

STRUCTURE AND NODAL POINTS OF SMART CITY INFRASTRUCTURE

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ABSTRACT

The development of Smart City systems and infrastructure should provide an implementation of assumptions for harmonious and sustainable development of urban areas. Implementation of Smart City assumptions within the city structure is related to introduction and development of passive and inert infrastructure that constitutes elements of the city infrastructure, as well as particular form of development of areas and buildings. The following research work concerns an analysis of spatial and infrastructure-related solutions as well as environmental, social and ICT systems applied within the city. Source material analyses (urban, architectural and technological sources) provide the basis for conclusions and formulation of typology and implementation of criteria for smart urban, social and ecosystem-related infrastructure implemented in the Smart City model, with the use of innovations in the field of intelligent information and communication technologies (ICT) as well as network infrastructure. The conclusions derived from the following research work contribute to the discussion on ways to shape the structure of infrastructure and nodal points in the Smart City development model in relation to sustainable development issues.

Key words: Smart City, Sustainable Urban Development, Data Center Information and Communication Technologies (ICT), green and blue infrastructure, modern services sector

INTRODUCTION

Contemporary civilization is based on the achievements of digital technologies and information systems. Societies that inhabit modern metropolises and cities are defined as the *knowledge society* and the *information society*, as they benefit from digital and information technologies developed. In cities, solutions for the sector of modern services, data processing and data management are being introduced.

In urban spaces and buildings, solutions for resource and parameter management of the environment built are applied.

Technological progress and management models under development lead to the application of analytic opportunities and computational abilities of modern

computers and databases that are being created to meet analytical and management-related needs. With the use of expert knowledge, optimization process has begun to provide the basis for the application of “smart” solutions within the city. Such solutions are introduced as the Smart City model in order to improve functionality, management efficiency and quality of city life. Smart City models concern multiple sectors of activity and user space. Therefore, in the Smart City model, management employs modern technologies, knowledge and skills, by means of using a database that contains expert data and information fed by user-society in the process of social participation. All the above occurs in an urban space equipped with infrastructure, sensors and systems with which urban applications connect. Statistical

and index information provide the basis for modeling, optimization and control of the city infrastructure parameters and city equipment.

The analysis of the Smart City model and the infrastructure for the implementation of Smart City goals related to the functional-spatial structure of the city are research issues for defining urban design guidelines. The research on determining the nodal points of Smart City infrastructure and dependence on the shaping of the urban tissue are used to determine the priority spaces of specialized development. The research objective is to indicate the needs and functions integrating the shape of the urban space and technological and innovative solutions in a modern city to implement the Smart City model. Then, the next phase of work is to identify the recommended development directions for the design of sustainable cities in the Human Smart City model.

MATERIAL AND METHODS

In order to develop the research issue, analyses of source materials and analytical materials from the multifaceted research and design work by the authors of the following study were conducted. The source material consisted of scientific publications, reports, rankings, legal regulations, maps, descriptions of the implementation activities effects, information on innovative technologies and smart solutions applied in buildings and urban space, examples of implementation in Polish and foreign cities. The basic method adopted for selecting and analysing source materials consisted in the reference to the Smart City assumptions, multi-criteria integrated design, circular economy, as well as the assumptions that underlie sustainable city development. The analysis highlighted the need to maintain a balance between attempts to increase efficiency and effectiveness of urban infrastructure, as well as the quality of city life. Relating the analytical process to the initial assumptions of the basic research issue, optimization based on own and external resources, with the application of smart systems and solutions should serve all city users who form the urban ecosystem. Such conclusions were drawn based on the assumption that consists in linking smart solutions in the Smart City infrastructure.

RESULTS AND DISCUSSION

The city may be understood as processes that occur in urbanized areas, i.e. urban areas shaped for human utility and functional needs. The city consists in a composition and a spatial layout of areas intended for specific purposes and functions, as well as of building developments, interconnected by means of communication and infrastructure.

Numerous publications provide guidelines for a sustainable smart city development (Ibrahim, El-Zaart & Adams, 2018). Reserchers presented a review of the literature on the opportunities of Smart Cities aims (Allam & Newman, 2018) and research results in urban factors for Smart City development: involvement, leadership, infrastructure (Sokolov, Veselitskaya, Carabias & Yildirim, 2019). The literature presents diverse functions such as neural networks throughout the city: ICT technology infrastructure, technologies (smart buildings, sensors, traffic, disaster management) and human infrastructure (Myeong, Jung & Lee, 2018). Indicated description of cases explaine holistic approach for increasing smart-city interconnectivity for stimulating more inclusive forms of urban infrastructure (Ersoy, 2017). Smart City model aims to enrich the quality of life (QoL) connected with processing real-time data management and service provisioning (Silva et al., 2018). Recommended data governance in the new smart city sustainability solutions (Paskaleva et al., 2017) is connected with tool indicators to adequately evaluate implementations (Patrão, Moura & de Almeida, 2020).

Infrastructure in the Smart City model

In 2015, the first Smart Cities ISO 37120:2014 standard – a set of international standards dedicated to the concept of smart cities was published in Poland. This standard covers 17 thematic fields to be implemented in functional and spatial structure of the city (ISO 37120:2014). These fields include economy, education, energy, environment, finance, crisis response, management, health, recreation, safety, shelters, solid waste, telecommunications and innovations, transport, urban planning, wastewater, water and sewage system. Some of the thematic areas indicated

above can be combined in order to specify the main integrated problem areas. In the source literature on the topic, successive generations of Smart City (Cohen, 2015) are presented, as well as the following six basic areas of Smart City: Smart Economy (economic competitiveness), Smart People (human and social capital), Smart Governance (participation in governance), Smart Mobility (transport and information and communication infrastructure – ICT), Smart Environment (sustainable resource management), Smart Living (quality of life) (TU WIEN). The development of competences among space users leads to an increasing role of social participation, indicating the city development in the Human Smart City model – smart cities co-created by residents and users.

Human Smart City (Smart City 3.0) may be understood as a city which features integrated activities to foster the use of smart technologies, human and technological potential for the purpose of sustainable development of both, the city and the region. It is a development process that is focused on collaboration and coordination of interdisciplinary activities to make optimal use of municipal resources, as well as a process of shaping the functional and spatial structure and building development in such a way as to improve living conditions within the city. Integrated activities concern economic, social, environmental and spatial development. The city is supposed to fulfil functions related to accommodation, work, recreation and development with the application of knowledge and skills of a given society by implementing modern technologies and resource, data, quality and risk management systems. In connection with the areas of Smart City development, the following categories of infrastructure in the city, spatial and functional systems in which smart solutions are introduced may be distinguished:

- technical and road infrastructure, implementation of the following assumptions: Smart Economy, Smart Environment, Smart Mobility;
- social and service-related infrastructure, implementation of the following assumptions: Smart People, Smart Governance, Smart Living;
- infrastructure for social communication and data management, implementation of the following

assumptions: Smart Governance, Smart Mobility, Smart People, Smart Economy, Smart Environment, Smart Living;

- ecosystem infrastructure (biologically active): green and blue infrastructure, implementation of the following assumptions: Smart Environment, Smart Living.

In individual areas of Smart City development, goals are interrelated and often require the use of similar infrastructure solutions. In order to optimize the implementation and attainment of Smart City goals, it would be necessary to integrate activities and infrastructure solutions for the purposes of employing city development strategy, given the assumption that smart solutions are applied. The component infrastructure systems are interconnected by a system of interdependencies that influence functioning and efficiency, as well as by resources needed to perform economic, functional, social and ecosystem processes.

Thus, functional and spatial structure of the city is designed along with the infrastructure equipped with facilities, devices and installations for social, economic, political and ecosystem development.

Social communication and data management infrastructure are crucial for the sake of achieving all the goals put forward by the Smart City model. Technological solutions related to data management infrastructure, as well as information and communication systems (ICT) together with Data Center provide an opportunity for development of smart solutions within the process and investment management in the city, as well as for progress in optimal management of municipal resources.

Structure and nodal points of infrastructural system connections

An analysis of methods for shaping of Smart City infrastructure (with regard to infrastructure systems) in relation to the assumed goals and areas of smart city development provides the basis for optimization and implementation of smart solutions in the city.

Solutions intended to improve:

- economic competitiveness;
- the use of human and social capital;
- support for participation in governance;

- improvement of the integrated transport systems and information and communication infrastructure (ICT) for data management in terms of knowledge society and information society;
- sustainable management of natural resources,
- optimization of the investment process;
- improving life quality and environmental parameters;
- a regenerative ecosystem;
- adaptation to climate change.

For this reason, it is important to outline the characteristics and determinants of systems within individual infrastructure categories. The research issue is to define structural connections and nodal (key, strategic, critical) points of particular infrastructure systems. The following stage is to identify nodal points in the Smart City model, as well as to specify common features and connections in order to increase city management efficiency.

Infrastructure of social communication and data management in the Smart City model

Energy supply, as well as energy resources and fuels necessary for the operation of smart technology and for operation of social communication and data management infrastructure provide the key to implementing smart solutions.

Social communication and data management infrastructure may be defined as physical and cybernetic systems (objects, devices or installations) necessary for data transfer and management. The infrastructure forms a functional and spatial structure that comprises areas, buildings, facilities, devices and installations implemented for the purposes of social communication, data transmission, as well as for data collection and management, such as ICT and telecommunications installations, smart information and communication systems (ICT), Data Center. The prevailing structure of solutions applied in the scope of this infrastructure consists in a network system with nodal points that constitute data collection and management centers, in the form of Data Centers.

Data Center is a building or facility together with the necessary equipment, installations and security measures introduced for the purpose of data collection and data processing. Facilities implemented with the

use of security measures that enable action continuity and data security by the application of protection, cooling and energy availability systems.

Private, public or commercial smart networks, the management of which consists in data analysis, optimization of efficiency and computing speed, distributed systems and parallel processing, machine learning, artificial intelligence, knowledge management, archiving and verification of knowledge, image analysis for automatic detection of facilities and incidents.

Since Data Center has been recognized as a key nodal point within the structure of this infrastructure category, facilities and buildings, Polish and foreign projects, publications and source materials were subject to an analysis.

Technical and road infrastructure in the Smart City model

Infrastructure and installation-related solutions are necessary for the operation and upkeep of urban areas, as they determine implementation of assumptions, such as Smart Economy, Smart Environment, Smart Mobility.

Technical infrastructure in the city comprises energy, transportation and water-sanitary systems, shaped as areas, structures, devices, facilities, installations and conductive networks, transmission systems that provide the city and the society with equipment to cover basic welfare needs in relation to services and production, supply and reception of electricity, usable and domestic water, heating, gas, sewage and in field of waste disposal or recycling.

Road infrastructure provides elements of the transportation network, areas within road demarcation lines, together with the transportation network equipment, all of which enable the movement of people and goods and facilitate the use of means of transport together with systems and installations for traffic organization and monitoring.

Road and technical infrastructure provides the subject for urban and professional studies in relation to development strategies and spatial policy, city development plans, as well as public investment plans and schemes for public purposes. Such infrastructure conditions the investment process, as well as the possibility for implementing public, private and commer-

cial building developments. Moreover, road structure is connected with the system of continuous and nest-like public spaces, which in fact facilitates the movement and gathering of people, as well as access to buildings and areas.

Transportation systems integrated with interchange hubs, synchronization points and integration spots for various transportation and parking systems are introduced in cities. Public transport and road infrastructure require an efficient technical infrastructure. In road demarcation lines, installations are fitted to supply city areas and quarters of building developments. Thus, while analysing the connections between technical and road infrastructure in the context of urban planning, a significant correlation of layout of elements that delineate functional and spatial structure with composition is noticeable. Moreover, numerous criteria emerge for the design of the direction, parameters and technological solutions in the field of technical and road infrastructure. These include technological issues, urbanized area spatial development policy, public and commercial investment plans, response to social and environmental needs (aeration corridors, greenery system).

As it provides the basis for the city functioning and management, technical and road infrastructure constitutes the primary area of implementation of Smart City model solutions, as well as of optimization-related solutions in terms of resource management and energy policy, with the application of smart solutions for energy saving and with implementation of solutions that benefit from renewable energy sources. While analysing this type of infrastructure in order to define the nodal point, the complexity of issues and the manner of their implementation in the city should be emphasized.

The majority of transmission installations and technical infrastructure devices are implemented underground, some of them are installed on the ground and some above the ground. Road infrastructure may also be multi-layered, in the form of underground, ground-based and above the ground (viaducts, flyovers) facilities. In connection with the diverse criteria have been adopted for defining nodal points implemented as underground and above-ground interconnected system of public spaces. A view on composition, landscape

and urban environment must be considered. Moreover, functional considerations, taking into account development and expansion must be noted, as do the needs related to data transmission installations and the operation of devices and smart technologies being developed. In the case of underground infrastructure, the key nodal facilities are the ones related to launching and reception of transport of a given medium (electricity, water, sewage, ICT data) and to its storage.

Road infrastructure is characterized with communication hubs, often multi-layered that feature viaducts and traffic allotment and distribution systems. Moreover, interchange hubs are crucial, as they are located at spots where various modes of transport or transport directions are spatially connected. Interchange hubs tend also to be equipped with complementary services, such as trade and catering services. It was recognized that interchange hubs provide road infrastructure nodal points in terms of the city functionality and urban and architectural planning. However, for the sake of city operation and management, facilities and areas related to commencing and managing public transport and media distribution are crucial for the integration of road and technical infrastructure. Thus, nodal points are generation, reception and storage facilities, such as power plants, combined heat and power plants, water facilities, sewage treatment plants and databases – Data Center. For these nodal points, smart solutions are introduced in order to improve the quality of management, efficiency and implementation of tasks with the use of new technologies and renewable energy sources.

In wastewater treatment plants, solutions are introduced to generate electricity with the use of solar technologies or with the application of biomass and algae farms. Urban Farms that also produce biomass can serve as a part of Smart City technical infrastructure. Industrialized Urban Farms that apply biomass production may introduce cogenerative solutions and photovoltaic solutions to generate electricity and heat for the city, as well as for the sake of rainwater retention and distribution of treated grey water and rainwater. Process optimization with the use of cogeneration methods Combined Heat and Power (CHP) in order to produce electricity and heat, together with the application of renewable energy sources provide

the basis for implementation of circular economy principles, smart solutions and sustainable resource management.

Therefore, nodal points of the technical and road infrastructure category should be understood as interchange hubs, as well as facilities and areas that generate, receive and process (electricity, water, sewage, ICT data), i.e. heat and power plants, sewage treatment plants, Data Center and facilities that produce and manage resources for renewable heat energy and electricity sources, as well as industrial Urban Farms that produce biomass from algae and that foster utility and food vegetation.

Intelligent Transportation Systems (ITS) provide also a market sector related to road infrastructure, for which ITS systems integrate technologies, devices and activities, all of which improve the functioning of metropolitan transportation in terms of communication, prevention, traffic control and management, incident detection, traffic supervision and registration of traffic offences.

Social and service infrastructure in the Smart City model

Social and service infrastructure provides the basis for the organization of economic sector development in order to implement the following assumptions: Smart People, Smart Governance, Smart Living.

Social infrastructure may be defined as the areas and buildings that constitute the basis for the functional and spatial system, as well as for the social life structure. It is implemented by equipping urban space and activities of institutions (institutions in the field of law, security, tuition and education, health services, etc.) with a view to social development and local community development, as well as social integration, and with the aim of stimulating scientific, cultural and organizational achievements.

Service infrastructure (of modern and creative services) consists of developed areas and buildings, together with their equipment, devices and installations, intended for the provision of services, as well as facilities and installations for the needs of transportation services employed in order to stimulate economic, scientific, cultural and organizational achievements and to lead to such progress. In the Smart City model

particular importance of modern services, the business services sector and the creative services sector is highlighted.

The report “Business services in Warsaw” prepared for the City of Warsaw by the Association of Business Service Leaders (Związek Liderów Sektora Usług Biznesowych [ABSL], n.d.), discusses the strengths and weaknesses, as well as opportunities and threats for the development of this sector in Warsaw, along with an analysis of the employment structure and the range of services provided on a global scale.

Investment assumptions mentioned in the report concern *demographic potential* (population in the productive age 18–44, mobile – able to change posts, jobs or to retrain) and *scientific potential* (number of universities, students and graduates). These assumptions are important for the assessment of possibility to recruit an employee in Warsaw in analysed specializations of eight sectors of business services. The most frequently served branches of industry are as follows: IT, banking, finances and insurance, commercial and professional services, as well as healthcare. The results on the use of smart technologies, artificial intelligence, learning systems and analytics are highlighted. Moreover, the development of trends in the area of Randstar talent management (Talent Treads) was noted. In the justification to development in modern services in Warsaw, the quality and potential of infrastructure for business were indicated, as well as a high assessment of the life quality in the city, analysed with respect to factors, such as green areas, safety, public and bicycle transport, access to education (care and education) and culture.

Moreover, another ABSL report, that is the report entitled “Sector of modern business services in Poland” (ABSL, 2019) discusses a significant share of modern business services in employment and the economy of Warsaw and Poznań, Łódź, Kraków, Wrocław and the Tricity, as well as the development potential observed in medium-sized Polish cities.

In the ranking of Ośrodek Usług dla Biznesu (Service Centers for Business), in terms of assessment of factors that influence the conduct of business, the following criteria were indicated: Availability of modern office space, Accessibility to transport (airports, trains), Quality of public transport, Cooperation with

local universities, Cooperation with the local investor service unit, Availability of a talent pool/highly qualified staff, Quality of life.

In the 2019 overall assessment by Ośrodek Usług dla Biznesu of cities most favourable for business, Poznań ranked the highest, followed by Kraków and Wrocław, whereas in 2018 Kraków, Warsaw and Wrocław were rated the highest. The studies indicated economic basis and justification for the development of modern services in connection with multi-criteria city management and with the development of the creative services sector.

The infrastructures of modern business-related services and creative services are interconnected and complement each other. Both are based on access to modern technologies, innovative solutions, information management, as well as on scientific and creative potentials, and are further related to the parameters assessed as *quality of life*.

Designing infrastructure for these sectors of services pertains to multifaceted shaping of functional and spatial structure of the city, as well as to the offer of public spaces and buildings that pave the way for flexible interior design. When analysing the nodal points for this type of activity, it is important to indicate the structure of public spaces in the city, universities, research and implementation centers, as well as Data Center with ICT systems.

Therefore, a conclusion may be drawn that Data Center and Science-Research Centers should be regarded as nodal points that provide impulses and offer a chance for implementation of Smart City concept in the analysed service areas.

Ecosystem-related (biologically active) infrastructure: green and blue infrastructure in the Smart City model

Quality of life is related to environmental parameters, adaptation to climate change, accessibility and effectiveness of green areas, urban greenery system and water resources management, also in the case of systems for purposes related to biodiversity and water retention. All these aspects constitute an *ecosystem, biologically active, infrastructure* which is part of implementation of the following assumptions: Smart Environment, Smart Living.

Green infrastructure may be defined as a system of areas, cubature and biologically active surfaces with biomass, vegetation and organisms that live in the city, together with accompanying technical infrastructure for the implementation of ecosystem goals and social tasks.

Blue infrastructure consists of sites, areas, buildings and technical infrastructure implemented on behalf of water resources management, storage, purification, transmission and distribution of water from rivers and watercourses, natural and artificial water reservoirs, retention water reservoirs and retention systems, as well as transmission networks.

Ecosystem-related services in the city are operated via biologically active infrastructure integrated with public spaces and building developments. Smart solutions concern management of resources such as greenery, biomass, domestic water and municipal water – industrial water, sewage, open areas and water retention system. Activities related to system management and optimization are also significant in the context of bio-economy, mitigating the heat island effect and improving the microclimate, as well as preventing droughts and floods, and applying biomass for the purposes of energy generation from renewable energy sources. Biological wastewater treatment plants of various scale are being introduced, as well as innovative solutions for the application of greenery on rooftops and walls of buildings, as well as for creation of water gardens and swamps on building rooftops. Vegetation in the city serves a variety of functions and applications and exerts various impacts, it is implemented on the ground, in soil and substrates in open areas, as well as inside and outside buildings. The urban greenery system is closely related to the water resource management system. In modern cities, spatial solutions and building developments are also introduced in order to make it possible to grow vegetation and breed animals for the local community. Urban Farms might be implemented in four categories, also as algae farms constructed inside and outside buildings as installations for obtaining biomass for energy purposes, as well as for water and air purification.

Being innovative production in the city, Urban Farms make use of server rooms and systems managed with the application of computing power. There-

fore, a conclusion follows that it is reasonable to combine Data Center and Urban Farm Functions for the intensification of activities in the field of acquisition, processing and usage of energy from renewable sources. The implementation of hybrid urban units of this type should be regarded as the key investments for development of Smart City structure and infrastructure. Application of greenery in open areas and water reservoirs, the so-called water gardens, is vital for the implementation of ecosystem infrastructure. For the execution of these tasks, the nodal points include parks with water reservoirs and greenery integrated with buildings, applied as intensive green roofs with effective water retention systems, as well as crop plant cultivation areas in the city.

CONCLUSIONS

Implementation of the Smart City model is related to the issues in the field of sustainable urban development and to tasks of optimal (smart) resource management. Such solutions are applied in order to ensure harmonious development of the city, of which the human is not the only user and inhabitant. The city is treated as a *living organism* in which life and production processes occur for urbanized areas equipped with infrastructure and ecosystem-related systems. In source literature on the topic, as well as in legislation, numerous definitions of sustainable city development in terms of society, economy and environment may be found. Principles of synergy and integrated design, with the use of modern resource management methods and smart management technologies are indicated.

Referring to the assumed development strategies towards climate change and the implemented Smart City and Sustainable development models, it is sensible to seek synergistic urban, infrastructural and architectural solutions at city nodal points. Based on the analyses of source materials, the selection criteria and the characteristics of nodal points in the selected categories of Smart City infrastructure were established. In the case of Infrastructure of social communication and data management, Data Center that constitute strategic and key elements for the Smart City development model were indicated as the nodal points.

In the case of technical and road Infrastructure, the following nodal points were determined: interchange hubs and heat and power plants, sewage treatment plants, Data Center (Fig. 1) and production facilities – industrial Urban Farms (Fig. 2). In the case of social and service Infrastructure, nodal points that provide impulses and enable the implementation of Smart City in the analysed areas, Data Center, as well as Science and Research Centers should be indicated. In the case of ecosystem Infrastructure (biologically active, green and blue infrastructure), parks with water reservoirs and greenery integrated with building developments, implemented as intensive green roofs and walls with effective water retention systems, as well as areas of crop plant cultivation in the city (Urban Farms) were indicated as nodal points. The functional and spatial structure of social communication and data management infrastructure, as well as location of Data Center facilities should provide an area of activity for interdisciplinary teams with participation of urban town planners, and architects. Data Center should be regarded as nodal points that constitute strategic and key elements for the Smart City development model. The structure of interdependencies and the needs related to cooling installations and energy supply determine the location of such facilities in urban space or on the city outskirts. The direction towards introducing solutions with the use of renewable energy sources and cooling methods is of great importance. This should be related to the water retention system and functions that can be combined with Data Center. For urban planners and architects, the aspect of applying new functions and modern services in urban revitalization programs proves important, as do the required urban and architectural assumptions for spatial and architectural dominant of the Data Center. Referring to the typology, Data Centre is defined as superbases that use Intelligent Transport System (ITS), large-scale or medium-scale, of regional or local range, for commercial and communal purposes, implemented by means of public-private partnership. The prevailing practices and models of city development in urban planning strategies and studies fail to provide sufficient basis or indications for the location of facilities with such characteristics. Moreover, no urban indicators or architectural guidelines exist that would facilitate the



Fig. 1. The Data Center building – near Ożarów in Poland (author's own materials)



Fig. 2. Pasona Urban Farm by Kono Designs (Andrews, 2013)

introduction of relevant provisions in local development plans or the city spatial policy. It should therefore be emphasized that this field of interest offers an important area of architectural and urban research and design activity, which should be considered a priority in city development and management under the Smart City model.

While considering development of social participation and activities of the local community, it is necessary to conduct architectural and urban planning analyses regarding the use, location and shaping of the architectural expression of modular compact (container-based), commercial or cooperative (social), local databases that apply wired technologies. Recognition of the possibilities of such solutions aimed at the local community and combined into a system that also enables data collocation provides an issue that may

serve as an impulse to redefine the neighbourhood unit, common spaces, social services, as well as the structure and functions of public and semi-public areas. The analysis should also focus on integrating compact Data Center with other services for the benefit of local community. An example of that may be the integration and intensification of the effects of social activities that use biomass obtained from plant cultivation in the city in order to generate energy with which to power the database, city fountains or brine inhalation facilities. Water, being a cooling medium, and electricity are crucial for the functioning of Data Center. By creating installations and connections in accordance with the principles of the circular economy, with the use of renewable energy sources, self-sufficient, attractive and functional spatial solutions can be created for the local community.

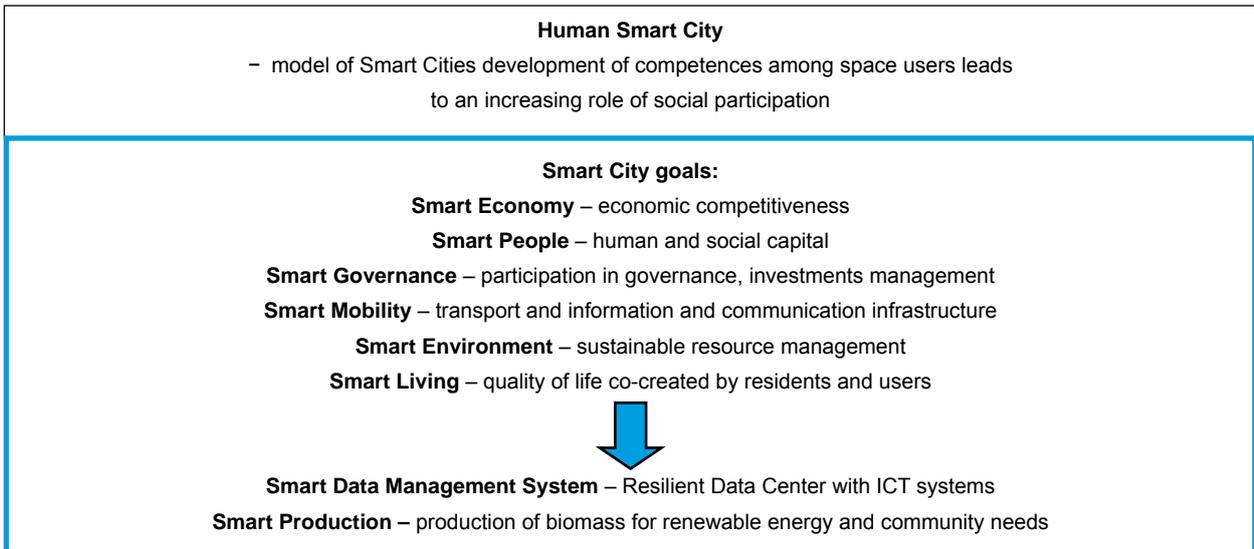


Fig. 3. Human Smart City Goals

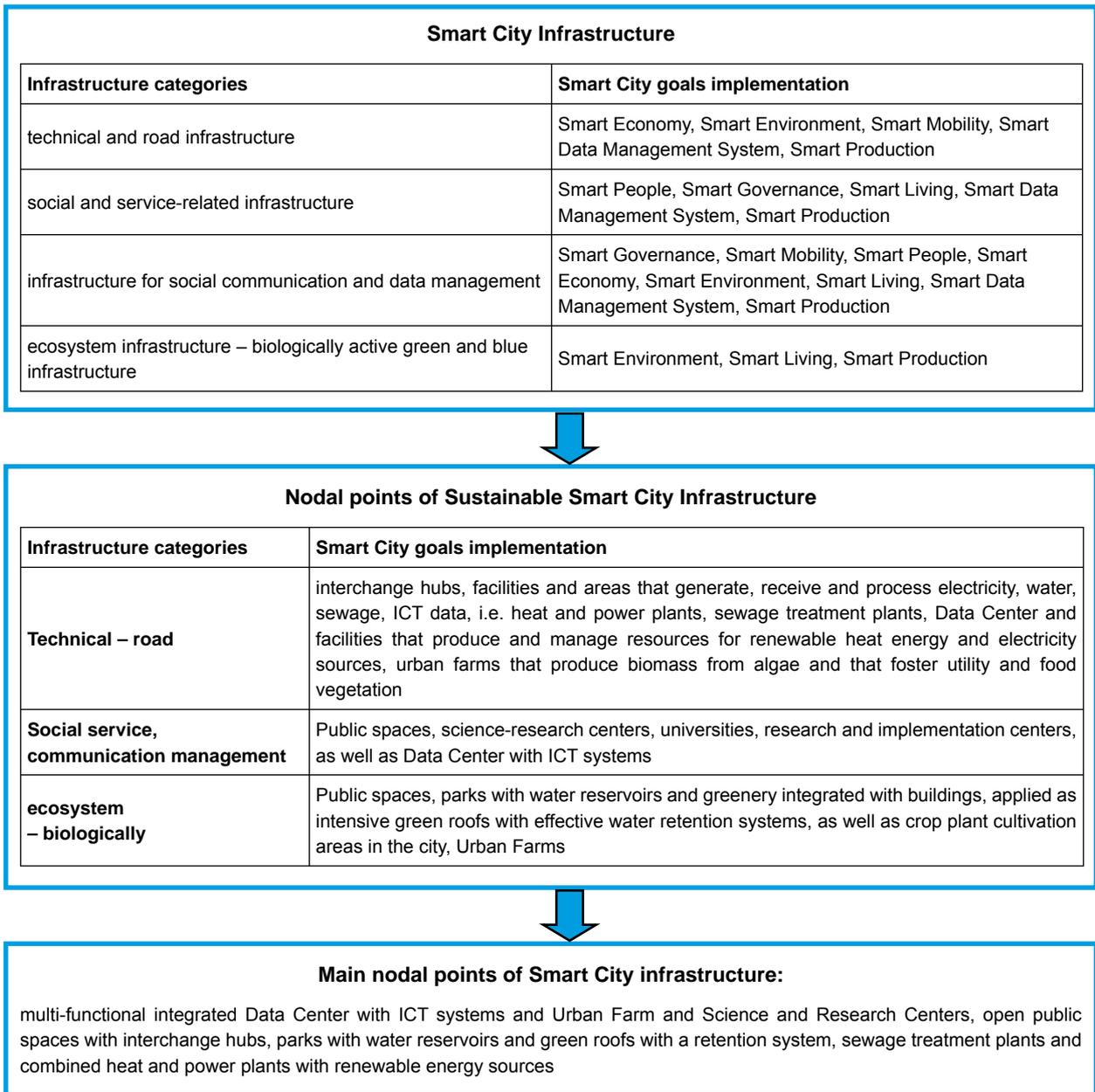


Fig. 4. Structure Smart City Infrastructure with nodal points

To summarize the multi-criteria analyses of Smart City infrastructure, the role of buildings and Data Center facilities should be pointed out. Data Center buildings, Urban Farms, science and research centers provide nodal points, with which to integrate and manage complex smart infrastructure of the Human Smart City (Fig. 3).

The analysis of the publications, current needs of the city and the Smart City infrastructure researches indicate the importance of complementing the Smart City model and specifying new goals identified as Smart Data Management System (resilient and self-sufficient databases and ICT system) and Smart Production (biomass production for renewable energy and self-sufficient community) (Fig. 4).

In addition, interchange hubs, parks with water reservoirs, green roofs and walls with a retention system, sewage treatment plants and combined heat and power, renewable energy sources are significant as nodal points. When designing city sustainable development that undertakes the implementation of the Smart City assumptions, it is advisable to shape the space and buildings in such a way as to implement multi-functional integrated Science and Research Centers, Data Center and Urban Farm facilities with the aim of generating electricity and housing data centers management, as well as in order to control ecosystem and social environment parameters in accordance with the principle of circular economy for the needs of optimizing the consumption and use of water, energy and biomass.

Urban planning, design and implementation activities are necessary, especially in the nodal points of the structure of infrastructure systems connection, with respect to the passive and active data management infrastructure and spatial infrastructure.

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STRUKTURA I MIEJSCA WĘZŁOWE INFRASTRUKTURY SMART CITY

STRESZCZENIE

Rozwój *smart city* powinien zapewnić realizację infrastruktury zgodnie z założeniami harmonijnego i zrównoważonego rozwoju tkanki miasta. Realizacja założeń *smart city* związana jest z wprowadzeniem i rozwojem infrastruktury, stanowiącej elementy infrastruktury miejskiej, a także szczególną formą zagospodarowania terenów i budynków. Poniższe prace badawcze dotyczą analizy rozwiązań przestrzennych i infrastrukturalnych oraz systemów środowiskowych, społecznych i teleinformatycznych stosowanych w mieście. Analizy materiałów źródłowych (źródła urbanistyczne, architektoniczne i technologiczne) stanowią podstawę do wniosków i sformułowania typologii i kryteriów dla infrastruktury miejskiej, społecznej i ekosystemowej realizowanej w modelu *smart city*, z wykorzystaniem innowacji z zakresu inteligentnych technologii informacyjno-komunikacyjnych (ICT) oraz infrastruktury sieciowej. Wnioski wynikające z prac badawczych przyczyniają się do dyskusji na temat sposobów kształtowania struktury infrastruktury i punktów węzłowych w modelu rozwoju *smart city* w odniesieniu do zagadnień zrównoważonego rozwoju.

Słowa kluczowe: zrównoważona infrastruktura, *smart city*, zrównoważony rozwój miast, technologie informacyjne i komunikacyjne (ICT), *Data Center*, zielona i niebieska infrastruktura, sektor nowoczesnych usług