smart cities

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The Future Possibilities and Security Challenges of City Digitalization

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Abstract: To adapt to current changes, such as globalization, climate change, and demographic growth, modern cities must embrace the digitalization of city management. In this paper, we examine a concept for digitalizing a city based on Rotterdam's digital twin showcase. Data-processing frameworks for different sources of data are presented. Security risks and the potential of smart cities for military usage are discussed. Lastly, using an example of available datasets for air quality and public lighting consumption, functions of the Rotterdam digital twin are compared with the Brno city digital platform. It was found that every city has its approach to digitalization, and it is probably impossible to unify every city's digitalization process. This means that the digitalization of the city is very individual. Both systems in their current form make it possible to visualize the collected data about the city. So far, however, these systems do not use advanced functions such as AI-assisted decision-making and prediction of various events in the city. Even so, they are a source of very interesting data that can be used by third parties.

Keywords: smart energy; smart solutions; digital twin; digitalization; sensors; security; military

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Citation: Barcik, P.; Coufalikova, A.; Frantis, P.; Vavra, J. The Future Possibilities and Security Challenges of City Digitalization. *Smart Cities* **2023**, *6*, 137–155. https://doi.org/10.3390/smartcities6010008

Academic Editor: Otmane Azeroual

Received: 28 November 2022
Revised: 22 December 2022
Accepted: 23 December 2022
Published: 30 December 2022

1. Introduction

The term digitalization is defined as the implementation of digital technologies into our everyday life [1]. Digitalization of the city positively stimulates and accelerates development and improves residents' lives in energy management, economic development and housing, community engagement, mobility, waste management, and healthcare and resource management [1].

Digitalization processes also give rise to new technological concepts, e.g., the Internet of Things (IoT). IoT devices consist of hardware, software and network, while the architecture of the IoT system is made up of three layers: perception layer, network layer, and application layer [2]. The perception layer is responsible for a physical layer consisting of sensors and actuators interacting with the physical world [3]. The network layer is responsible for transmitting information between a gateway and IoT nodes. The application layer provides services and applications for end users and customers. The four IoT architectures for a smart city are proposed in [4]. The first architecture is cloud architecture where all data are stored in a centralized cloud data centre. The second architecture is fog architecture, where fog nodes interact with each other and interact with a central data centre. The third architecture is edge architecture, where it is possible to use edge nodes for fast, computationally less-demanding tasks, where the basic calculation takes place. A fog architecture uses fog nodes which are placed as close to the edge as possible to reduce network latency. According to [3] the importance of IoT is increasingly closely linked to the evolution of smart cities, for which IoT represents one of the key components for more ingenious innovation and sustainable development. Digitalization of the city brings challenges that must be solved. One of the challenges is the growing number of sensors, which brings greater demands on energy efficiency and the lifetime of individual nodes [5–8]. The digital platform must deal with processing a massive amount of data, so it is advisable to pre-process the data as much as possible already in the individual nodes [9,10]. The subsequent processing of received data and their evaluation is also a problem [11]. Data can be processed in the time, frequency, or delay domain [12].

The current turbulent situation in the energy market pursues the transition into smart and sustainable energy sources even quicker. The local management of energy flow based on the current needs must be able to react very quickly to new situations. Besides responding flexibly to various critical and emergency situations that may arise in the city, it is also necessary to prevent or anticipate them. A network of sensors is needed [13] to recognize these situations adequately and collected data could be input into the digital twin of the city [14]. The information gathered from this platform can be analyzed, used to implement various smart solutions or optimize city services, which will positively impact city life and the environment [15]. The digital twin tool, originally used to help in industrial production and use in Industry 4.0, has also found its application in the digitalization of cities [16,17]. The digital twin offers the possibility of space–time visualization of gathered data and simulation or prediction of the behaviour of various physical entities of the city.

In today's world, the digitalization of the city is a necessity, not a choice. On the other hand, the digital transition of the city, together with the growth of intelligent technologies, can create a specific security risk [18,19]. In the event that the enemy gains control of the city's sensor network, that network can be used for malicious purposes, for instance, posing a threat to the city's critical infrastructure. Regardless of the method, a certain framework is needed that can assess the security risk when applying individual smart solutions [20].

Within the RUGGEDISED project funded under the European Union's Horizon 2020 research and innovation programme, three lighthouse cities (Rotterdam, Glasgow, Umeå) and three fellow cities (Brno, Gdansk, Parma) were brought together to implement the smart city model. The paper discusses the employment of the smart city model from Rotterdam and assesses the possibilities and actual state of implementation in Brno in the Czech Republic. Part of the paper has the character of the review; part of the paper is a comparative study with insight into the future and military applications. Digitalization procedures must be considered according to physical and social reality, which is unique for particular areas, and unifying it for every city is impossible. As a result, a specific digital urban community is created. The article's novelty is in presenting the general platform for implementing the city's digital twin, based on which the 3D urban model of the city of Rotterdam works. Because both cities have chosen a different approach to city digitalization, the article compares the individual implemented solutions. The recentness of this work is supported by looking at the smart city in the context of security and the usability of data from smart solutions by the military. Cyber security should be considered from the very beginning of the design. The detection of threats and the adoption of proper mitigations against them can help in this. The methodology used within the paper is the following:

- Define the main framework for the architecture of the city digital platform.
- Define how to deal with gathered data.
- Identify possible security threats.
- Define future trends and military usage.
- Compare Rotterdam and Brno digital platforms.

The paper is structured as follows. The next section presents a review of current research dealing with the digital transformation of the city from different points of view. Based on an implementation experience in Rotterdam, the third section introduces the framework for digital twin cities, as well as a possible method of processing data from various sources. Section 4 discusses the cyber security of smart cities and the possible use of individual data from sensors for the army in the event of an armed conflict or in the event of a natural threat. Section 5 presents the current state of the digital platforms of the cities of Rotterdam and Brno together with air quality and public lighting consumption data. Section 6 discusses the previous results and Section 7 provides the future possibilities of city digitalization.

2. Related Works

The concept of city digitalization, in general, has become a hot topic over the last decade. It has been supported by several publications specializing in smart solutions [21], IoT [13], digitalization [22], digital twins etc. [23]. We used the Web of Science database to search for currently available literature dealing with the digitalization of the city. We searched by keywords such as "smart city", "smart cities", and "digitalization". There were 47,929 results for the last ten years (see Figure 1). The number of articles has stagnated this year because they still need to be entered into the database.

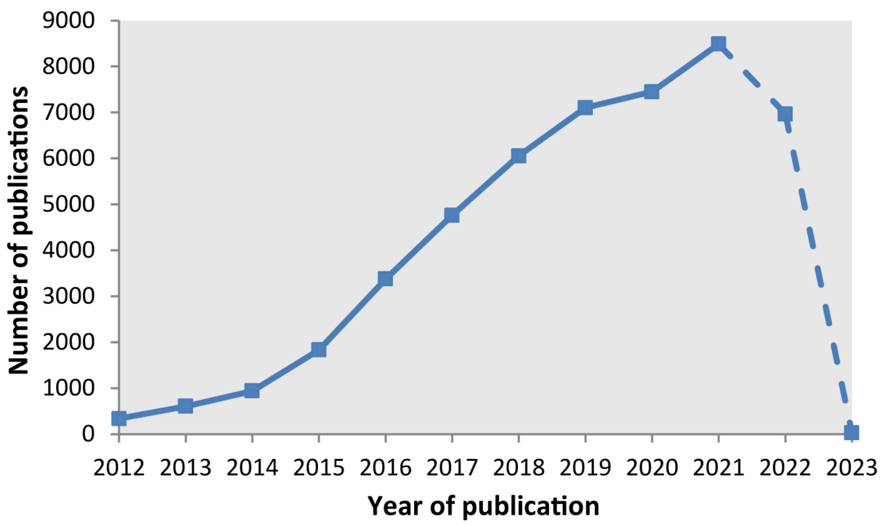


Figure 1. Number of publications focused on smart cities.

From the basic theoretical concept, over a couple of installed sensors in the building or street, the digital twin of the whole city became a real thing. Digitalizing the city and creating a digital twin of the city enables a dynamic interaction between the virtual copy of the city, which is filled with data from virtual sensors in real time, and the actual physical entities of the city [24]. Cities use various forms of digital twin visualization, either in the form of a 3D [25–28] or a 2D model [29]. Both forms have their advantages and disadvantages. The 3D model is more illustrative, but at the same time, it is more difficult to navigate in it, and it is more demanding on the user's hardware. The 2D form is easier to control, but the user does not perceive the individual layers of the city. The similar works focused on digital twin or data city platform are summarized in Table 1. The knowledge obtained from the virtual model of the city can be used to support and improve various aspects of the city, e.g., green infrastructure, implementation of renewable resources, city infrastructure, construction planning, quality of life in the city, etc. The authors in [30] propose a single urban digital twin structure which consists of four modules: Mobility management, Water management, Energy management and Atmospheric monitoring and prediction. However, there are also other possible areas of implementation.

Table 1. Comparison of similar works.

Reference	Topic/Purpose	Visualization	Scope
[31]	Digital twin concept	-	City
[32]	Digital twin	3D	Infrastructure
[33]	Use a Digital Twin	3D	Port
[34]	Data Platforms for Smart Cities	-	City
[35]	Developing 3D digital model	3D	City
[36]	Taxonomy	-	City
[37]	Urban digital twin	3D	City
[38]	Web Based 3D Smart City Model	3D	City
[39]	3D city model of park	3D	Infrastructure
[27]	Concept of digital twin	3D	City
[40]	Smart City Data Platform	-	City
[41]	Virtual 3D city model	3D	Campus
[42]	Digital twin of park	3D	Infrastructure
[43]	Smart Data Platform	3D/2D	City
[44]	Smart city data platform	2D	Campus
[45]	Overview of digital twin	3D	Port

Together with rapid urbanization, the relationship between urban environments and human environments is becoming difficult. Virtual geographic environments platform is presented in [46] which helps in urban modeling and simulation. In [46] the interesting concept of "metaverse" is introduced which emphasizes the intercommunication of human behaviour in real and virtual environments. The concept of "Self-Organizing City" is introduced in [47]. The concept presents the ideal connection between the digital twin of the city, together with complete information from the cloud and through citizen participation through smartphones. In other words, the digital twin of the city can assist the decision-making process and encourage citizen participation. In [48], the authors present a smart government using a digital twin in Japan. Within the integration of the intelligent building industry and high-quality development, new opportunities and challenges arise. Newly, the climate and environmental aspects of the building should be taken into account. The Intelligent Green Building (IGB) concept is proposed in [49], where the authors stress that the green concept should be incorporated into all aspects of construction, operation, and maintenance. To fulfill this concept, digital and energy innovation must be combined and infiltrated into all links. The paper presents the impact of the Digital twin of the city on the green building operation and maintenance stage. The future perspectives of the digital twin in the green deal era are discussed in [50].

The concept of a digital twin should be advantageously used for monitoring and intelligent management of civil infrastructures [51]. It has been determined in [15] that using advanced technologies including IoT and a digital twin can significantly reduce infrastructure maintenance costs. The collected data could be further analyzed and visualized to assist with maintenance decision-making, modeling predictions and other applications. From the analysis of the data, predictions could be stated. Paper [52] deals with the forecast of energy consumption for the next day using the unique data obtained from a digital twin model of the building. Several forecasting methods were tested such as the naive method, linear regression, long-short term memory (LSTM) and the Prophet method. The proposed prediction model helps to reduce electricity consumption, match a photovoltaic source energy demand and use electricity battery storage effectively. The authors proposed that only devices in a building which are responsible for major electrical consumption should be monitored due to the reduction of consumption at each measuring point.

Although the impact of smart cities from the perspective of security and defence is still unexplored and unclear, as advanced technologies are being used in existing cities, the possibility of cyber threats is increasing. For this reason, cyber security and user privacy are of great importance presently [53]. Cyber-attack scenarios on a smart city are identified and analyzed in [54]. The security of individual smart networks within the smart city must also be ensured. In the article, the authors discuss the security of the IoT network [55,56]. From a security perspective, critical utility networks [57], transportation [58], and healthcare [59] are critical. The authors in [60] describe what misestimating the impact of a connected infrastructure can cause during post-conflict operations in the networked urban environment and propose a methodology to assess and manage risks associated with smart solutions within the cities.

The process of digitalization is also an opportunity for the defence sector. It is shown in [61] that digital technologies can improve the effectiveness and technological sovereignty of Europe's armed forces. In [62], the authors discuss how IoT may be used for military purposes.

3. City Digitalization

The platform of the general digital twin of the city is based on real-time visualization of the data from the core usually called Urban Data Platform (UDP). Thanks to the 3D visualization of the city, it is easier to understand the city's spatial and temporal flows together with interactions between humans, infrastructure and technology [63]. According to [63] UDP comprises two levels, namely a supply layer and demand layer (see Figure 2). The supply layer is used for various data sources, and the demand layer consists of the data possible for applications. UDP serves primarily as a link between these two levels. This link collects, processes, integrates, stores, shares, visualizes and analyzes data from individual smart solutions. To provide a broader context, the collected data can be further enriched with additional data from other non-municipal sources. The presented framework in Figure 2 could be applied during digital city platform conceptualization and identification of its subsystems.

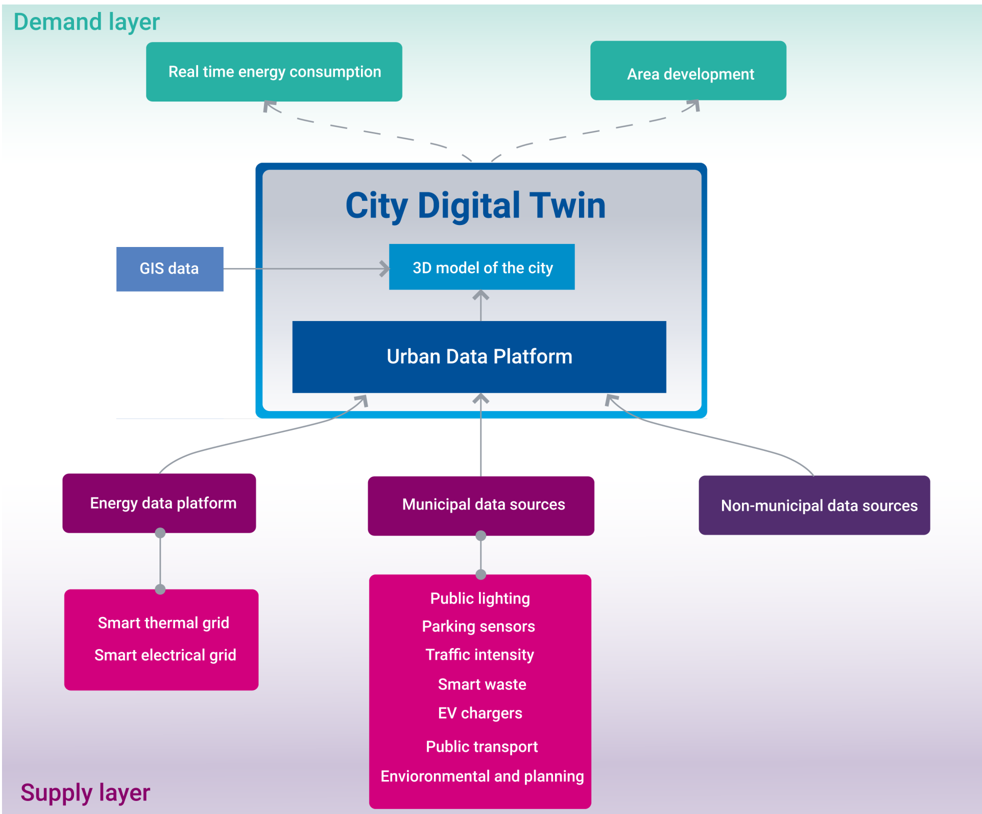


Figure 2. Platform of the city digital twin.

A comprehensive view of the current state of the city can serve as a basis for making appropriate decisions in many areas of the city, making it an essential task of the UDP. According to [64], the following knowledge can be obtained from UDP:

- Operational: properties of urban objects and activities, derivation of opportunities for improvement.
- Critical: monitoring and deriving incident or crisis response recommendations.
- Analytical: identifying and assessing patterns to subsequently derive predictions about urban innovation.
- Strategic: assisting in the progress of strategies between goals, plans and decisions in the urban environment.

As UDP receives data from different sources, they may be inconsistent, which can cause problems with its further processing. Therefore, it is necessary to consider their modification and processing before entering the UDP. An ideal solution would be to create a data format that all data providers would follow; however, it is difficult to achieve. The framework for receiving and publishing data while ensuring data privacy inspired by [65] is presented in Figure 3.

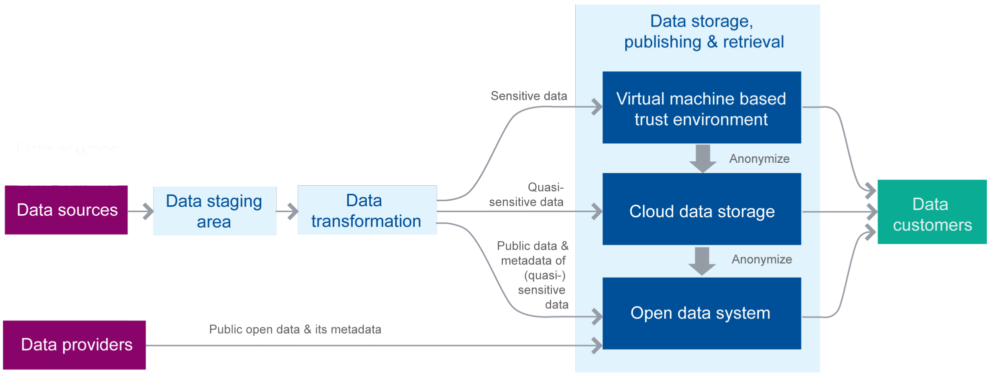


Figure 3. Architecture of data framework.

The data from multiple sources (sensors, metering, IoT, traffic information, weather information, pollution) is collected in a staging area. There, the data are corrected if they are missing or merged with data from another source. Inside the data-transformation block, it is transformed into the appropriate data format suitable for UDP and further processing. Afterwards, the data are cleansed, and sensitive personal attributes must be identified. Before data are transferred to the customer, they must be divided based on the level of sensitivity and anonymized.

4. Security Risk and the Potential of Digitalization for the Military

In general, smart cities are the interconnection of information, operational, and communication technology. The individual components may present potential vulnerabilities, and we must anticipate the constant threat of a cyber-attack. The goal of cyber security is primarily to prevent data leakage, to prevent denial of service, or time delays. Therefore, it is necessary not only to secure individual parts but also to protect the entire infrastructure as a whole. This approach poses a significant challenge.

The risk management process should start with risk assessment. The risk assessment could be formal or informal. The formal risk assessment usually conducted by an organization consists of the following four parts: Asset Identification, Risk Analysis/Threats analysis, Vulnerabilities or Pre-Disposed Conditions, Mitigating controls and Risk likelihood (see Figure 4).

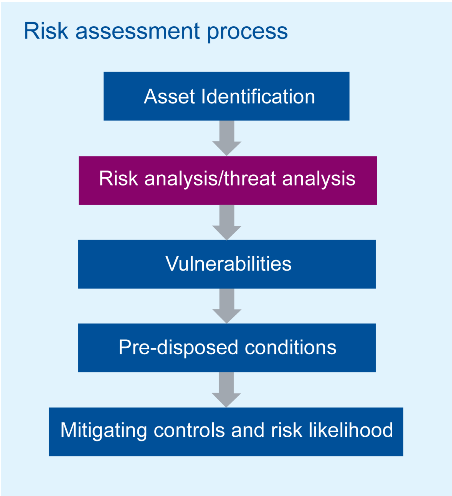


Figure 4. Risk assessment process.

Several comprehensive taxonomies can be used to assess security risks and identify threats which help clearly define threats within the company or between professionals with different perspectives [66]. Open Threat Taxonomy (OTT) published in 2015 covers most of the relevant threats to an information system's operation and divides a total of 75 threat actions into four main categories: physical threats, resource threats, personnel threats and technical threats. The European Union Agency for Network and Information Security (ENISA) thread taxonomy published in 2016 introduces eight high-level threats: Physical Attack, Unintentional Damages, Disasters, Failures/Malfunction, Outages, Eavesdropping/Interception/Hijacking, Nefarious Activity/Abuse and Legal. Each high-level threat is divided into particular threats with details. The National Institute of Standards and Technology (NIST) published a guide for conducting risk assessments where the threats are divided only into two high levels: Adversarial and Non-adversarial.

The following are selected examples of threats to sensors and the cloud environment [67]:

- Confidentiality and integrity compromise: Only authorized devices should have access to stored sensor data. If unauthorized devices gain access to the sensor data, their integrity could be compromised.
- Eavesdropping: The integrity of the transmitted data can be compromised by unsafe communication between individual sensors and the gateway. Unauthorized interception of communication may occur during transmission, which may result in discrediting, manipulation of transmitted data, and improper functioning of the entire system.
- Data loss: Loss or theft of sensitive data and information by attackers can disrupt the operation of a smart city.
- Availability compromise: Established plans and procedures must identify possible sensor failure and prevent a negative impact on the function of the smart city. Sensor failure without established procedures and contingency plans could lead to dangerous and unpredictable situations.
- Remote exploitation: Since the sensor network communicates with the master server, an adversary can gain unauthorized access to the network's internal systems by exploiting vulnerabilities such as an error in a program or a valid account. Subsequently, an adversary can run unauthorized code to take over the system.

The sensor data of a smart city is usually stored in the cloud, due to easy accessibility to individual customers. The cloud system is usually not managed by the city, but a third-party cloud system is used. For this reason, data stored on the cloud may be exposed to the following security threats [67]:

- Data leakage: By managing smart city data with a third-party cloud system, the city loses control over the data, and the data may be stolen by adversaries.
- Insecure APIs: The interaction of the cloud system with user applications is mostly ensured using the API interface. The API interface used must ensure secure communication.
- Malicious Insider threats: A background check of individual employees working for cloud service providers may not reveal unauthorized handling of client data.
- Denial of Service Attacks (DoS): Because the city data cloud is operated by a third party, the smart city system may become inoperable or inaccessible due to a DoS attack.
- Malware Injection: The infrastructure of cloud systems is vulnerable to malware injection attacks. An attacker creates a fraudulent application and injects it into the cloud system. Subsequently, the malicious application is launched as one of the valid instances in the cloud system.
- System and Application vulnerabilities: The city has no control over the processing and security of the data, as they are managed by a cloud system provider. For this reason, the provider must be verified and trustworthy.

According to [53] the cyber security of a smart city can be compromised by methods such as malware (viruses, trojans, ransomware, spyware, adware and botnets), SQL injection, phishing, man-in-the-middle attack, denial of service attack and social engineering. All the considered cyber security threats in the context of digital twin of the city are depicted in Figure 5.

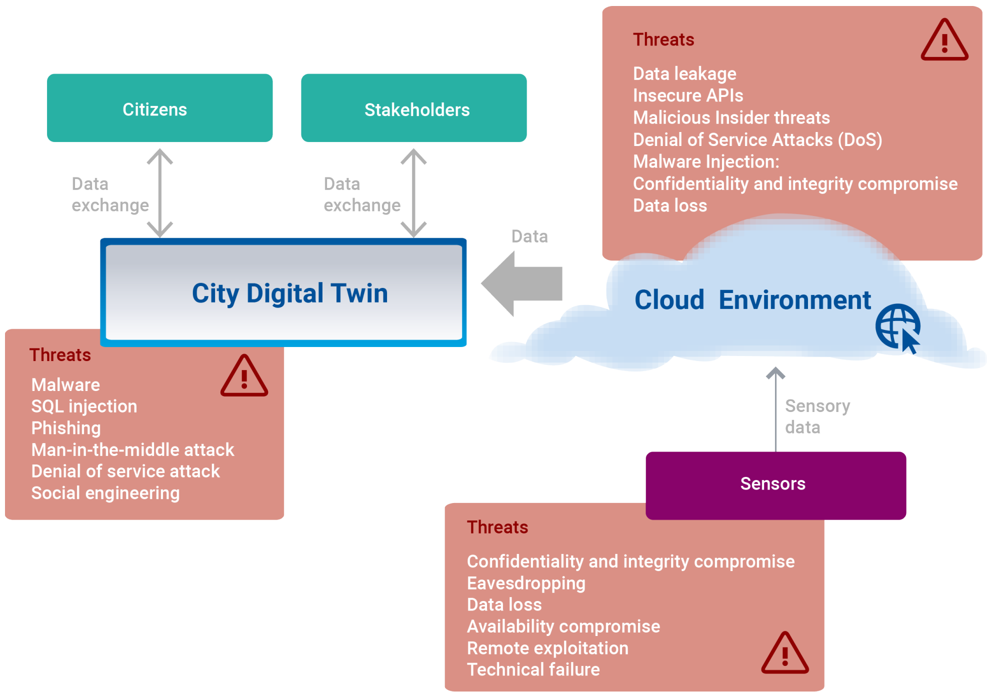


Figure 5. View of the possible cyber security threats in the context of city digital twin.

Some of the mitigation techniques related to the threats of smart city applications are summarized in [68]. Where the threat mitigation solutions are divided into two groups. The first group is focused on IT-based mitigations e.g.,:

- Ensuring protection against malware
- Frequent evaluation of the vulnerability of individual components of intelligent systems
- Implementation of best practice awareness programs for users
- Offering frequent training for employees
- Device monitoring of legacy smart systems
- Being aware of the incompatibility of potential suppliers' security mitigations

- Securing network communication using a VPN
- Using smart devices to communicate only operational/critical data and not all private consumer information
- Using a public key infrastructure to secure information exchange
- Design and implementation of a network intrusion prevention system
- Permission should only be guaranteed by specifying the correct authentication mechanism and protocols.

The second group includes mitigation of physical threats, e.g.,:

- Building a resilient physical network and a secure infrastructure
- Securing components inside and outside
- Protective equipment
- Hard-to-crack devices with built-in security by design
- Ensuring the installation and maintenance of the surveillance mechanism
- Frequent checking of all hardware

There is also a need to determine whether selected smart city segments will be rated as important information systems or critical infrastructure systems. Such systems will have to comply with the regulations set out in the relevant legislation. However, legislation will also have to evolve as smart cities develop.

Military Usage

The technical design of a smart city should also be considered from the perspective of ensuring the defence of the state from two different perspectives:

- Misuse of the technical infrastructure by the enemy to support their attack. This must be preceded by a successful cyber-attack on the smart city system to take control of the control systems.
- The use of the smart city's technical infrastructure to support the defence of its own territory when attacked by the enemy.

The misuse of the technical infrastructure by the enemy is well described in [60]. It is primarily to obtain intelligence from the smart city sensors and then to cause panic and chaos that will make it difficult to defend the city.

The use of the technical infrastructure to support the defence of their own territory is mainly concerned with the integration of system solutions into military command and control systems. In the event of an armed conflict or a natural disaster, modern cities are threatened with enormous damage to the inhabited areas or to the urban infrastructure. In such situations, the help of the army in rescue and recovery work can be irreplaceable and very effective. However, the goal is to anticipate and avert such situations in the urban environment. According to [69], military efforts can be envisioned along three dimensions:

1. Military moves directly into the area of the urban conflict. The main part of the work is carried out by the infantry with the support of the air force and ground vehicles.
2. Distant Intelligence, Surveillance and Reconnaissance (ISR). Gaining and maintaining current situational awareness is critical to planning and executing counter and recovery operations.
3. Ground support from the infantry/air force that gains support from neutralizing the enemy at long range.

The use of the smart city infrastructure by the military is, according to [69], possible in different areas:

- Sensors deployed in buildings can provide data on air quality, chemical/smoke, radiation, and gas to indicate various types of chemical leaks, explosions, and hostile activities in areas.
- An intelligent traffic management system can guide the navigation of ground assault support so that infantry can move rapidly through the objective area.

- A smart grid and distribution network would allow the military to manage power in the event of outages or intermittent supplies. The military can use smart points/hubs around the city as an alternative source of energy to power their equipment. Likewise, the grid would allow the military to restore power for essential services in the city using its secondary power sources.
- Water quality sensors can be used to detect if the water system of the city has been compromised.

The operational readiness and efficiency of the armed forces can be significantly improved with the help of digital technologies. On the other hand, the digitalization and interconnection of communication, sensing, logistics, command and control places high demands on cyber defence, which has become an important element of increasing the resilience of the armed forces [61]. The architecture of the smart city and army technologies would need to be developed in mutual compliance to avoid interoperability issues. Only then will it be possible to take advantage of all the benefits that cooperation between smart city technologies and the army offers.

5. Rotterdam vs. Brno Implementation State

5.1. Rotterdam

As part of the city's electric mobility initiatives, electric buses are being deployed in Rotterdam. Charging batteries from photovoltaic (PV) panels located on the roofs of large buildings, together with optimizing the routes and timetable of individual lines with charging time, help significantly reduce NOx levels in the city [70]. Smart waste management showed many positive and quantifiable results (e.g., 20% reduction of mileage of waste trucks, collections and routes decreased, less overflow of containers, CO_2 emission, and noise reduction, and substantial savings in fuel, time, and cost). It is achieved using autonomous network sensors to measure the degree of filling of containers, based on which the optimal route for the waste truck is calculated. Substantial energy savings and CO_2 reduction can be expected after installing efficient and intelligent street-lighting. Automatic notifications about malfunctions from each lamppost, a central maintenance management system and remote lighting control (easy dimming of an LED according to daytime or events in the area) are advantages that bring remotely controllable street-lighting. All the mentioned smart solutions have already been implemented in Rotterdam city, and their telemetry data fed into the city's digital twin.

The development of a 3D city operations model in Rotterdam city is currently in the proof-of-concept process. According to the implementation report [71], real parking data were successfully disclosed in the 3D city model. The real-time data regarding traffic, public transport and opened bridges are shared within the model. The 3D model of the city includes individual layers of the city, where individual parts of the city infrastructure are visualized (roads, water canals, public lighting).

Rotterdam has many underground objects (pipes, electricity lines, metro, underground spaces). Mapping these structures and entering them into a 3D model makes work more accessible, e.g., when planning new construction or in emergency situations. Urban development and information about individual buildings are also part of the model. Detailed plans of high-rise buildings are also considered for integration in the future for access by firefighters in the case of an emergency. The next layer is tree-mapping data, which includes information about all trees located within the city. Providing traffic information assists in resolving unexpected traffic problems. The model is also intended to assist in preparing future building plans. Through augmented reality, city citizens will be able to see a 3D model of a planned building or park by scanning a QR code directly at the construction site. Figure 6a presents the screenshots of the 3D city model, with information about a particular building, such as the year of construction, number of floors, and number of underground bases, etc. The city's infrastructure is depicted in Figure 6b, where roads, electricity, telecommunication grids, water and sewage pipes are seen.

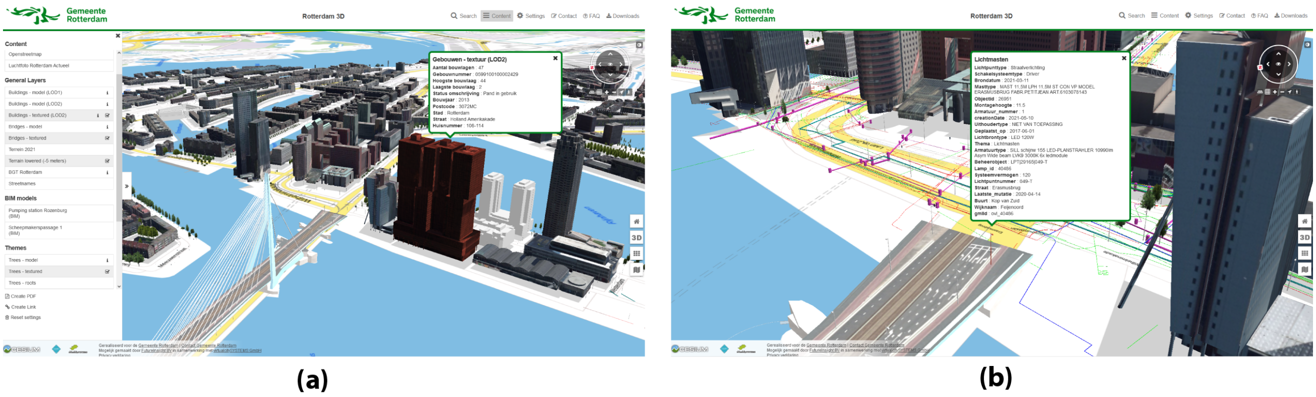
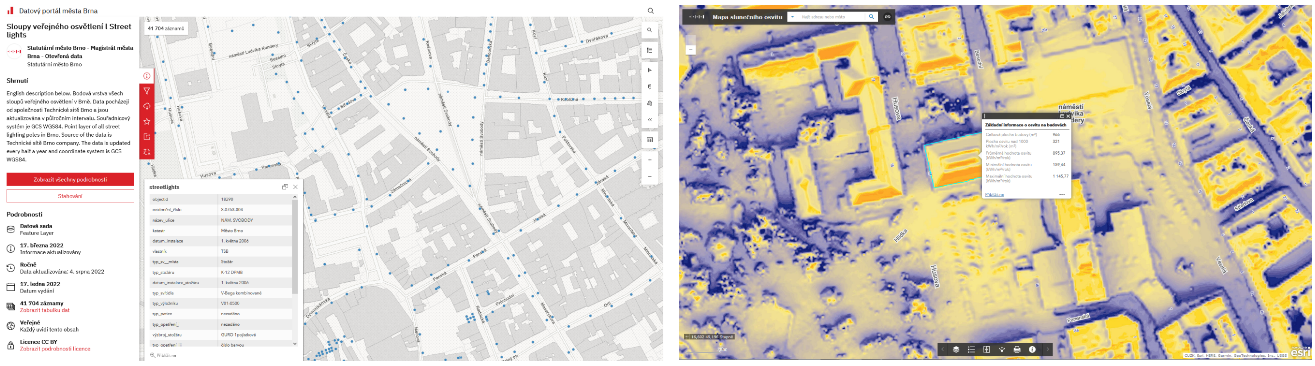


Figure 6. The Rotterdam 3D city model—a digital twin: (**a**) Detail of 3D city model application with building information. (**b**) The layer of city infrastructure with public lamp details [72].

5.2. Brno

The city of Brno runs the web data platform data.Brno [29]. The database currently contains 143 datasets, and the number is constantly increasing. For instance, some datasets contain data on traffic conditions (based on WAZE for Cities), air quality (PM10, PM2.5, O3 and NO2), location of public transportation vehicles, bike traffic, and car park capacity. Other data are regularly updated. In addition to technical information (traffic conditions, public lighting, recycling and waste management, etc.) the datasets also provide information on economics, history, environment, study, safety, and health. Digitalization of the city increases the potential for creating startups and new business opportunities by making the city's data and data analysis available. Thanks to a comprehensive overview of the city's ongoing processes, it is possible to immediately reduce the price of urban services and make them more efficient. From a social point of view, it is a great advantage to support the creation of communities and the possibility of citizens' involvement in the city organization. As a result, it is possible to create an overall picture of the given location of the city together with social and economic aspects. The data are publicly available and open, allowing users to analyze or use the API to generate tools and applications.

The data are visualized in a 2D map (see Figure 7) only and there are currently no plans to import them into a 3D city model. The 3D model of the city is a separate application and contains data from the height measurement of buildings and tree-mapping in the city. The datasets do not yet contain information about critical infrastructure such as water, electricity, etc., as well as sensitive personal data. For this reason, there is no great threat of data misuse. To address the topic of renewable energy sources, the photovoltaic potential map is available. The map visualizes how much sunlight falls across the whole city and can be useful for citizens to estimate rooftops' potential for installing PV panels [73]. The values of solar radiation intensity for the territory of the city of Brno have been calculated by the company TopGis, s.r.o. for using the Brno 2019 digital surface model (stereophotogrammetric) with a resolution of 1 m. The calculation was made for all 365 days of the year within the interval of half an hour. The values of the individual pixels of the grid are, therefore, the sum of the intensity of direct and diffuse radiation in kWh for the whole year [29]. The datasets also contain data about the position and properties of recharge stations for electric vehicles and shared micro-mobility. Figure 7a represents the data platform of the city of Brno with the street-lighting dataset turned on. Each light point on the map contains data such as lamp type and power, kind of lamp post, date of installation and exact location. This picture illustrates how individual datasets can be displayed in the given platform. Figure 7b shows the solar radiation intensity map for Brno city, which is available in data.Brno platform. The figure shows the particular building where one could find the area of the building, average, minimal and maximal value of annual solar radiation in kWh/m^2/year units.



(a) **(b)**

Figure 7. The data.Brno city data platform: (**a**) Dataset of public lighting with information about lamps. (**b**) The map of solar radiation intensity [29].

5.3. Urban Data Portals Comparison

To compare both urban data portals, we present Table 2, which summarizes and compares the main features of the platforms. The main difference is in the visual presentation of the available datasets. Rotterdam presents data in 3D, while Brno has a data portal based on a 2D map. The Rotterdam city portal takes advantage of the 3D visualization and allows city residents to participate in new projects through voting, commenting and visualization using augmented reality. It also makes it possible to use the individual layers of the city and display engineering networks (electricity and communication cables, water and sewage pipes, metro lines) in the city's underground. The data portal of the city of Brno does not provide this option. However, it does present data from the city council meeting and, at least in this way, enables the city's residents to be informed about city politics. The advantage of the Brno data portal is the ability to download data to custom-made applications using the API interface regularly. Another advantage is the possibility of viewing individual datasets on the 2D map and other advanced analyzes using available applications in the portal.

As for sensory data, both portals currently offer limited functions, namely the display of the location of public transport vehicles, traffic events, air quality, and intensity of cyclists from bicycle detectors and occupancy of parking garages, and the openness of bridges (Rotterdam).

Table 2. Smart city platforms comparison.

	Rotterdam	Brno
Visualization	3D	2D
API for downloading the data	No	Yes
Possibility of participation	Yes	No
Augmented reality	Yes	No
Underground layers	Yes	No
Information from the city council	No	Yes
Real-time datasets	Yes (limited)	Yes (limited)
Additional applications and further analysis	No	Yes

Some interesting statistics comparing both cities can be gained from available datasets. The improvement of air quality is one of the criteria and the motivation for applying smart solutions in a modern city. Figure 8 shows the yearly average of overall Air Quality Parameter (AQI) [74] for the city of Rotterdam and Brno. It is clear that the air pollution level in Brno is in the yellow "Moderate" area, and Rotterdam is in the green "Good" area. Data for 2022 are only available for the first half of the year. Construction activity in the city centre may also have contributed to poorer air quality in Brno in the last four years. To improve the situation, Brno could follow Rotterdam's lead by focusing more on electric buses. However, in the current economic situation, the Brno Transport Company does not plan to purchase electric buses, given that during the last few years, the company has been focusing on replacing diesel buses with CNG-powered buses. Additionally, two thirds of the fleet already runs on electricity (trams and trolleybuses). The decision has also been influenced by the current economic situation and the short range of electric buses, including the lack of charging infrastructure at terminals.

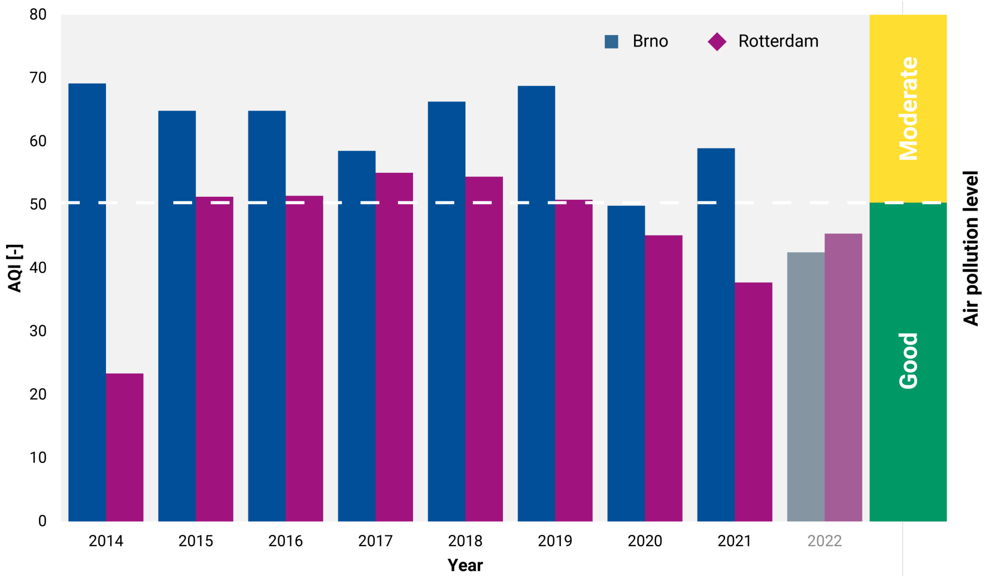


Figure 8. Year average overall Air Quality Index (AQI) for the city centre of Brno and Rotterdam.

Another criterion for comparison can be the consumption of electricity for public lighting. Figure 9 shows both the annual power consumption and the average power per each light point. It is clear from the graph that in the city of Brno the average power per light point is around 80 W, in Rotterdam, it is half that amount. In the city of Brno, the share of LED lights within public lighting is 11% compared to the city of Rotterdam, where the share of LED lights is 60%. Rotterdam plans to replace all sources of street-lighting with LEDs by 2025. In Brno, gradual replacement of LED lights is planned for 2023 at a level of 13.5%.

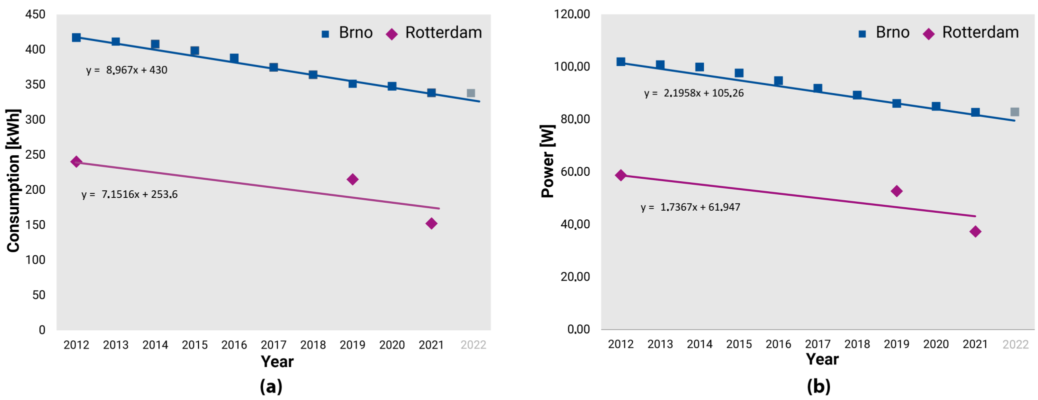


Figure 9. Public lighting consumption for Brno and Rotterdam: (**a**) Consumption per single light point. (**b**) Power per single light point.

Regarding the applicability of smart lights, Brno uses the DALI system for communication between street-lighting and dispatching. The lights are controlled from 400 switching points, communicating with dispatch using a private radio network. Around 100 light points are dimmed to lower power consumption. According to Technical networks Brno company, there are currently no plans to deploy smart lights with additional sensors and with ability to control them individually on a larger scale.

The purpose was to provide some practical examples of how digitalization approaches have been implemented in Rotterdam and Brno. Compared to the city of Rotterdam, Brno does not try to present sensory data in the form of a 3D map; it only displays data on a 2D map, which is more convenient in some cases. Through the efforts of the data portal, Brno is making open data available and leaving it up to users to work with the data, analyze it, and then display it in their applications and tools. A suggestion for improving the data.Brno portal could be the implementation of more live sensory data. Implementing AI data processing to create predictive models would also be interesting. Currently, Brno is launching several innovative projects, such as electric car chargers in residential areas, photovoltaic panels on the buildings at the Brno thermal power plant, transition to LED public lighting, revitalization of brownfields, long-term sustainable waste management, and construction of a heat pipe from the Dukovany nuclear power plant to Brno. In the future, this can improve quality of life in the city and contribute to the use of renewable energy sources.

6. Discussion

As part of the Ruggedised project, cities such as Brno should be inspired by modern European cities and should try to implement some of the standard smart solutions used in Western Europe. By comparing the city of Rotterdam (the digital twin of the city) to a city such as Brno we concluded with the following important results: the digital twin concept is replicable, but its content is developed specifically for the city of Rotterdam; each municipality must create it by itself, with topics related to local realities; the digital platform gives an excellent basis for implementing innovative solutions (PV panels installation, intelligent street lightning, electromobility implementation etc.).

Additionally, since the current situation in Eastern Europe is becoming unstable, it is a big question how the digitalization of the city could contribute to the protection of the city's inhabitants or whether the enemy could misuse the city's infrastructure. For this purpose, security measures should be applied that are briefly reported here: Smart City architecture and military technology would need to be developed in accord; the digitalization and interconnection of communication, sensing, logistics, command and control places high demands on cyber defence; from the beginning of the hardware (IoT nodes, gateways, sensors) and software (cloud system, web platform) design, security and the threat of possible misuse must be taken into account; essential information systems or critical infrastructure systems will have to meet the regulations set out in the relevant legislation.

The results and experiences from the implementation in the city of Rotterdam and Brno can help create the initial concept of the city's digital platform.

7. Future Trends

Making cities more human and focus more on the inhabitants of these cities should be the primary motivation for digitalization [75–77]. One of the main supporting topics of future smart cities will be green planning for public spaces. Cities worldwide publish heat maps showing the temperature difference between green and concrete areas. Data from these maps should be a driving force for cities and motivation to reduce carbon emissions, cool down city centres and achieve ecosystem resilience. Another future trend is to create a healthy environment for city residents and, at the same time, support city residents, companies and public institutions in implementing digital health services [78]. Using these services, it is possible to take preventive measures for a group of people and prevent unhealthy behaviour in the future. This can improve the life and health of the city's residents and, at the same time, better availability of health services for those who need them.

A significant point is supporting the "15-minute city" concept and creating opportunities for intelligent and sustainable mobility. Reducing cars in city centres and promoting electrification, shared services, and intelligent mobility is essential for future cities. Support for innovation and digital transformation of the city using platforms such as innovation hubs and leveraging data. Bringing new impulses to the city and solving the city's most burning issues using publicly available data is essential.

Another future trend is the construction of green buildings and an intelligent and sustainable infrastructure. New buildings built in city centres should be made of sustainable materials and be energy efficient. A green building should be able to produce electricity for its consumption using renewable energy sources such as PV panels. However, the city's residents should also support the construction of new urban projects. A tool for expressing opinion and support for planned construction should be participation platforms, where information about planned projects will be available. In this way, the local government can extend responsibility for new projects to the city's residents.

The use of digital platforms for AI optimization and managing urban activity, predictive analysis and visual representation of data is auspicious. Another possibility is the support of local government using data-driven decisions. Cybersecurity is a critical element in the concept of planning future smart cities. The number of interconnected devices puts a high emphasis on cyber security. The use of a smart city infrastructure to fight crime in the city or against natural disasters is a very current and future-considered topic. In this case, the military can use the data to plan necessary interventions.

8. Conclusions

In this article, we presented a framework for city digitalization based on experience from implementation in the city of Rotterdam. A significant challenge of digitalization is collecting information from multiple sources in an open format to be further used in the data platform. Furthermore, data anonymization must be ensured to avoid leaking sensitive information from the data provider. The city's digital platform is driven by its data users, who can create custom applications and tools using available datasets from the city's digital twin. Using the digital city concept, the main objective is to improve quality of life and the environment and support sustainable living using renewable resources. In addition, the article shows another critical aspect of the digitalization of the city, namely the provision of cyber security. From a military perspective, the digital twin is expected to be used primarily for defence planning purposes. From an attacker's perspective, the digital twin represents a very valuable source of information that could be easily exploited for possible offensive operations. It is, therefore, advisable to protect these data appropriately and to allow access to them only under a special access control scheme. As part of the crisis management process, the military may collect data from individual sensors located throughout a city in response to natural or unnatural crises. The article concludes by comparing the digital platforms of Rotterdam and Brno and presenting their features and capabilities. The article results in the following findings:

- The platform presented in the third section could be used for designing the basic architecture of the city's digital twin.
- Before implementing the digital twin of the city, it must be defined who will be responsible for the gathered data to create trust between the city, companies, citizens and research institutes. It is suggested that the municipality should be primarily responsible for the city's digital platform and open data. The security and privacy of the data must be ensured before importing data into the platform. Open data standards must be unified to make them compatible with the urban data platform.
- Every city has its approach to digitalization, and it is impossible to unify every city's digitalization process. Rotterdam and Brno choose a different way of visualizing the

data. The Rotterdam infrastructure is multi-layered (water canals, bridges, underground), and a 3D visualization platform better represents it.
- There are several security threats that a risk assessment must detect before starting the digitalization process of the city. Security threats can be identified using several taxonomies. The article summarizes threats that occur in sensors-cloud architecture.
- Data visualization is well-managed in existing digital platforms, but AI-assisted applications such as self-decision and prediction in city management issues are still not widely implemented.
- The current situation in Europe gives rise to the possibility of using a smart infrastructure and digital twin cities for the protection of the population in the city. It was found that the architecture of the smart cities and military technologies must be developed in mutual compliance to assure interoperability.
- Primary motivation for future trends is to make cities more friendly to people.

Author Contributions: Conceptualization, P.B., A.C., P.F. and J.V.; data curation, P.B.; writing—original draft preparation, P.B., A.C., P.F. and J.V.; visualization, P.B.; supervision, P.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been conducted as part of EU Horizon 2020 project RUGGEDISED and received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no 731198.

Data Availability Statement: Not applicable.

Acknowledgments: I would like to thank Peter Wijnands from Gemeente Rotterdam and Lubomir Boza from Technicke Site Brno for providing data on public lighting consumption. I would also like to thank RIVM—Rijksinstituut voor Volksgezondheid en Milieum, Landelijk Meetnet Luchtkwaliteit and Czech Hydrometeorological Institute for providing Air Quality Data. I would like to thank Zbynek Raida and Ostrenko Yuliya for managing meetings with individual contacts in the city of Brno and Rotterdam.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PV	Photovoltaic
NOx	The gases nitric oxide and nitrogen dioxide
CO_2	Carbon dioxide
LED	Light-emitting diode
IoT	Internet of Things
AI	Artificial Intelligence
IGB	Intelligent Green Building
LSTM	Long-short term memory
UDP	Urban data platform
GIS	Geographic information system
NIST	The National Institute of Standards and Technology
SCCF	Smart Cities and Communities Framework
API	Application Programming Interface
PM10	Particulate matter that are generally 10 micrometers and smaller
PM2.5	Particulate matter that are generally 2.5 micrometers and smaller
AQI	Air Quality Index

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