

Article

# ICT Supported Urban Sustainability by Example of Silesian Metropolis

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**Abstract:** The implementation of sustainability in urban spaces has been studied for many years in different countries. Sustainability means maintaining a certain ecological status enabling longevity and durability. However, in the case of smart cities, sustainability is supported by information communication technology (ICT) adoption and implementation. In this paper, authors focus on metropolis architecture modeling and recommend positive experiences gathered by municipalities in different countries. The collected experiences and good practices concern ICT implementation for sustainable metropolis management. Authors formulated an original Model of Metropolis Ecosystem Architecture in the ArchiMate language. This model preparation required literature review and studies on ICT implementation opportunities for urban governance. The Metropolis Ecosystem Architecture Model (MEAM) is to support strategic planning and ICT eco-innovation management in the Silesian Metropolis. This significant model emphasized the metropolis stakeholders' interests combined with ICT solutions.

**Keywords:** urban sustainability; metropolis; city cooperation; ArchiMate; smart city



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## 1. Introduction

The rapid increase of urbanization formulates new challenges and creates new problems, such as insufficient fresh water supply, unreliable transportation, overcrowded cities and roads, and limited access to medical, cultural, and educational services, creating pressure on the natural environment or environment degradation. More people leave villages and move to towns, which change into metropolises. In this paper, metropolis is defined as a consortium of towns and communities closely located and having joint metropolitan problems. Slowly but systematically, metropolises implement modern ICT solutions to improve the life of citizens as well as to support investors, visitors, tourists, and other metropolis stakeholders. Therefore, metropolises develop transport infrastructure, freight transit, car-sharing systems, and autonomous electric vehicles to reduce the use of private automobiles without compromising mobility [1]. There are many different individual and autonomous local initiatives and solutions created by residents and business units, i.e., bike-renting systems, roof gardens, and honey production on private house roofs. Local initiatives may find followers. The main thesis of this study is as follows: for their sustainable development, metropolises need a holistic approach for ICT implementation in the urban space as well as the usage and popularization of positive experiences and solutions successfully applied in other cities. This thesis is supported by literature review on ICT adoption for urban sustainability as well as by case study, including the analysis of recommendations for Silesian Metropolis. The paper consists of five parts. The next section covers description of research methodology. The third section includes literature review on urban sustainability. Further, the fourth section comprises characteristics of Silesian Metropolis. The fifth section is on MEAM model development and its realization possibilities. In the MEAM development section, authors focused on the model conceptualization resulting from literature review and studies of metropolitan authority documents

and regulations, as well as experiences of national and foreign urban areas. Eventually, authors present discussion and conclusions.

## 2. Research Methodology

The research methodology is based on the following research steps:

1. Research gap identification: The ICT Application in Smart Sustainable Cities
2. Collecting material (Scopus, Web of Science, norms, standards, reports, strategies, best practices, etc.)
3. The literature review and best practices of ICT in urban sustainability development
4. The case study of Silesian Metropolis
5. MEAM concept in ArchiMate 3.0 framework
6. The holistic view of SMEAM concept for sustainable Silesian Metropolis development
7. ICT implementation examples in SMEAM

The first step of the research methodology was to identify the research gap. The research gap was to describe the ICT application domains in smart sustainable cities because of the metropolises' sustainability development. The collecting materials and literature study gave the background to describe the context of urban sustainability study.

The second step was to collect different research material from research repositories such as Scopus or Web of Science, as well as some reports, strategies, best practices, etc. Then, the literature review of urban sustainability was presented with some best practices examples of ICT in sustainable urban development in Section 3. The practical research study of ICT examples in metropolis needed to be studied deeper in some case studies. The case study of Silesian Metropolis was proposed and described in Section 4. Based on the case study, the holistic model of eco-metropolis was developed and the MEAM concept in ArchiMate 3.0 framework was proposed. The holistic view of SMEAM concept for sustainable Silesian Metropolis development was presented with the ICT implementation examples in SMEAM in Section 5.

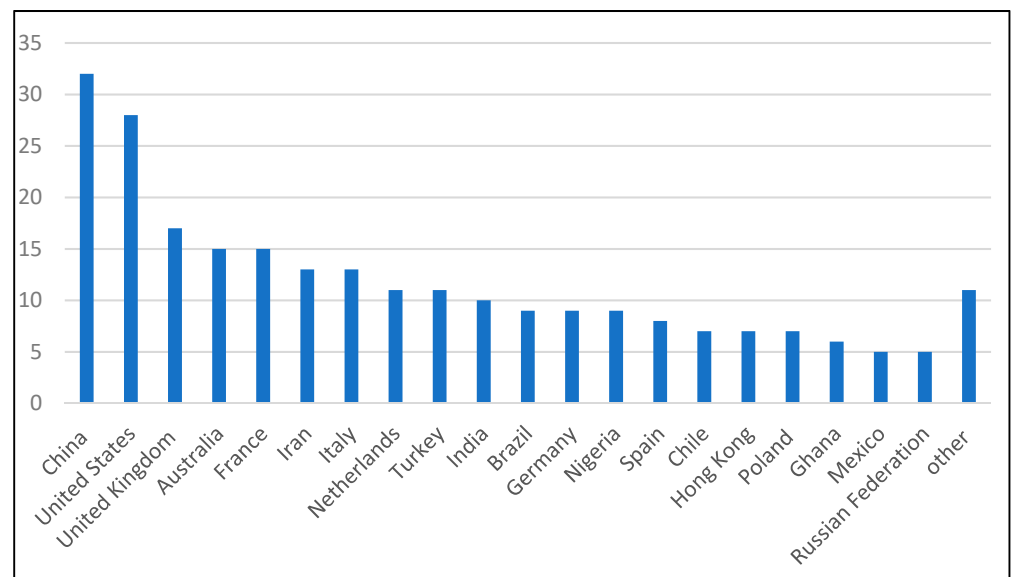
## 3. Urban Sustainability Literature Review and ICT Application Development in Sustainable Smart Metropolises

There are many comparative studies on how sustainability is included in urban planning in metropolises. The literature survey was carried out on Scopus repository, Web of Science repository, and standards, norms, reports, strategies, best practices, etc. The principal investigation questions were formulated as follows:

Research Question 1 (RQ1): What ICT-connected challenges are faced by metropolises during the urban sustainability strategy realization?

Research Question 2 (RQ2): How are ICT applications developed in sustainable smart metropolises?

The searching RQ1 was conducted via the search words "urban" and "sustainability" and "metropolis". Hence, 248 valuable results were found in the Scopus repository, which includes the highest quality publications. The search was realized within the Article title, Abstract, and Keywords scope and covering the period of 1989–2022. That number of Scopus publications is not high, thus urban sustainability can be understood as a challenge for researchers many countries. The publications mainly come up from China (32 positions), United States (28), United Kingdom (17), Australia (15), France (15), Iran (13), Italy (13) and others, such as Netherlands, Turkey, India, Brazil, Germany, Nigeria, Spain, Chile, Hong Kong, Poland, Ghana, Mexico, and Russian Federation (Figure 1). Therefore, the problem of urban sustainability is important in highly industrialized countries and in overpopulated, young generations' countries in Asia, Africa, and South America.



**Figure 1.** Metropolis Urban Sustainability Publications in Scopus in 1989–2022.

Authors' own studies on how sustainability is presented in comprehensive plans of metropolises allow to investigate what kind of investments are necessary to align sustainable development with ICT implementation. This section also aims to discuss how urban sustainability is realized through planning over the last thirty years, and what ideas and solutions are constructed. Adolfsson et al. [1] argue that a comprehensive metropolitan plan should include an analysis of climate and environmental issues, efficient water and wastage management, renewable energy source usage, housing design, green strategy, circular economy, transport, employment, and unemployment risks. The subject of sustainability in urban planning indicates certain relations among these issues, although there are institutional, political, and cultural differences leading to various meanings of sustainability.

Urban sustainability issues are included in standards ISO 37,120 [2] and ISO 37,122 [3] as well as in the document United Nations Sustainable Development Goals [4]. ISO 37,122 [3] Standard defines methodologies for indicators to measure the performance of smart cities and quality of life. In this standard, indicators directly connected with ICT usage are as follows:

- Percentage of the labor force employed in the ICT sector;
- Number of computers, laptops, tablets, or other digital learning devices available per 1000 students;
- Number of science, technology, engineering, and mathematics (STEM) high education degrees per 100,000 population;
- Percentage of payments to the city that are paid electronically based on electronic invoices;
- Annual number of online visits to the municipal open data portal per 100,000 citizens;
- Percentage of city services requested online;
- Average downtime of the city's ICT infrastructure;
- Percentage of the city's population having online access to healthcare providers;
- Percentage of households with smart energy or water meters;
- Percentage of public recreation services that can be booked online;
- Percentage of the city area covered by digital surveillance camera;
- Percentage of waste containers equipped with telemetering;
- Number of online bookings for cultural events per 100,000 citizens;
- Number of e-book titles per 100,000 population;
- Percentage of the city population with access to fast broadband;
- Percentage of city area not covered by telecommunication connectivity;
- Percentage of city streets covered by real time online traffic alerts and information;

- Percentage of public transport lines equipped with publicly accessible real-time information system;
- Percentage of public parking spaces equipped with e-payment systems;
- Percentage of public transport routes with municipally provided and managed Internet connectivity for commuters;
- Percentage of the city's land area covered by an online food-supplier mapping system.

Beyond that, the ISO 37,120 (2018) standard supports municipalities to identify indicators for sustainable development. Both standards ISO 37,120 [2] and ISO 37,122 (2019) focus on urban sustainability. However, the ISO 37,120 [2] standard covers indicators which concern socio-organizational solutions, while the ISO 37,122 [3] standard includes measures of digital city development.

The UN Sustainable Development Goals [4] identifies 17 goals and 169 global targets established by the United Nations to be achieved by 2030. Therefore, progress is expected to be made in some areas, i.e., child health, access to electricity, protection of natural environment, reduction of food insecurity, growth of adequate housing, access to running water, waste management system implementation, or public transport effectiveness. ISO standards and UN reports [4] provide guidelines for smart metropolises in the future. ISO standards recommend a holistic approach to sustainable cities and communities' development. These recommendations include system frameworks that city leaders and planners can use to define objectives and priorities for making their cities more sustainable. The recommendations include guidelines for energy management, road safety, and intelligent transports, as well as water consumption, health protection, and cybersecurity. Smart metropolises can be understood as a consortium of smart cities that are embedded within ICT systems to provide a balance between economic development, environmental preservation, and high quality of life.

Carrabs et al. [5] define urban distribution network as an extension of vehicle routing network for goods' distribution, and they argue that the aim of a sustainable urban distribution network is to provide the means to properly meet economic, environmental, and social needs efficiently and equitably, while minimizing negative impacts and their associated cost, including environmental issues such as congestion, noise, and air pollution. In this sense, sustainability can be understood as a certain compromise achieved by metropolis stakeholders. Additionally, Reyes-Rubiano et al. [6] perceive sustainability in these three aspects, i.e., economic, social, and environmental.

Pelton and Singh [7] say that each country with its unique social, economic, linguistic and governance structures will have in general a similar approach to creating and sustaining a successful smart metropolis. Unfortunately, in practice there are many differences in these approaches' realization. The design of a successful smart metropolis varies significantly from country to country, due to political, cultural, or religious reasons. Religion is a part of human culture, which determines attitudes towards sustainability. Religion as well as education have impacts on human behaviour, human respect for nature, and human intolerance of injustices, inequalities, or digital exclusion. These categories, as well as social inclusion (e.g., acceptance of minorities and disabled people), are included in discussions on sustainable metropolis.

Urban planners need to know more about key new capabilities, which can be used to provide smart metropolis services as well as about vulnerabilities, where more protections are needed [7].

The cyber-vulnerabilities are following:

- Mobile services and mobile apps;
- The Dark Web and cyber-criminal attacks;
- Internet of Things;
- The Cloud computing and tradeoffs between planned performance and digital defense;
- Industrial Control Systems, fires, industrial accidents;
- Meteorological and surveillance satellites;
- Cybersecurity for military systems, where special capabilities and processes are necessary;

- Diagnostic systems to discover cyber vulnerabilities.

Through the literature review, this section answers the research question (RQ1). Therefore, Tables 1–3 include the most valuable findings. Authors of these selected publications present issues that are important and valuable for discussion and for adopting as good practices. The challenges have been divided into three groups. The first group includes initiatives connected with metropolitan transport (Table 1).

**Table 1.** Challenges concerning transport in Metropolises’ Sustainability Strategy Realization.

No	Authors	Findings	CN *
1	Larin et al. [8]	The organization of high-speed passenger transportation in metropolises is substantiated. Authors proposed to use the tube-type high-speed rail lines system that provides synchronous and balanced air exchange during the train movement.	0
2	Kramarz & Przybylska, [9]	Authors focused on the analysis of the impact of multimodal freight transport on sustainable development of the cities in the Silesian Metropolis. Authors identified factors that should be included in city strategy for sustainable development.	0
3	Matusiewicz et al. [10]	The sustainable urban freight transport in Gdansk-Gdynia-Sopot metropolis in Poland is a challenge. Authors present their survey results. They argue that the collected opinions are important for the sustainable urban logistics plans in many European cities.	5
4	Huang & Wey, [11]	Authors explore and summarize the design criteria of Green Transit-Oriented Development (TOD) for the next-generation metropolis. The applied research methodology covers literature review and gathering expert opinions. Authors have used Fuzzy Delphi Technique (FDT), Fuzzy Analytic Network Process (FANP), and Quality Function Deployment (QFD). The research approach is recommended as an initial reference for improving the planning and design of sustainable transportation environment.	7

\* Citation Number (CN).

**Table 2.** Challenges concerning Technology Implementation in Metropolises’ Sustainability Strategy Realization.

No	Authors	Findings	CN *
1	Medeiros et al. [12]	Authors investigated the way in which urban planning policies helped to renew the waterfront areas in the Lisbon metropolis. This initiative changed industrial and harbor areas into leisure, ecological, and touristic places.	2
2	Shah et al. [13]	Authors presented an eco-efficiency analysis of eco-industrial development projects at the industrial park level and at the regional level. The analytical reports concern reduction of waste generation and energy use related to the technological improvements and urban-industrial symbiosis.	20
3	Gong & Hu, [14]	Authors argue that ecological infrastructure planning is a way of constructing urban ecological grid for metropolises, cities, and towns. According to authors, ecological infrastructure is to ensure fresh air, food, recreation, safety, aesthetics, and education. The article covers an example of Philadelphia ecological storm water infrastructure planning, implementation, and assessment.	4
4	Toubin et al. [15]	Urban resilience is considered a challenge for metropolises. By example of the City of Paris, authors revealed the short- and long-term impacts, spatial dependencies, and inequalities. Technical networks and urban services providing water, public transportation, etc. are interested in applying the resilience concept. The city auto diagnosis identified the service dependencies and its capacity for operation in case of disturbances.	18

\* Citation Number (CN).

Public and freight transport in the metropolises plays an important role in meeting the needs of citizens, and it contributes to the generation of negative effects, especially for the environment and society. These problems have a universal character. They arrive in industrialized countries as well as in low-income and overpopulated countries. The second group covers technical proposals to ensure post-industrial re-cultivation, eco-industrial development, innovative public spaces, and hybrid forms of using the city places (Table 2).

The third group includes political and organizational solutions for metropolis sustainability (Table 3). In metropolises, complex urban regeneration policies, consolidation of initiatives, or citizen science for different projects' support are highly appreciated, particularly if they are accompanied by opportunities to transfer the practices to the surrounding areas [16]. Urban sustainability researchers mentioned the competitiveness among metropolises as a stimulant of development. However, it would be better to support development of cooperation of communities within a metropolis, or among metropolises. In social sciences, cooperation is defined as an act of cooperation among competing business units, usually among companies. Cooperation is expected to generate effects of synergy for businesses as well as unique values and benefits for their customers. Cooperation is a form of strategic alliance applicable to communities within a metropolis and strongly supported by ICT and joint investments.

**Table 3.** Challenges concerning Political and Administrative Decisions in Metropolises' Sustainability Strategy Realization.

No	Authors	Findings	CN *
1	Orttung et al. [17]	Authors highlight urban problems in Arctic cities outside of Russia and the possibilities for the cities to adapt to changes in the global environment and economy.	2
2	Yin et al. [18]	Flood disaster preparedness is a challenge, which is highlighted as a way to manage the flood risk in Accra Metropolis, Ghana. The research work revealed that income, education, house ownership, and communication among residents as well as individual characteristics have a significant positive impact on preparedness for flood disasters. Authors suggested that effective policies to mitigate flood risk must be communicated to residents.	0
3	Lu et al. [19]	The efficient use of land and the coordination of stakeholders' interests in suburban villages are metropolitan challenges. Authors provide practical guidance on how to integrate urban and rural areas.	0
4	Dhanaraj & Angadi [20]	The availability of geospatial data for generating information databases and models to support local scale decision-making processes is a challenge in developing countries. However, the remote sensing technology is cost-effective and efficient to collect urban data, to integrate them with various geographical information systems, and to build statistical models.	1
5	Alfasi & Margalit, [21]	The challenge is to remove the obstacles related to planning and regulations that stem from the structure of urban planning organizations and the incompatibilities between them and new technology opportunities. Hence, the timely adaptation of programs and means, communication between urban and governmental bodies, and preparation for frequent coordination and consultation in various combinations are necessary.	0
6	Henderson & Lawhon, [22]	The challenge is to change the thinking that big cities are less green and less desirable places to live. Authors emphasized the multiplicity of environmental initiatives to point out possibilities for sustainable future.	0
7	ArastehTaleshmeikaill et al. [23]	In Teheran Metropolis, the challenge is the development of renewable energy sources and their application in different sectors to achieve sustainability. Authors focus on the application of specific stimuli and incentives for electricity producers to accelerate the renewable energy usage.	2



Table 3. Cont.

No	Authors	Findings	CN *
8	Ghalehtemouri et al. [24]	Authors analyze the competitiveness of metropolises in Iran. They indicate that commuting time, traffic, property price, and healthcare are factors in the selection of a living place. They conclude that metropolises' competitiveness should be a driver to stimulate sustainable development	0
9	Jesudass et al. [25]	The research work aimed at developing an integrated model for waste management by studying the waste management practices in the state of Tamil Nadu, India. Authors proposed a decentralized model of management so that the transportation and huge landfilling is avoided and transportation cost is reduced.	0
10	Soyinka & Siu, [26]	Authors investigated urban informality, housing insecurity, and social exclusion in Hong Kong and Lagos metropolises. Authors argue that sustainable urban development should be based on economic empowerment, adequate housing strategies, and social and environmental interaction design strategies.	12

\* Citation Number (CN).

Coopetition of communities is based on special legal regulations, appropriate governmental and political systems, judicial systems, and social institutions of civil society. Ordoñez-Ponce [27] emphasizes the meaning of trust, communication channels, changing perceptions, culture, history, geographical location, language, and customs for coopetition development. As currently, smart metropolises are more than just an application of technologies to cities, the cooperation of communities supports and is supported by people connections, information exchange, shared services, and joint initiatives to create sustainable cities. In the Scopus repository, just 23 publications on cities' coopetition have been registered till 2021. However, even there, arguments on positive impact of municipal coopetition are recognizable. Hirvensalo et al. [28] argue that cities' coopetition is located in the domain of strategic management, and it should be explored in the context of sustainability. This term describes a dynamic process of joint interaction, communication, and value creation separately or together with other business units. In the theory of market acts, in a situation of perfect competition, the cooperation may be perceived as a market imperfection and the positive impact of cooperation on competitive dynamics is not considered. Coopetition cannot be identified with the collusion of market suppliers. There are many models of interorganizational relationships, i.e., alliances, networks, value chains, or supply chains. In coopetition, the cooperation is based on the convergence of interests and achieving common goals by means of collective actions. Coopetition involves interorganizational knowledge sharing and joint learning. Communities in metropolises can achieve their socio-economic goals only by respecting the actions of other neighboring communities. This situation is a dynamic equilibrium.

Habermas has explained that mutual coordination is mediated by power, authority, and money [29]. Damayanti et al. [30] have studied the smart tourism coopetition. They concluded that this strategy integrates the advanced technology application into advanced physical infrastructure in order to enhance innovative services for tourists. Farelnik has presented the question of coopetition of slow cities in Poland [31]. She has identified main cooperation areas for slow cities, i.e., tourism, urban space promotion, culture events, revitalization programs, local history exploration, slow food philosophy, and local products and crafts cultivation. The coopetitive communities need not be located in the same region, but they have similar strategies and knowledge acquisition requirements for strategy management.

Coordination, collaboration, and coopetition of communities are needed for metropolis strategy operationalization. For example, the metropolis digital ecosystem should enable data sharing that can be applied to different sectors in the metropolis context, e.g., transportation, energy usage monitoring, flood risk, cyber threats, or citizen engagement in

mass events [32]. Barros et al. [33] have noticed that the main difficulty in the cooperation of business units was the internal competition and lack of skilled labor.

The second part of the study was based on research question 2 (RQ2): How are ICT applications developed in sustainable smart metropolises?

The answer was based on a literature study of the Web of Science repository and some best practices of ICT application development in sustainable smart metropolises. The research question 2 gave the assumption to point to some thesis: Sustainable development of cities and metropolises is related to the concept of smart cities. A smart sustainable city is an innovative city that uses information and communication technologies (ICT) and other measures to improve the quality of life, the efficiency of urban functioning and services, and competitiveness [34–40]. Among the factors influencing the urban development of a sustainable city or metropolis, there are economic, social, environmental, and organizational factors.

The following attributes appear consistently in the literature [41–50] in the context of the description of a smart sustainable city in the context of balancing factors related to the quality of life of inhabitants, urban infrastructure, and the use of modern ICT technology. Sustainable development is related to advanced ICT applications using big data and IoT technology [51,52] for energy management and factors influencing climate change, including Pollution and waste, and social, economic, and health issues in smart cities.

The research study showed the factors of smart city development in areas of e-government mobile applications, WiFi infrastructure, CO<sub>2</sub> sensors, and ecologic public transport with car sharing systems, public safety, and traffic applications, and building energy and maintenance application [53].

Answering the RQ2 is included in the different classification of smart city domains and sub-domains [54] or fields of ICT applications in smart cities [55]. The classification is showing the areas of adoption of ICT application tools. There are six main domains with some sub-domains [54]:

1. Natural Resources and Energy;
2. Transport and Mobility;
3. Buildings;
4. Living;
5. Government;
6. Economy and People.

Neirotti et al. [54] have presented some “soft” and “hard” ICT application domains in smart cities (Table 4). The “soft” ICT domains are focusing on ICT in education and culture promotion, to reduce the barriers between citizens, and to build the transparent e-governance system. In “hard” domains there are applications for optimizing energy distribution and waste management, logistics, and transport in urban areas through traffic analysis as well as providing users with dynamic access to information on traffic and transport efficiency, and providing sustainable public transport by environmentally friendly means, and healthcare and public security.

The ICT impact in categories of Natural Resources and Energy would be applied to improve the physical municipal infrastructures of smart grids, public lighting, eco green energies, and waste management as well. In area of Transport and Mobility, there is the ICT application development for improving urban logistics flows with accurate distribution of selected information, especially important for people’s mobility, in connected cities and metropolises. Smart cities are characterized by the widespread use of information and communication technologies (ICT) that help residents to better use the resources of cities and metropolises in context of Buildings domain. ICT-based solutions can improve the sustainability of cities and metropolises in domain of Living, Government, and Economy as well [54]. In these domains there are some important indicators of ICT usage in urban sustainable development in context of building infrastructure, culture and public spaces management, transparency of municipal government and procurement, and innovation in entrepreneurship and digital education.



**Table 4.** ICT Application Domains [54].

ICT Application Domains	
“Soft” Domains	“Hard” Domains
Education and culture	Energy grids
Social inclusion and welfare	Public lighting, natural resources, and water management
Public administration and (e-) government	Waste management
Economy	Environment
	Transport, mobility, and logistics
	Office and residential buildings
	Healthcare
	Public security

ICT development in fields of smart city includes smart economy, smart people, smart management, smart mobility, smart living, and a smart environment web-based applications [55]. The ICT based evolution of cities make the background for changes in separate urban organization and developing into “Connected Cities”, and in metropolises as well.

The ICT application in smart sustainable cities should be able to describe in some general dimensions: Information and Communication Technology, Environmental Sustainability, Productivity, Quality of Life, Equity and Social Inclusion, and Physical Infrastructure. Information and Communication Technology concentrates on ICT infrastructure, which is the basis for other ICT solutions and smart sustainable promotions. The ICT infrastructure includes network and access, services and information platforms, information security and privacy, and electromagnetic field.

Transport is the most important part of civil services. ICT application could counter various negative transport effects. The basis for the development of a metropolis is the implementation of an intelligent integrated public transport (IIPT) management system. A key factor in this development is the use of internet-based ICT applications to improve service levels and the efficiency of the transport system. In addition, ICT solutions allow for the integration of data from different carriers, allow the exchange of data with various operators in the cities of a given region, which ensures a better integrated transport service. The increase of data exchange controls multiple services and assets leads to a higher degree of automation in the city. This leads IIPT operators, municipalities, policy makers as well as manufacturers, solution providers and vendors to adopt specific solutions with low scalability and disparate requirements. The data-driven smart cities of the future will manage the different data sources to develop more intelligent transport system of eco-cities, creating workplaces, public spaces, public transportation, with walking and cycling as well [56].

The diversity of ICT application is connected with smart and sustainable development of cities with different smart urban policies. There are some examples of ICT in urban sustainability development. An example of a smart city of Singapore today is undergoing rapid transition [57,58]. Some good practices are showing the example of the city of Singapore and the city of Adelaide [59]. Singapore developed ICT applications with artificial intelligence (AI). The structure of the city is a multi-level conglomerate related to the use of available resources and the use of land above and below the ground. Traditional two-dimensional maps have proved insufficient to support effective city management. To solve this problem, Singapore Land Authority is implementing the concept of a three-dimensional national topographic map and high-quality 3D datasets. These maps store 3D data about building elements, terrain, and road. The 3D map is the primary data source for meeting the growing needs and improvement of government and government agencies for development planning, policy making, and risk management [58]. The city of Adelaide is an example of smart city developments in Australia. Adelaide has become a smart city thanks to a development

strategy that has allowed for a change in public and private investment. Adelaide has become an interesting example of a change in urban planning in order to change a declining medium-sized city into an interesting city that is willingly chosen by investors. The strategy of new smart city is connected with smart city policy which is formulated and operationalized in technological, economic, and governance contexts [59].

There are some examples of ICT-based mobile application [60,61], especially for transport and tourism in European agglomerations, e.g., the Next Stop Paris (<https://play.google.com/store/apps/details?id=net.ixxi.ratp.tourisme&hl=pl&gl=US>, accessed on 24 January 2022) and the Trojmiasto.pl (<https://play.google.com/store/apps/details?id=pl.trojmiasto.mobile>, accessed on 24 January 2022). The Next Stop Paris app is aimed at tourists visiting the Paris agglomeration. It allows the residents and visitors to search for the route and the method of transport between the selected places along with the approximate travel costs. The application has a predefined list of the most popular places, which makes it easier to navigate around the agglomeration. It also allows the visitors to check the tariff of single-travel and short-term tickets in its selected parts. In addition, the application allows visitors to view information and advice for tourists, for example information on safety or scenarios for using public transport.

Another useful feature is the ability to download the map offline. This is especially important for travelers from outside the European Union for whom the roaming charges of data transfers are very high. In addition, the application provides a map with locations of the most popular places. The application is available in English, German, French, Spanish, Italian, Dutch, Russian, Chinese, and Japanese.

The Trojmiasto.pl application is an application created for the needs of the Gdańsk agglomeration. It allows you to read the latest news, sports, and cultural information and weather forecasts. Additionally, you can check the timetables agglomeration communication or arrivals and departures from the airport in Gdańsk, as well as information about companies and tourist information. There is the possibility of co-creating content through integration with the local classifieds portal, reporting incidents (e.g., traffic difficulties) or participating in a discussion forum.

The possibility of saving articles in the clipboard also encourages the use of the application. They can be read later, for example, offline. In addition, the GUI has possibility to change the font size and set the scope of notifications—the latest information, road and communication reports, culture, and sports information. There is the ability to quickly check the status of the city card as well by entering the identification number to receive information about the details. The application is available in Polish.

#### **4. The ICT-Based Urban Sustainable Development—The Case Study of Silesian Metropolis (Metropolitan Association of Upper Silesia and Dąbrowa Basin)**

Metropolitan Association of Upper Silesia and Dąbrowa Basin is a metropolitan association located in the central part of the Silesian Province. It is located between two large urban centers—Ostrava and Krakow. It is adjacent to the Rybnik, Bielsko-Biała, Częstochowa, and Opole agglomerations. The association is based in Katowice (Metropolia GZM, 2019). The metropolis covers the territory of 2554 km<sup>2</sup> (for comparison, the area of the Śląskie Voivodeship is 12,334 km<sup>2</sup>). It consists of 41 communes, of which 26 cities can be distinguished, 2 urban-rural communes, and 13 rural communes. The union is inhabited by about 2.245 million people and the average number of people living in its area per square kilometer is 879 people (as of 31 December 2019) (Metropolia GZM, 2019).

The largest cities in the Metropolis in terms of the number of inhabitants are: Katowice (294.5 thousand), Sosnowiec (202 thousand), Gliwice (179.8 thousand), Zabrze (173.4 thousand), and Bytom (166.8 thousand) (Metropolia GZM, 2019). Two motorways (A1 and A4), two expressways (S1, S86), and many national and provincial roads [62] pass through the territory of the metropolitan union. The main road connecting the DK86 and DK88 roads along DK79 and DW902 is also very important. It connects Gliwice, Zabrze, Ruda Śląska, Świętochłowice, Chorzów, and Katowice. Many railway lines also

pass through the Metropolis. The largest passenger station is in Katowice. According to data collected by the Office of Rail Transport, it was in the 8th place in the country in the passenger exchange ranking in terms of the number of passengers in 2017 (11.9 million, i.e., approx. 33 thousand passengers per day). According to the guidelines of the European Commission, it has been classified as the main station, i.e., one that handles traffic in the number of over 10,000 passengers per day. The Gliwice station was categorized in a similar way.

The central part of Upper Silesia is a region characterized by a very high level of urbanization and a large share of heavy industry. The reason for this was the rapid economic, demographic, and civilization development that took place in the mid-nineteenth century, which was influenced by the boom in the steel and mining industries (silver, lead, and hard coal). Moreover, the region was influenced by many countries.

For example, before World War I, these were Prussia and the Russian Empire, and in the interwar period, Germany and Poland. The region consists of many settlement units. Many of them were built in the Middle Ages, e.g., the city of Gliwice gained city rights before 1276, and Bytom in 1254, and still others arose at a time of rapid industrial development, e.g., Katowice in 1865 and Chorzów in 1868. Workers' housing estates were also established, which over time became part of larger cities [62]. The agglomeration is polycentric.

This region was called the Upper Silesian Industrial District due to the fact that industrial functions were more important than service and settlement functions.

The region is characterized by a very high degree of management difficulties. The reason for this is, among others very high population density, large exchange of passengers as part of public transport and constant competition between neighboring local governments.

Another challenge that needs to be addressed is the problem of environmental protection and the revitalization of post-industrial areas. An example of such activities is the re-use of land belonging to the former coal mine "KWK Katowice" and the creation of the Silesian Museum. First organizational concepts of sustainable urban development and the first steps to define the boundary of the Silesian Agglomeration (or delimitation) were undertaken in 1953, when the regional plan of the Upper Silesian Industrial District (GOP, Górnośląski Okręg Przemysłowy) was announced, designed by R. Pieńkowski [62]. It was planned to create two areas—the central one and external (in the form of a ring around the central area). The purpose of this division was to transfer the residential function to the outer part, which was to prevent spatial and environmental conflicts. It was important to create a residential area outside the areas of intensive industrial activity, and it was planned to leave it independent "at limited costs". The GOP central area included 13 cities: Gliwice, Zabrze, Ruda Śląska, Bytom, Świętochłowice, Piekary Śl., Siemianowice Śl., Chorzów, Katowice, Czeladź, Będzin, Sosnowiec, and Mysłowice.

On 29 June 2017, the Council of Ministers issued an ordinance establishing a metropolitan union called the Metropolitan Association of Upper Silesia and Dąbrowa Basin (shortly: Silesian Metropolis, or Metropolis GZM). It was established on 1 July 2017. On 1 January 2018, it began the implementation of the assigned tasks [62].

The Act on the Metropolitan Union indicates the public tasks that have been assigned to the Metropolis from 1 January 2018. These are (Journal of Laws of 2017, item 730, art. 12 Section 1):

- Shaping the spatial order;
- Stimulating the social and economic development of the union;
- Conducting logistic activities in the context of the public collective transport system, including the organization of metropolitan passenger transport;
- Cooperation with entities responsible for the route of national and provincial roads passing through the area of the Metropolis;
- Conducting promotional activities of the union and its area.
- An action plan for the Silesian Metropolis has also been developed. The following goals were defined in the document titled Strategic Action Program for the Metropolis GZM until 2022 [63].

- Shaping the spatial and ecological order—increasing the importance of green areas, rational water management, integration of waste management (“circular economy”) and reduction of electricity consumption; the goal is to increase the importance of ecology in the Metropolis;
- Development of urban mobility and sustainable urban mobility—integration of entities organizing public transport, optimization of connections, launching bus lines towards the airport and integration of the tariff and ticket offer, as well as the purchase of emission-free buses and the creation of the Metropolitan Bike system;
- Socio-economic development—subsidies from the Silesian Metropolis Solidarity Fund, the beneficiaries of which are the municipalities belonging to it, testing and popularizing the use of unmanned aerial vehicles (drones) and conducting a senior policy;
- Promotion of the Metropolis and its area—building a brand and metropolitan awareness, including promoting the advantages of member communes and the entire area, as well as cooperation with other metropolises in the world and participation in international events;
- Institutional development—for example, the establishment of the Metropolitan Socio-Economic Observatory, a platform for good practices or an internal management system.

The establishment of the Metropolis GZM was a turning point in the process of searching for an effective transport management process. As a result, the public transport system was modernized, first of all, by unifying the transport offer and promoting metropolitan transport. PKM Tychy, which is a new type of terminal servicing ŚKUP cards as well as contactless payment cards, have been installed. New planning concepts were also created for the functioning of bicycle transport and rail transport. Another activity was the modernization of the Silesian Public Service Card system to support the Metroticket and ego vehicles. Public transport in the Metropolis GZM have been assigned to two entities: the Metropolitan Transport Authority and the Silesian Railways.

The biggest problems of the public transport system before the formal creation of the Metropolis GZM were certainly the multitude of organizers of bus, tram, and trolleybus transport, shortly named as follows: KZK GOP, MZK Tychy, and MZKP Tarnowskie Góry, as well as the uneven transport and tariff offer, which could potentially increase travel costs and was a problem for residents and visitors. The transport tariff was integrated in two steps. On 1 January 2018, shared single tickets were introduced, and on 1 April of the same year, shared season tickets were introduced. Moreover, from the same year, children up to 16 years of age living in the Metropolis can travel free of charge.

The last stage of the carrier integration was the establishment of the Metropolitan Transport Authority on 1 January 2019. The Metropolitan Transport Authority undertakes many activities to develop and improve the quality of public transport. For example, in November 2018, bus connections were launched connecting the airport in Pyrzowice with eight cities of the Metropolis, i.e., Gliwice, Zabrze, Bytom, Piekary Śląskie, Katowice, Sosnowiec, Będzin, and Tychy. In June 2019, the offer was extended to the so-called Metroticket, i.e., the joint offer of ZTM and Koleje Śląskie. There are seven variants of the monthly Metroticket encoded on a personalized metropolitan ŚKUP card and the Metroticket 6H available at Koleje Śląskie ticket offices or in the SkyCash mobile application Mobile ŚKUP, for managing a metropolitan card (ŚKUP) via a smartphone [64]. Mobile applications enable the purchase of ZTM tickets via a mobile phone: SkyCash, mPay, moBiLET, and jakdojade. There is also an original application entitled Mobilny ŚKUP (<https://play.google.com/store/apps/details?id=pl.assecods.mpapp.prod>, accessed on 24 January 2022).

In the internal dimension, the Metropolis GZM is focused on spatial, social, and economic cohesion and ensuring a high quality of life for the inhabitants. In the external dimension, it focuses on building the image of a metropolitan center, recognized internationally, attractive for living, investing, and visiting. For this purpose, five development priorities to be implemented in 2018–2022 have been identified, which take into account the

trends resulting from national and regional strategic documents and refer to public tasks specified in the act on the metropolitan union in the Śląskie Voivodeship.

Actions assigned to these priorities are therefore to integrate the individual potentials of 41 member communes, initiate development activities, and inspire innovative solutions for the gradual strengthening of metropolitan functions and improvement of the quality of life. Dynamics and the effective implementation of these activities requires the involvement of not only local governments and GZM authorities, but also many other entities. The adoption of the current so-called “small strategy” in November 2018 is the beginning of the process of change.

The GZM Metropolis have planned the ICT systems implementation for urban sustainability adoption in following areas of transport, logistics, and urban sustainability management in social, economic, and environmental dimensions of urban sustainability:

- Implementation of metropolitan lines and lines operating in the delivery and delivery system;
- Introduction of process management in ZTM (Metropolitan Transport Association);
- Process optimization of the connection network—adapted to the changing the evolving needs of passengers;
- Standardizing the functionality and appearance of stops and ticket machines;
- Purchase of additional ticket machines;
- Creating applications that improve the comfort of using public transport;
- Modernization of the System of the Silesian Public Services Card (ŚKUP);
- Introduction of a metropolitan system of automatic passenger counting in vehicles commissioned by the ZTM;
- Integrated tariff and ticket system in public transport—extension of the Metroticket with new groups entitled to use and new types of tickets;
- Construction of the Metropolitan Railway;
- Metropolitan Bike—implementation of a bicycle rental system on the premises of GZM;
- Construction of velostrads;
- Develop a sustainable urban mobility plan;
- Expansion of the road system of strategic importance for the GZM area (DTS north, DTS east, Chorzów bypass);
- Development of the GZM Development Strategy for the years 2021–2027 with a perspective until 2035;
- Organization of the celebration of the Metropolis—an innovation festival integrating municipalities and residents;
- A promotional campaign for the Metropolis as a good place to live, work, study, and spend free time;
- Building an International Cooperation Network;
- GZM Data Store (stage II)—launching an open data platform;
- Activities related to the pursuit of an energy self-sufficient metropolis by 2050;
- Integrated municipal waste management in the GZM area;
- Development and implementation of a metropolitan air quality improvement program;
- ELENA program—improving the energy efficiency of multi-family buildings in the GZM.

The proposed strategy implementation needs to follow the important ICT tools and systems with appropriate transport and IT infrastructure, which had already been implemented in GZM Metropolis:

- Metropolitan Railway conception with study for tram communication in the area of GZM (supplement to WSWKM), and co-financing of rail connections in the Metropolis from 2019;
- Preparation of standards and guidelines for shaping bicycle infrastructure;
- Development of the Study of the System of Bicycle Routes for GZM;
- By bike or on a wheel—purchase of electric bikes for city and commune offices, City Guards and the Police;



- Publication of a guide to encourage residents to reflect on their travel habits;
- Development of the concept of road connections of metropolitan importance;
- Metropolitan Fund for the Support of Science—a project enabling cooperation between universities and the world academics class;
- Signing a cooperation agreement with the Ruhr Metropolis, joint activities for the development of regions;
- Creation of the Metropolitan Socio-Economic Observatory and the InfoGZM portal (successive database building, monitoring of changes, and processes taking place in GZM);
- Electricity Purchasing Group 2019 (73 ordering parties);
- Metropolis on the side of the environment—preparation of educational materials for the inhabitants of the Metropolis on how to prevent drought and small retention;
- Action program to reduce low emissions;
- Metropolitan Solidarity Fund 2018, 2019 equalizing development opportunities for municipalities.

### 5. Metropolis Ecosystem Architecture Model

System architecture management has evolved to become an important discipline in practice throughout the past years. From a conceptual point of view, the system architecture is suitable for enterprise architecture modeling. However, this enterprise is defined as a business organization, as it is common in management science, but not as an organization generating profits and costs, as it is in economics science. Enterprise architecture management is equated with business ICT architecture management. Enterprise architecture modeling is suitable for designing business information systems at the strategic level. Ross et al. [65] introduced the idea that enterprise architecture is a strategy. Other researchers support this approach, however not so enthusiastically and they focus on enterprise modeling for ICT implementation. In this paper, the enterprise architecture is considered as a process of translating business vision and strategy into effective enterprise that can be viewed in many different aspects, e.g., business, information, work, application, technology [66]. This section aims to present the Metropolis Ecosystem Architecture Model (MEAM) as an original conceptual model important at the preliminary stage of ICT implementation in metropolis to support communication on the Internet, according to the following models: public Administration to CitiZen (A2Z), CitiZen to CitiZen (Z2Z), and Machine to Machine (M2M). A metropolis is understood as a business organization, having its location, stakeholders, strategy, resources, processes, software, and hardware components. A metropolis, like any business organization, has its budgets, authorities, and resources. Presented in this section is a model of Silesian Metropolis developed by the authors as their original work. The conceptual model of system architecture is written in ArchiMate language with the use of open-source The Open Group software tool Archi version 4.9.2 (<http://archimatetool.com/download/>). The architecture design in ArchiMate language begins with a set of relatively generic concepts. They are specialized towards application at different architectural layers. In the ArchiMate language, a model is a collection of concepts, which are elements or relationships between elements. The fundamental layers in ArchiMate language are as follows:

- The Business layer covering services, processes, objects, actors;
- The Application layer including software elements and application processes;
- The Technology layer depicting technology services such as processing, storage, and communication networks.

Beyond these core layers, the ArchiMate Full Framework covers Motivation Elements, which are the following artefacts: stakeholder, value, meaning, drivers, assessment, goal, principle, requirement, constraint, or outcome. The Motivation Elements explain the context of ecosystem architecture modeling. They are necessary to answer the question of why the ICT architecture is needed, and what intentions are the premises of the ICT investment decisions.

The proposed MEAM modeling concerns the Silesian Metropolis [67]. Metropolis ecosystem architecture modeling starts with the explanation of metropolis characteristics and its fundamentals of development. The Metropolitan Association of Upper Silesia and Dabrowa Basin, also named Metropolis GZM, or Silesian Metropolis, covers 41 communities with 2.3 million residents. They generate approximately 8 percent of country's Gross Domestic Product (GDP). The Silesian Metropolis is not as big as the City of Paris, Tokyo, San Paulo, or many others, but the proposed conceptual model is a demonstration of scalable solution, where universal issues are emphasized.

Within the Silesian Metropolis, the communities are closely located, thus in many cases there is no area for expanding nor for taking over rural areas for investment. The industry development for years led to the situation where industrial plants are located near residential housing. Residential constructions are expanding at the cost of green area loss. Silesian Metropolis development was initiated for improvement of the quality and comfort of life of Upper Silesia residents. The communities are independent in their decision-making on the potential usage of local budget, in the realization of public administration processes, on local investments and usage of water and energy. Economic development of these communities is differentiated and non-uniform. On the one hand, they are competitive one to another; on the other hand, however, they need to cooperate for the regional social goals' achievement. The cooperation of the communities enables realization of tasks, which are above local economic problems, and which are common for all these communities, e.g., joint metropolitan ticket, transportation network, metropolitan railway, bike rentals. Other important metropolitan tasks, which are expected to be realized, are as follows:

- Development of green areas, rational management of water resources, waste management, electricity consumption;
- Sustainable public transport, zero-emission buses, reconstruction of road network;
- Creating the Data Store as an open data repository on various metropolitan projects;
- Cooperation with similar metropolitan associations in country and abroad;
- Development of internal management system and metropolis strategy.

The MEAM model constitutes a context for ICT implementation. Figure 2 includes the specification of ICT solutions for smart metropolis, and the identification of initiatives of sustainable metropolis.

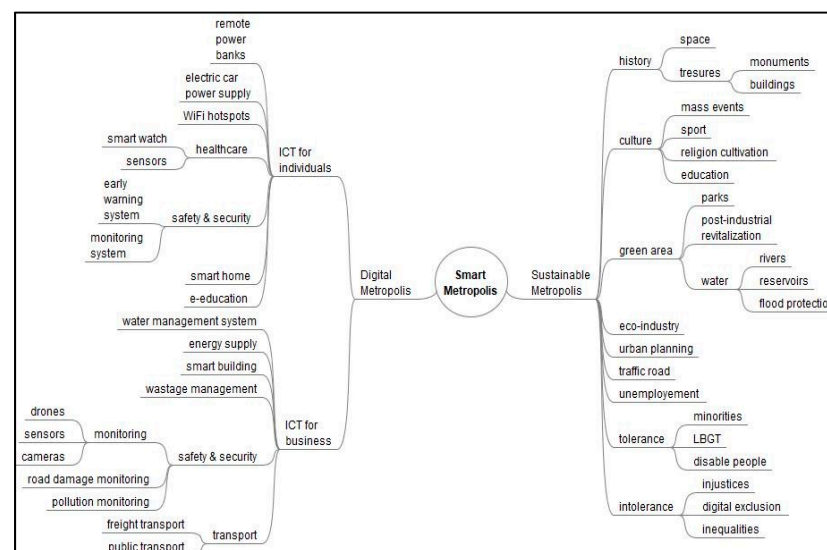


Figure 2. Smart metropolis technologies and solutions.

The MEAM conceptual model is to support answering the question of how sustainability is translated into practical policy solutions and outcomes in urban management domain. Studying and comparing sustainability innovations is mostly possible through the analysis

of comprehensive plans of cities, decision-making structures, national politics, and system architecture conceptual models, which are available in research publications. Figure 3 includes the Silesian Metropolis Ecosystem Architecture Model (SMEAM), which consists of the following layers: Business, Application, Infrastructure, and Motivation Elements. As sustainability dimensions are included in ISO 37,120 [2] and ISO 37,122 [3] standards, and in the UN document on Sustainable Development Goals, these documents are treated as principles in the architecture model. In ArchiMate language, principles are normative guidelines for the design of possible solutions in a given context.

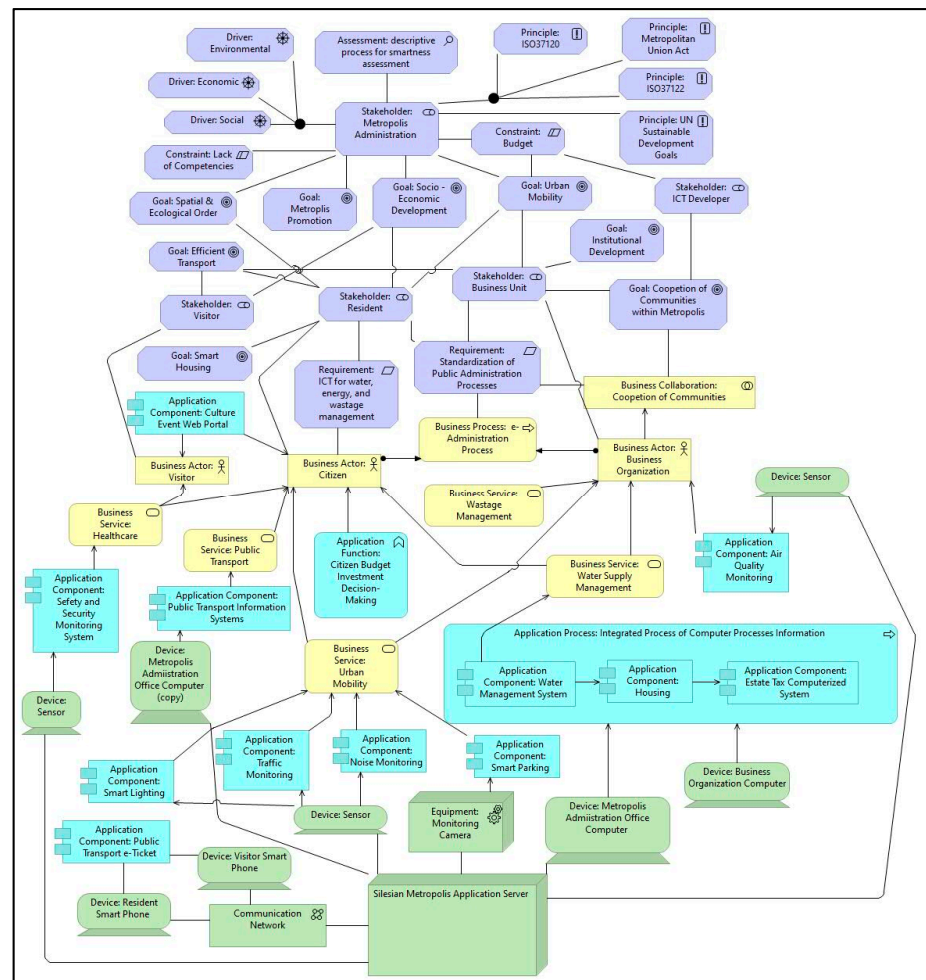


Figure 3. Silesian Metropolis Ecosystem Architecture Model.

In the SMEAM model, there are three kinds of drivers which are understood as conditions that motivate this particular metropolis to define its goals and to implement changes necessary to achieve them. Drivers are considered as Motivation Elements in Figure 3. The economic drivers deal with productivity and resource efficiency. The social driver ensures equality, justice, security, health, community development, and cultural heritage preservation [61]. The environmental driver concerns preserving and mitigating climate change, preventing pollution, conserving non-renewable resources, and protecting biodiversity.

Managers of urban renewal and developers of revitalization strategies in the Silesian Metropolis should focus on citizens' needs. Therefore, developers ought to be actively engaged in participatory processes and the population awareness of the environmental impact must be increased. Hence, residents, visitors, business units, metropolis administration, and even ICT developers are to be identified as the architecture stakeholders (see Figure 3). Generally, in ArchiMate language, an assessment represents the results of an analysis of the business affairs' states. This assessment is assumed to include the SWOT

analysis element, i.e., Strengths, Weaknesses, Opportunities, and Threats. In the case of SMEAM, the assessment elements cover criteria used in the descriptive process, i.e., smart transportation system, high-quality utility services, and minimization of pollution.

The smart metropolis must be planned on the basis of right technology, to adapt to changing demographics, education, and health needs, employment, and tax bases. Real program adaptation depends on budgets based on the city's finances, taxation revenues, employment trends. Limited budget in confrontation with cost of investments is always a constraint (see Figure 3). A metropolis as a whole identifies the goals for its residents, visitors, and business units, i.e., industry partners and service organizations. Business units as well as individuals are able to specify their business requirements (e.g., standardization of processes) as well as the ICT requirements (e.g., public e-administration services, public transport information systems, information systems for management of energy, water, and wastage, or street monitoring system for safety and security).

The Business Layer in the SMEAM are business services, processes, and actors. Therefore, the first and foremost business service is the public transport, integrated within metropolis, next-integrated healthcare system, safety and security monitoring system, further water supply, and waste management. Realization of processes and services is possible through applications, web portals, and other business information systems. In ArchiMate language, an application component represents a business software aligned to business organization structure. The application process enables the integration of different application components and the M2M communication. The applications are available on end-users' mobile devices or computers. Data repositories are located on servers.

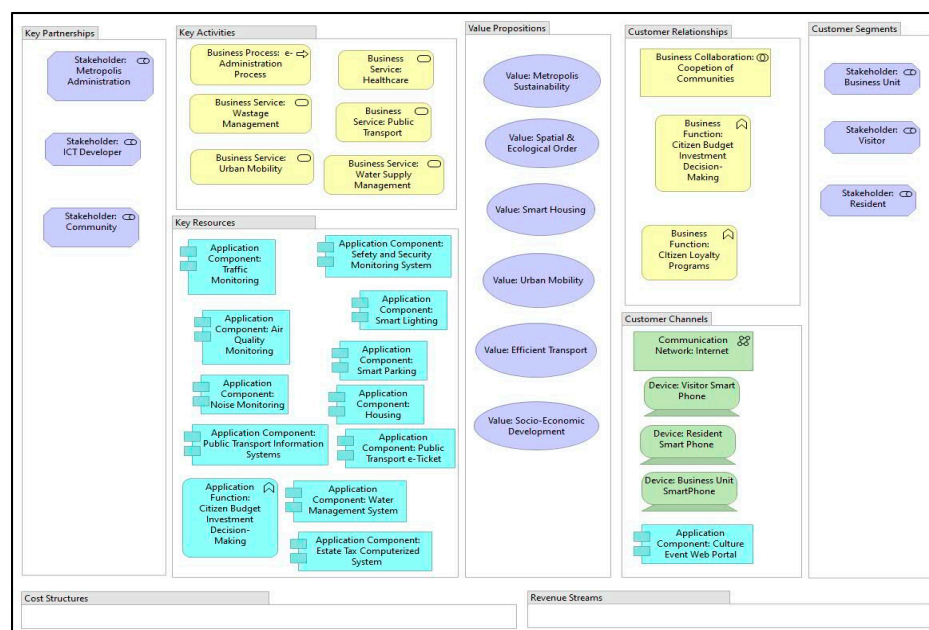
Citizens are actively involved in the daily use of digital facilities. The role of residents is not only to receive information, but to participate in its concrete functioning. The digital urban strategy requires high attention to the digital education, social involvement in urban planning, and urban decision-making on citizen budget investments. In Figure 3, healthcare as a business service is supported by safety and security monitoring information systems. Urban mobility as a service is realized through several applications, i.e., smart lighting, traffic monitoring, smart parking, and noise monitoring information systems. Beyond that, air quality monitoring system is to serve business organizations to control their sustainable functioning. The ArchiMate language is very suitable for the metropolis' strategic planning as it enables modeling business and technology issues, combining them and present in one model. However, business strategic management can be supported by other models, e.g., Business Canvas Model (BCM). Figure 4 includes a mapping of the ArchiMate SMEAM model into Business Canvas Model.

That mapping (Figure 4) permits to notice that ArchiMate modeling omits economic categories, i.e., costs, revenues streams. These issues are out of the scope; however, the value is considered an important category in ICT architecture planning. Figure 4 covers critical resources of smart metropolis, e.g., software applications. The business functions, services, or processes are treated as activities. Figure 4 emphasizes the co-competition of communities and involvement of citizens in the metropolis's strategic management. The Internet is considered a fundamental communication channel. This transformation is currently enabled by various types of technologies, such as data-driven development application, internet of things (IoT) and artificial intelligence (AI), that are embedded into the city's infrastructure system.

The presented SMEAM model is a holistic view of the managerial issues in Silesian Metropolis. This view has revealed important problem of communities' collaboration in joint interest, as well as limitations of ICT investments because of a limited budget. The scope of business services, processes and applications is also changeable and still under discussion. The model has revealed strong dependency of ICT investments on political and organizational decision-making models. The question is how autonomous communities and business organizations can be, and how strong metropolitan authority must be to ensure the metropolis' sustainability. The proposed architecture model realization depends on financial possibilities as well as on the willingness of communities to be involved in joint



ventures under auspices of metropolitan authority. Successfully, many metropolises are announcing their positive experiences on the Internet, therefore they create opportunities to follow their practices.



**Figure 4.** Silesian Metropolis Architecture Model transformed into Business Canvas Model.

The case study of GZM Metropolis showed some pros and cons which have to be managed. The case study showed some gaps in urban sustainable development strategy to do by using the holistic Silesian Metropolis Ecosystem Architecture Model (SMEAM):

- Standardization of visual identification of vehicles;
- Expansion of the Dynamic Passenger Information System (SDIP II) with new 462 electronic boards and a new dispatching system;
- Improving the quality of services provided directly by operators subject to the ZTM;
- Construction, reconstruction and renovation of bus shelters—development of standards for models of bus shelters in the area of the Metropolis, preparation of procedures for a joint purchase of new shelters, arrangements with municipalities;
- eMagazyn—electronic ticket warehouse for sale in mobile applications;
- Implementation of a mobile application for travel planning and presentation of passenger information;
- Trams—a project aimed at improving tram communication (analysis of the causes of delays, shortening the travel time);
- Automatic passenger counting system—proceedings for the delivery of software, with the possibility of connecting 160 vehicles already equipped with counting gates;
- Integrated tariff and ticket system—ongoing tariff update, preparation of assumptions for the new tariff in connection with the modification of the ŚKUP system;
- Metropolitan Railway: starting work on the preliminary feasibility study (WSWKM), submission of 15 applications to the Kolej Plus Program (6 cable and 9 points) with municipalities;
- Metropolitan bike: the concept of a bicycle rental system;
- Velostrady—concepts for the course of the fast bicycle route on the sections: Katowice—the cities of the Dąbrowski Basin, Katowice–Bytom, and Katowice Tychy;
- Mobile Metropolis—analysis project and improving urban mobility (diagnosis, testing the habits of the inhabitants of the Metropolis);
- Introduction of a uniform standard for the maintenance of Drogowa Trasa Średnicowa (DTŚ);



- Central European Drone Demonstrator—creating a new branch of development for science and business, testing new possibilities of using unmanned aerial vehicles;
- Senior-friendly metropolis—activities for a coherent social policy towards the elderly;
- Young People Make Metropolis—a project involving pupils and students in work on the development directions of GZM;
- Implementation of international projects allowing for the exchange of experiences, good practices and mutual promotion;
- GZM Data Store (stage I)—creating a platform, inventorying data sets in communes;
- Electricity Purchasing Group 2020–2021 (113 ordering parties)—Gas Purchasing Group 2020–2021 (25 ordering parties);
- Installation of Thermal Waste Conversion;
- Pioneers into Practise program—energy self-sufficiency of GZM until 2050, implemented jointly with the Polish Academy of Sciences and EIT Climate-KIC;
- Metropolitan Solidarity Fund 2020.

## 6. Discussion

Nowadays the urban sustainability of metropolises is following the smart cities development. Giffinger et al. is describing the smart city as a well-performing city in fields of economy, people, governance, mobility, environment, and living [55]. Gardner [68] has mentioned some examples of sustainable cities in the different case studies where the transport, renewable energy, and climate changes issues were developed, i.e., Vancouver, Aspen, San Francisco, Tokyo, Munich, Ulm, Malmö, or Amsterdam. Hall et al. described deeper the smarter [69]. Harrison et al. developed the description of foundation for “smarter city” [70]. Hiremath et al. had developed some indicator for urban sustainability [71]. Höjer et al. showed the definition of smart sustainable cities [72]. Hallands presented critical polemic of different point of view of smart city definitions and some general principles of high tech in smart “entrepreneurial city” [73]. The previous studies of smart sustainable city development by Huovila et al. [74] showed the difficulties to describe the indicators which can be used to characterize smart sustainable city, and due to smart sustainable city concept of International Telecommunication Union Recommendation ITU-T Y.4900-X [75], this study shows a smart sustainable city as an innovative city that uses information and communication technologies (ICTs) to improve efficiency of urban environment based on a plenty of different factors [76,77], developing in different domains of “soft” and “hard” ICT application [54] and smart city fields [55]. The standard definition of “smart sustainable cities” [75] is used in this study as reference.

In this paper, a metropolis is a consortium of communities, for which cooperation is important. Meijers [78] has discussed a model of spatial organization called “network mode” in opposition to “central place model”. In general, metropolises accept different structural constellations, which are also changeable. They become intensively integrated or loosely dispersed. Meijers has mentioned also about “polycentric or polynuclear urban region” by Kloosterman and Musterd, “polynucleated metropolitan regions” by Dieleman and Faludi, “city network” by Camagni and Salone, and “network city” by Batten [78].

Smart metropolises should use the experience resulting from the implementation of innovations in smart cities. A smart city is the backbone of the collective intelligence of a connected city in metropolises and aims to become more efficient, sustainable, and livable, and to have an impact on the sustainable development strategy of metropolises. Smart city is a very broad concept that includes not only physical infrastructure, but also the human and social factor. Smart cities, and thus also smart metropolises, are cities that, on the one hand, increasingly use ICT solutions for sustainable development, and on the other hand, whose economy and management are driven by innovation, creativity, and entrepreneurship, which is largely due to intelligent residents actively involved in changing the existing solutions. A smart city seeks to invest in ICT and through participatory processes change the specific investments in public and transport services that can ensure sustainable socio-economic development and increased quality of life and have an impact

on the improvement and quality of natural resource management. As it is currently understood, a smart city is one that strategically uses network infrastructure and the related analysis of big data and data [56,58,59], various forms of Internet applications, IoT, artificial intelligence, cloud computing, and mobile applications [60,61]. A smart city understood as a technologically advanced city will be able to use its potential stored in digital data. Thus, it is possible to analyze, monitor, and better understand the needs of residents. This can be taken as an element of the basis for the development of the region and its inhabitants' surroundings. The use of artificial intelligence for data analysis will help to obtain useful knowledge to improve the lives of residents. Smart cities connected regionally are the basis for building the concept of sustainable urban development, which can be used to transform cities into sustainable metropolitan environments.

## 7. Conclusions

The principal study in the paper was conducted due to two research questions: RQ1: What ICT-connected challenges are faced by metropolises during the urban sustainability strategy realization? and RQ2: How are ICT applications developed in sustainable smart connected cities or metropolises?

The answering for the research questions gave the background to describe the holistic view of different asset of ICT-supported urban sustainable development strategies. The research methodology was based on previous research studies in context of smart cities development and showed the new model of the sustainable urban strategy architecture. The background of the strategy was developed in previous research studies. The impact of information and communication technologies (ICT) on the quality of life in cities and agglomerations has been observed, mainly characterized by the development of mobile devices as well as the emerging artificial intelligence and the Internet of Things. This is complemented by other technologies and approaches such as cloud computing or open and big data. However, the effective use of digital resources by society requires in-depth research to support the impact of these technologies on the quality of life of society in cities, with clear indicators of whether they can actually improve living conditions in cities and metropolises.

Building a strategy for urban development is related to various important factors outlined in the Metropolis Ecosystem Architecture Model (MEAM). Many organizational units operating in cities, both public and private (Business layer), should be involved in inventing, supporting, implementing, and maintaining smart city projects (Application layer). Ideas emanating from the IT industry to modernize city structure and management with the use of ICT can cover almost all areas of urban activity, including housing, networks, mobility, energy, and infrastructure (Technology layer). Developers, planners, and designers are keen to integrate these technologies in built environments. The inhabitants of the city are the end users of the technology being implemented; however, they may also be the source of a change in the development of other urban developments (Motivation layer). There have been attempts to measure the information society [79], either globally or partially, since computing and telecommunications became ICT some thirty years ago. Measuring the impact of ICT development and applications for local urban purposes can allow for an evaluation of ICT implementations or a comparison in a wider framework. Measuring the socio-economic value of information and communication technologies is particularly difficult [53,55]. The challenge is not only to count the items, connections, or implemented applications, but also to assess to what extent ICT investments generate new added value and increase the overall performance of cities and metropolises in chosen regions [80,81]. Sustainable urban development responds to the strong push of many national governments to adopt ICT solutions in the management of public affairs, thus realizing the so-called smart city concept. For example, in an area of people mobility, sustainability of an urban agglomeration or a metropolis is associated with the accessibility and managing of public transport services and another operators of transport services, like taxi, car-sharing, bus, tram, trolleybus, metro, urban rail, suburban transport, bus, and rail connections to the airport for citizens information. ICT implementation has the aim to

make a better use of the public resources, increasing the quality of the services offered to the citizens, while reducing the operational costs of the public administrations, especially in the area of transport Web-based applications with open data innovations [82].

The case study showed some implementation of ICT system in GZM Metropolis which have the most important impact for urban sustainability of the region of Metropolis:

- Integration of the previous three public transport organizers (KZK GOP, MZKP Tarnowskie Góry, MZK Tychy);
- Launch of airport bus lines between the main cities of the Metropolis and the Katowice International Airport in Pyrzowice;
- Implementation of a free ticket for children and youth up to 16 years of age;
- Launch of the Traffic Management Center;
- Launching the ŚKUP mobile application;
- Implementation of the ŚKUP system in vehicles in the Tychy area with the launch of payment for tickets with a contactless card (solution awarded with an award in the Smart City Competition);
- Shipment of ŚKUP cards to the passenger's/customer's home;
- Metroticket—introduction of a joint monthly ticket for public transport (bus, tram, trolleybus) and Koleje Śląskie trains.

Proposed Model of Metropolis Ecosystem Architecture is a point of reference for strategic initiative planning, realization of above-mentioned ICT solutions, as well for controlling already implemented ICT systems.

There are some limitations in the research case study for literature review. The next literature review needs to be based more on diversity of literature repository, i.e., Scopus, Web of Science, and PUBMED. The future research studies should be focused on the further development of smart cities [83]; and urban sustainable development could be the key factor to optimize the connected cities [84] in a dynamic way in order to offer a better quality of life to the citizens through the application of information and communication technology (ICT) with IoT and AI application in context of sustainable green urban development [85]. Although currently there are socio-economic and ecological differences within metropolises, the rapid development of ICT and easiness of ICT solution access are expected to reduce the internal differences.

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