lackner, M. *Virtual Reality und Augmented Reality in der Digitalen Produktion*; Springer: Berlin/Heidelberg, Germany, 2020; ISBN 9783658290085.
8. Zuckerberg, M. Founder's Letter. 2021. Available online: https://about.fb.com/news/2021/10/founders-letter/ (accessed on 18 August 2022).
9. Weinberger, M.; Gross, D. A comparison of virtual worlds based on the metaverse maturity model. *ITU J. Futur. Evol. Technol.* **2023**, *4*, 537–548. [CrossRef]
10. PVH. Tommy Hilfiger Joins the First-Ever Decentraland Metaverse Fashion Week. Available online: https://www.pvh.com/news/tommy-hilfiger-metaverse-fashion-week-2022 (accessed on 24 October 2022).
11. Jeon, H.-J.; Youn, H.; Ko, S.; Kim, T. Blockchain and AI Meet in the Metaverse. In *Advances in the Convergence of Blockchain and Artificial Intelligence*; Fernández-Caramés, T.M., Fraga-Lamas, P., Eds.; IntechOpen: London, UK, 2022; ISBN 9781789840940.
12. Casillo, M.; Cecere, L.; Colace, F.; Lorusso, A.; Santaniello, D.; Valentino, C. Digital Twin and Metaverse Supporting Smart Cities: New Perspectives and Potentials. In *Intelligent Sustainable Systems: Selected Papers of WorldS4 2023*, 1st ed.; Nagar, A.K., Jat, D.S., Mishra, D.K., Joshi, A., Eds.; Springer Nature Singapore: Singapore, 2024; Volume 4, pp. 111–119. ISBN 978-981-99-8110-6.
13. Lai, C.M.T.; Cole, A. Measuring progress of smart cities: Indexing the smart city indices. *Urban Gov.* **2023**, *3*, 45–57. [CrossRef]
14. Caragliu, A.; Del Bo, C.; Nijkamp, P. Smart Cities in Europe. *J. Urban Technol.* **2011**, *18*, 65–82. [CrossRef]
15. Doleski, O.D. Smart City und Utility 4.0—Natürliche Partner Moderner Urbanität. Available online: https://bundesverband-smart-city.org/smart-city-und-utility-4-0-natuerliche-partner-moderner-urbanitaet (accessed on 16 February 2024).
16. Okafor, C.C.; Aigbavboa, C.O.; Akinradewo, O.I.; Thwala, W.D. The future of smart city: A review of the impending smart city technologies in the world. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1107*, 12228. [CrossRef]

17. Bibri, S.E. The Social Shaping of the Metaverse as an Alternative to the Imaginaries of Data-Driven Smart Cities: A Study in Science, Technology, and Society. *Smart Cities* **2022**, *5*, 832–874. [CrossRef]
18. Stadt Aalen. Virtueller Bürgerdialog. Available online: https://www.aalen.de/virtueller-buergerdialog.208940.25.htm (accessed on 15 March 2024).
19. Chen, Z.; Gan, W.; Wu, J.; Lin, H.; Chen, C.-M. Metaverse for smart cities: A survey. *Internet Things Cyber-Phys. Syst.* **2024**, *4*, 203–216. [CrossRef]
20. Nikulchev, E.; Ilin, D.; Gusev, A. Technology Stack Selection Model for Software Design of Digital Platforms. *Mathematics* **2021**, *9*, 308. [CrossRef]
21. *ISO/IEC 7498-1:1994*; Information Technology—Open Systems Interconnection: Basic Reference Model: The Basic Model, 90.93rd ed. ISO: Geneva, Switzerland, 1994. Available online: https://www.iso.org/standard/20269.html (accessed on 11 January 2024).
22. Kuru, K. MetaOmniCity: Toward Immersive Urban Metaverse Cyberspaces Using Smart City Digital Twins. *IEEE Access* **2023**, *11*, 43844–43868. [CrossRef]
23. Radoff, J. The Metaverse Value-Chain. Available online: https://meditations.metavert.io/p/the-metaverse-value-chain-afcf9e09e3a7?utm_source=/search/metaverse%2520value%2520chain&utm_medium=reader2 (accessed on 18 February 2024).
24. Yaqoob, I.; Salah, K.; Jayaraman, R.; Omar, M. Metaverse applications in smart cities: Enabling technologies, opportunities, challenges, and future directions. *Internet Things* **2023**, *23*, 100884. [CrossRef]
25. Wang, J.; Medvegy, G. Exploration of the future of the metaverse and smart cities. In Proceedings of the International Conference on Electronic Business (ICEB), Online, 13–17 October 2022; Volume 22, pp. 106–115.
26. Weinberger, M. Eine Smart City Kommt am Metaverse Nicht Vorbei. Available online: https://background.tagesspiegel.de/smart-city/eine-smart-city-kommt-am-metaverse-nicht-vorbei (accessed on 10 January 2024).
27. Riese, R.; Wiring, R. Das Healthcare Metaverse: Neue Gesundheitsversorgung, Neues Recht. Available online: https://www.cmshs-bloggt.de/rechtsthemen/metaverse/das-healthcare-metaverse-neue-gesundheitsversorgung-neues-recht/ (accessed on 10 January 2024).
28. Tross, R.; Chung, J.; Bangash, T. The Traveler's Guide to Unlocking the Value of Metaverse in Government: The Public Sector May Have Opportunities to Serve Constituents Better by Blending the Physical, Digital, and Social Worlds Using Metaverse Technologies. Available online: https://www2.deloitte.com/uk/en/insights/industry/public-sector/metaverse-technologies-public-and-government.html (accessed on 18 February 2024).
29. Corridore, M. The Metaverse: Revolutionizing the Way Government Agencies Function. Available online: https://www2.deloitte.com/ca/en/pages/technology-media-and-telecommunications/articles/metaverse-considerations-government-public-service.html (accessed on 18 February 2024).
30. Zhang, X.; Yang, D.; Yow, C.H.; Huang, L.; Wu, X.; Huang, X.; Guo, J.; Zhou, S.; Cai, Y. Metaverse for Cultural Heritages. *Electronics* **2022**, *11*, 3730. [CrossRef]
31. Cureton, D. Catalonia Launches CatVers Metaverse Project. Available online: https://www.xrtoday.com/mixed-reality/catalonia-launches-catvers-metaverse-project/ (accessed on 1 March 2024).
32. Ramos, J. Seoul Is the First City to Join the Metaverse (and This Is What Can Already Be Done). Available online: https://www.tomorrow.city/seoul-metaverse/ (accessed on 20 January 2024).
33. Seoul Metropolitan Government. Metaverse Seoul. Available online: https://metaverseseoul.kr/user/ (accessed on 20 January 2024).
34. City of Helsinki. Virtual Helsinki. Available online: https://www.myhelsinki.fi/en/see-and-do/sights/virtual-helsinki (accessed on 1 March 2024).
35. Zoan Corporation. The Virtual Capital. Available online: https://virtualhelsinki.fi (accessed on 1 March 2024).
36. Thurman, A. Barbados to Become First Sovereign Nation with an Embassy in the Metaverse. Available online: https://www.coindesk.com/business/2021/11/15/barbados-to-become-first-sovereign-nation-with-an-embassy-in-the-metaverse/ (accessed on 1 March 2024).
37. VU.CITY London. Available online: https://www.vu.city/cities/london (accessed on 1 March 2024).
38. PR Newswire. Nextech AR Chosen by the City of London for Metaverse Launch. Available online: https://www.prnewswire.com/news-releases/nextech-ar-chosen-by-the-city-of-london-for-metaverse-launch-301398859.html (accessed on 1 March 2024).
39. Reid, R.L. In NYC, Digital Twin Project Tackles Traffic. Available online: https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2022/09/in-nyc-digital-twin-project-tackles-traffic (accessed on 1 March 2024).
40. Bautista, P.S. City Branding and Place Branding in the Metaverse: How Real Cities Build their Virtual Image and How Virtual Cities Do It. *Fuori Luogo J. Sociol. Territ. Tour. Technol.* **2022**, *13*, 16–32. [CrossRef]
41. Muhammad, I. Shanghai Aims to Build a $52B Metaverse Industry Come 2025. Available online: https://www.beyondgames.biz/24735/shanghai-aims-to-build-a-52b-metaverse-industry-come-2025/ (accessed on 1 March 2024).
42. Pereira, D. Speculative Design: "Virtual Singapore" Is a Massive, Fully Functional Digital Twin of the Asian City-State. Available online: https://www.oodaloop.com/archive/2023/05/23/speculative-design-virtual-singapore-is-a-massive-fully-functional-digital-twin-of-the-asian-city-state/ (accessed on 1 March 2024).

43. The Government of Dubai. RTA Exhibits Metaverse Dubai Metro Stations Network, Digital Platforms at GITEX 2022. Available online: https://mediaoffice.ae/en/news/2022/October/09-10/RTA-exhibits-Metaverse-Dubai-Metro (accessed on 1 March 2024).
44. City Benidorm. Benidorm Jumps into the Metaverse. Available online: https://benidorm.org/en/news/benidorm-jumps-metaverse (accessed on 10 January 2024).
45. Frankish, K.; Ramsey, W.M. *The Cambridge Handbook of Artificial Intelligence*; Cambridge University Press: Cambridge, UK, 2014; ISBN 9780521871426.
46. Bibri, S.E.; Allam, Z. The Metaverse as a virtual form of data-driven smart cities: The ethics of the hyper-connectivity, datafication, algorithmization, and platformization of urban society. *Comput. Urban Sci.* **2022**, *2*, 22. [CrossRef] [PubMed]
47. Barclay, D.A. *Fake News, Propaganda, and Plain Old Lies: How to Find Trustworthy Information in the Digital Age*, 1st ed.; Rowman & Littlefield Publishers Incorporated: Blue Ridge Summit, PA, USA, 2018; ISBN 978-1538108895.
48. Gaur, L. (Ed.) *Deepfakes: Creation, Detection, and Impact*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2023; ISBN 9781032139203.
49. Law, K.H.; Lynch, J.P. *Smart City: Technologies and Challenges*; IEEE: New York, NY, USA, 2019.
50. Mystakidis, S. Metaverse. *Encyclopedia* **2022**, *2*, 486–497. [CrossRef]
51. Lin, H.; Wan, S.; Gan, W.; Chen, J.; Chao, H.-C. Metaverse in Education: Vision, Opportunities, and Challenges. In Proceedings of the 2022 IEEE International Conference on Big Data, Osaka, Japan, 17–20 December 2022; Tsumoto, S., Ed.; IEEE: Piscataway, NJ, USA, 2022; pp. 2857–2866, ISBN 978-1-6654-8045-1.
52. Bansal, G.; Rajgopal, K.; Chamola, V.; Xiong, Z.; Niyato, D. Healthcare in Metaverse: A Survey on Current Metaverse Applications in Healthcare. *IEEE Access* **2022**, *10*, 119914–119946. [CrossRef]