Edited by
Barbara **SENSUŁA** Tomasz **KRYKOWSKI**
Grzegorz **SIERPIŃSKI**

MONOGRAPH

TECHNOLOGIES AND TRENDS IN PLANNING AND DEVELOPMENT OF SMART CITY

Smart cities
and future mobility

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Redakcja techniczna
Ewa TENEROWICZ

Opracowanie edytorskie
Joanna JENCZEWSKA-PAJKA

Projekt okładki
Maciej MUTWIL

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SPIS TREŚCI

INTRODUCTION

This publication is the next volume of the series on smart cities and future mobility, related to Priority Research Area 4 (POB4).

The research and the analysis carried out at the Silesian University of Technology indicate possibilities how science can be useful at sustainable development on a local, regional and global scale.

In recent years, dynamic development and significant changes can be observed in the design of the Smart Cities concept. Innovations introduced take into account both social aspects and the application of modern technology. The development of science, technology, and, in particular, communication, is an integral part of the challenges for society to ensure sustainable development and better living conditions for everyone.

We would like to thank the sub-area coordinators in POB4 for their significant contribution to the creation of this volume, the authors of all chapters for presenting the results of research and analysis, and the reviewers for their valuable comments.

Giving this publication to the Readers, we trust that you will find an interesting area to establish cooperation or its further development with the Silesian University of Technology.

Barbara Sensuła, Tomasz Krykowski and Grzegorz Sierpiński
Gliwice, 2023

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Zbigniew ORBIK[1]

1. ON THE AXIOLOGICAL FOUNDATIONS OF THE SMART CITY CONCEPT

1.1. Introduction

The concept of a smart city is a multi-dimensional project. It is based on various assumptions about the nature of the world, the role and place of man in it, the model of civilization development, etc. There are various interpretations of the smart city concept[2]. The research conducted so far on the way of understanding the concept of smart cities by various entities involved in the implementation of this idea seems to be insufficient[3]. There is a lack of coherence in the numerous published empirical studies, but also in theoretical considerations. So far, it has not been possible to work out a commonly accepted definition of a smart city[4], or a uniform model for the implementation of this concept. Depending on the adopted definition, various functions are emphasized that a smart city is to fulfil, ranging from improving the quality of life of residents through supporting civic activity, accepting ICT in urban systems, focusing on human capital or supporting innovation and striving for sustainable development of urban areas. The very concept of a smart city has undergone an evolution that has been going on for decades. Its result is the smart city model assuming the evolution of cities towards such development of their physical and legal infrastructure that supports economic development, while ensuring social integration and environmental protection. The implementation of such a defined model of urban development assumes actions that must be taken by politicians, managers, business leaders, scientists, planners, architects and

[1] Silesian University of Technology, Faculty of Organization and Management, Department of Applied Social Sciences, Zabrze, e-mail: zbigniew.orbik@polsl.pl.

[2] See Chrisidu-Budnik A., Przedańska, J.: Smart City: From Concept To Implementation. Wroclaw Review of Law, Administration & Economics, Vol. 9, No. 2, 2019, pp. 24–39.

[3] Desdemoustier J., Crutzen N., Cools M., Teller J.: Smart City appropriation by local actors: An instrument in the making. Cities, Vol. 92, 2019, pp. 175–186.

[4] Artur Pawłowski lists them, for example, see Pawłowski A.: Rozwój zrównoważony: idea, filozofia, praktyka. Monografie Komitetu Inżynierii Środowiska PAN, Vol. 51, Komitet Inżynierii Środowiska, Lublin 2008.

representatives of other professional groups in such areas as economy, education, energy, environment, finance, health, management, security, recreation, waste management, telecommunications, innovation, transport, spatial planning, water resources[5]. The most important moment in the long history of the development of the smart city concept was the adaptation to its needs. According to this approach, a smart city is one that is characterized by its sustainable development, as it was stated in the 1987 Brundtland Commission report entitled "Our Common Future".

In the light of this report, sustainable development is one that, while meeting the needs of today's inhabitants, does not reduce the ability to meet the needs of future generations. It is to take place on three levels: environmental, social and economic. The concept of sustainable development found its expression in a document called Agenda 21. It is a program document relating to the way of implementing sustainable development programs in local conditions. It was formulated at the conference "Environment and Development" organized at the initiative of the United Nations in Rio de Janeiro in 1992. It is the most complementary, on the international scale, approach to the issue of sustainable development. It covers social and economic issues related to human resource management, sustainable development of various social groups, the role of science and the possibilities of implementing this concept. In the light of this concept, the development of the city towards a smart city is to be sustainable development. As the smart city concept develops, attention is paid not only to technological development, but also to its impact on residents[6]. The growing importance of the social factor, as well as the universal nature of the concept under discussion, which covers all spheres of human life, also raises questions about the axiological structure of this development.

1.2. The issues of axiology of sustainable city development

The concept of smart city understood in the 21st century as the idea of sustainable urban development is a paradigm of a new perspective for the development of civilization[7]. One of the most important elements of any culture is underlying it value system. The issues of values, their ontological status, types, hierarchies, and mutual relations have been present in the area of European culture since ancient times. Values

[5] Eremia M., Toma L., Sanduleac M.: The smart city concept in the 21st century. Procedia Engineering. Vol. 181, 2017, pp. 12–19.
[6] Masik G., Studzińska D.: Ewolucja koncepcji i badania miasta inteligentnego. Przegląd Geograficzny, Vol. 90, No. 4, 2018, pp. 557–571.
[7] See Gawor L.: Idea zrównoważonego rozwoju jako projekt nowej ogólnoludzkiej cywilizacji. Diametros, Vol. 9, 2006, pp. 84–104.

seem to accompany all human experiences[8]. For all human decisions, choices and judgments presuppose the choice of certain values. This applies not only to the activities of individuals, but also to all projects of a social nature.

The science of values – axiology is not only a purely theoretical knowledge of various types of values. Its social role becomes apparent in the moments of local or global social crises. This is because there are often conflicts of values at their roots. Besides, it should be remembered that axiology is not the only science of values. Alongside it, one can indicate specific disciplines dealing with the issues of values, such as, for example, aesthetics dealing with values related to aesthetic experiences, ethics analysing issues of morality, or economics studying values related to the production, exchange and consumption of goods. Also other disciplines not directly related to the study of values, such as psychology, anthropology, sociology, political science or history, assume the existence of specific values. Due to the fact that axiology is the most general science that studies values, the results achieved in its field are also important for other disciplines involved in values study in any way.

There is no single axiology resp. philosophy of sustainable development. Andrzej Papuziński explains this fact in the following words: "Differences in approaches to sustainable development, including to the axiology of that programme, are determined by many different causes. Among them we may list ignorance, particularistic interests, the vagueness and ambiguity of the categories used to define sustainable development, as well as controlling ideas of humanity, world views, value systems and methodological approaches that determine any picture of reality"[9]. It seems that the outlined above situation is largely caused by the fact that the concept of sustainable development, despite the fact that it is the subject of numerous and intense research efforts, is still not a fully mature concept in terms of its theoretical foundations.

An attempt to answer the question about the values underlying the concept of smart city development understood as its sustainable development should be preceded by the question about its very definition. And here again, it is difficult to talk about unanimity both among researchers dealing with this issue and those involved in its implementation. In the literature on the subject, you can, inter alia, find the following definition of sustainable development as: a category understood intuitively as a certain set of concepts defining the development of cities towards smart cities, a synonym for eco-development or its features, a synonym for the development of the natural environment or unconventional development, which transcends the development of this environment

[8] Bahm A.J.: Axiology: the science of values. Vol. 2, Rodopi, 1993.

[9] Papuziński A.: The Axiology of Sustainable Development: An Attempt at Typologization (Aksjologia zrównoważonego rozwoju: próba typologizacji). Problemy Ekorozwoju/Problems of Sustainable Development, Vol. 8, No. 1, 2013, p. 7.

towards the creation of a specifically human way of being in the world. There are also definitions of sustainable development as complementary to durable development ensuring its durability or as a certain process reflecting dynamic changes taking place in the natural environment. There are also concepts of sustainable development that deny that it is any development at all[10]. The conclusion can be drawn that the concept of sustainable development is a vague concept. This is by no means a feature that eliminates its use in scientific discourse. The vast majority of names (concepts) functioning in the broadly understood humanities, or even more broadly in natural language, are vague names[11]. The concept of sustainable development fulfils the function of integrating various types of activities, the common denominator of which is focusing on developing such a model of city functioning that will be able to provide optimal living conditions for its inhabitants to the greatest extent, while at the same time taking care to preserve the natural environment in the best possible condition.

By accepting the view that the concept of smart city is an exemplification of the idea of sustainable development, we come closer to the theoretical approach to its philosophical and axiological foundations contained in eco-philosophy (eco-ethics). One can distinguish three basic types of philosophical discourse devoted to the issues of sustainable development: pragmatic, systemic, and conservational[12]. The foundation of the pragmatic version of the philosophy of sustainable development is the belief that its essence is striving to maintain a balance between economic growth and the state of the natural environment. In this approach, it is also assumed that a person is a being guided by the principle of rationalism, manifested by a tendency to change behaviour if it is in any way unfavourable for him. The basic assumption of the systemic philosophy of sustainable development is the principle of biocentrism expressed in the attitude of human responsibility for the entire natural environment. It results from the acceptance of the ontological principle of realism, which recognizes human existence as rooted in an objectively existing reality. Conservational philosophy, in turn, takes an extremely anthropocentric point of view. It recognizes the primacy of economic growth over the condition of ecosystems and the quality of human life. This concept also assumes that man is characterized by constant moral progress. The environment is important, but only in the perspective of economic development.

It is worth noting that the distinguished philosophical paradigms of sustainable development refer to two different anthropological concepts of man. In pragmatic and

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[10] Fiut I.S.: Obraz zrównoważonego rozwoju na łamach Problemów Ekorozwoju/Problems of Sustainable Development. Problemy Ekorozwoju, Vol. 6, No. 2, 2011, pp. 93–100.

[11] Kohl M.: Bertrand Russell on vagueness. Australasian Journal of Philosophy, Vol. 47, No.1, 1969, pp. 31–41.

[12] Orbik Z.: O filozoficznych podstawach koncepcji zrównoważonego rozwoju. Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie, Vol. 85, 2015, pp. 383–393.

systemic philosophies, it is assumed that man is a personal being. This implies, inter alia, a thesis that he possesses individuality, rationality and freedom that every human being a person is entitled to[13]. In the personalistic approach, man is characterized by transcendence (superiority) in relation to nature and society. In relation to nature, it manifests itself through intellectual cognition, freedom and love. In relation to society, it is expressed as subjectivity towards the legal order, completeness and dignity[14]. The human being understood this way is the subject of actions undertaken by him, for which he is responsible. In his relations with others he is guided by moral principles. In conservational philosophy, man is understood as the subject of various undertaken by him activities within social relations (e.g. subject of work or subject of consumption). The motives of the activity of such a subject are individualism, egoism and the belief that rights take precedence over good. The theoretical description of the subject understood this way is not so much the concept of a person but of an individual. Man is reduced here to the role of an individual being, the essence of which is determined by the ability to conclude various types of contracts (e.g. service provider or recipient of various types of services).

The outlined above perspectives of the philosophical approach to the concept of sustainable development are the exemplifications of certain general philosophical assumptions. These are theses of a metaphysical, epistemological, historiosophical, anthropological, and axiological nature. Leszek Gawor describes them in the following words: “The fundamental metaphysical theses of the philosophy of sustainable development undoubtedly include naturalistic monism, which requires us to perceive reality as a dynamic ontic unity. (...) In the field of epistemological reflection, the idea of sustainable development is based on views adopted by modern science, mainly natural science, but also social sciences. Thus, the view of epistemological critical realism with regard to partial Spencer's like agnosticism is widely accepted. (...) In the domain of historiosophy, the foundation of sustainable development is the idea of humanity as the only subject of the social world and subjected to historical changeability. (...) Another fundamental assumption of sustainable development is the thesis in the field of philosophical anthropology about the rationality of human nature. (...) The axiological realm of the concept of sustainable development is made up of values existing on three levels: social, economic, and ecological”[15]. Obviously, the above quotation does not contain a complete list of philosophical assumptions underlying the concept of

[13] Gryżenia K.: Etyczne implikacje (nie) osobowego traktowania człowieka. Forum Pedagogiczne, Vol. 1, No. 2, 2011, pp. 71–96.
[14] Krąpiec M.A.: Człowiek jako osoba. Polskie Towarzystwo Tomasza z Akwinu, Lublin 2009.
[15] Gawor L.: Filozofia zrównoważonego rozwoju: preliminaria. Problemy Ekorozwoju: studia filozoficzno-sozologiczne, Vol. 5, No. 2, 2010, pp. 69–76.

sustainable development, *resp.* smart city. The presented theses imply a whole range of statements about the nature of the world, man's place in it, his relationship to the environment in which he lives, the way of knowing it, and the motives of the undertaken actions. From the point of view of the subject matter discussed in this text, theses of an axiological nature are important.

As stated above, the values underlying the concept of sustainable smart city development relate to three dimensions: social, economic and ecological. The concept of smart city development assumes that this development includes three basic elements: human resources, economy and the environment. Other components of this development, such as quality of life, management, innovation, and mobility seem to be of less importance. This is in line with the approach of the European Commission. In its 2011 report we read: "European cities should be locations where advanced social and environmental progress is taking place, while maintaining economic attractiveness and economic growth based on an integrated approach that takes into account all aspects of sustainable growth"[16]. Many researchers in their attempts to define smart city indicate that the distinguished areas in the development of smart cities are related[17]. As far as the issue of values is concerned, it should be noted that they are not assigned to only one of the distinguished areas of city development, but they most often apply to all of them. This leads to greater effectiveness of actions taken in relation to the inhabitants, the economy and the environment. Values become a factor that integrates these activities. Awareness of this also helps to mitigate potential conflicts that may arise between man, economy and the environment[18].

Cities as the most complex and at the same time the most perfect territorial forms of social life organizations are the subject of numerous analyses of various sciences. Due to the complexity of the cities structure and their dynamic nature, these analyses are among the most difficult and are necessarily interdisciplinary. Among the many functions assigned to cities, one is value creation. These are, of course, different values when we consider the long history of urban development. In an article devoted to the city as a place of value creation, Michał Kudłacz lists, after Roman Ingarden, five types of them: artistic, aesthetic, social, moral and economic. The mentioned author, trying to make

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[16] As cited in: Szczech-Pietkiewicz E.: Smart city – próba definicji i pomiaru. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu. Vol. 391, 2015, pp. 71–82.

[17] See e.g. Caragliu A., Del Bo Ch., Nijkamp P.: Smart Cities in Europe. Journal of Urban Technology, Vol. 18, No. 2, 2011, pp. 65–82.

[18] Franciszek Piontek points out that the acceptance of the principles of sustainable development (also city development) is able to ensure "a lasting improvement in the quality of life of modern and future generations through the appropriate shaping of the proportions between the various types of capital: economic, human and natural", Piontek F.: Ekonomia, a rozwój zrównoważony. Teoria i kształcenie. Vol. 1, Wydawnictwo Ekonomia i Środowisko, Białystok 2001.

a general characterization of these values, states: “Each of these elements is a value, so it should be assumed that in the 21st century the values in cities are those qualities that are developmental, city-forming, regardless of the nature, direction or range of impact. Values defined this way may be both material and intangible, but their common feature is a positive impact on the functional or morphological character of the city”[19]. The values created by cities change along with their historical development. At the same time, a certain regularity can be noticed, which is manifested in the tendency to more and more emphasize the factors (values) which favour: (a) the functionality of using the space of urbanized areas for residents, entrepreneurs and tourists; (b) stopping the processes degrading the environment and emphasizing the importance of cultural and historical heritage; (c) increasing the quality of life of the inhabitants and multiculturalism; (d) compliance with the law and improvement of safety; (e) increase in the level of knowledge, innovation and development of modern technologies. A smart city does not only produce values, but also becomes their consumer. It is also worth noting that despite some variability of values resulting from the historical development of cities, some of them are universal in nature (they can be found in all periods of cities development and in all their types). By pointing to a few turning points in the history of urban development, M. Kudłacz notices them in the emergence of ancient metropolises, Renaissance cities, industrial revolution cities, and Ebenzer Howard's garden cities. According to this author, modern cities are characterized by: globalization, metropolization, digitization and the increasing importance of services and intangible factors of their development, such as knowledge or culture[20].

It is noticeable that the author of the concept presented above uses a subjective understanding of value as a feature assigned to a given object by a specific subject. We read: “Values depend on specific features (an individual set of developmental determinants, i.e. uncontrollable conditions and controllable factors). They can be perceived differently, e.g. in an industrial or post-industrial city (where the value is e.g. a green area), and differently in a tourist city (where uncrowded streets may be of value)”[21]. There seems to have been a confusion here of the notion of a thing (object) to which a value is assigned with that value itself. Obviously, this does not discredit the presented analyses, on the contrary, they bring a new look at the development of cities from the perspective of things or phenomena considered valuable in them. This remark is only intended to draw attention to the fact that this article seeks the axiological basis of the concept of a smart city as a set of certain values understood objectively, i.e. as certain ideal entities defining the goals of activities undertaken in the urban environment.

[19] Kudłacz M.: Miasto jako miejsce wytwarzania wartości. Zarządzanie Publiczne, Vol. 39, 2017, p. 103.
[20] Kudłacz M.: Miasto jako miejsce wytwarzania wartości. Zarządzanie Publiczne, Vol. 39, 2017, p. 110.
[21] Kudłacz M.: Miasto jako miejsce wytwarzania wartości. Zarządzanie Publiczne, Vol. 39, 2017, p. 112.

1.3. Values founding the smart city concept

Behind each of the distinguished philosophical perspectives there are certain values considered fundamental. So far, it has not been possible to reach a consensus on the set of values constituting the axiological foundation for the development of a city implementing the smart city postulate. Their hierarchy was also not established. However, various approaches to this issue are linked by the conviction that it is necessary to take into account three orders in the conducted analyses: environmental (ecological), social and economic[22].

Piotr Domeracki and Włodzimierz Tyburski in their work on shaping social awareness in the spirit of sustainable development point to the value of life, health, responsibility, moderation, solidarity, and justice as the key to this concept. Scholars write: "The axiology of sustainable development proposes a set of universal values such as: life, health, justice, which have the advantage that every person is ready to accept them, and that is why people around the globe can be united around them"[23]. Therefore, they rightly point out that the choice of universal values has a function that motivates people to obey them. The acceptance of these values results in more detailed principles regulating the social order, such as: the principle of solidarity, social egalitarianism, balanced and fair consumption, distributive justice, progress (intellectual and moral), subsidiarity, democratization of life and socialization of decisions, adherence to human rights, recognition of the quality of life as the main goal of socio-economic development and retributive justice[24].

Leszek Gawor, in turn, in his attempt to grasp the axiological system underlying the concept of sustainable development refers to three groups of values: 1. rudimentary (initial); 2.teleological (intentional) and 3.instrumental (helpful)[25]. The rudimentary ones include, first of all, pacifism and freedom. The group of teleological values include: dignity, egalitarianism, justice and life. The third group – instrumental values constitute:

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[22] Papuziński A.: The Axiology of Sustainable Development: An Attempt at Typologization (Aksjologia zrównoważonego rozwoju: próba typologizacji). Problemy Ekorozwoju/Problems of Sustainable Development, Vol. 8, No. 1, 2013, p. 9.

[23] Domeracki P., Tyburski W.: Podstawy edukacji i kształtowania świadomości społecznej w duchu zrównoważonego rozwoju. [In:] Tyburski W. (ed.): Zasady kształtowania postaw sprzyjających wdrażaniu zrównoważonego rozwoju, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń 2011, p. 236.

[24] These principles are not discussed because the text deals with the issue of the values themselves and not the resulting rules and principles of conduct. Domeracki P., Tyburski W.: Podstawy edukacji i kształtowania świadomości społecznej w duchu zrównoważonego rozwoju. [In:] Tyburski W. (ed.): Zasady kształtowania postaw sprzyjających wdrażaniu zrównoważonego rozwoju, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń 2011, p. 236.

[25] Gawor L.: Filozofia zrównoważonego rozwoju: preliminaria. Problemy Ekorozwoju: studia filozoficzno-sozologiczne, Vol. 5, No. 2, 2010, p. 72.

community, responsibility and moderation. Interestingly, the author of the typology did not classify the value of life as rudimentary, while he recognizes pacifism as such, that is, a value whose goal is the protection of life and freedom. Although the scholar points out that the rudimentary values are such for the "human social world", it seems that life is, however, superior to the two mentioned. Especially that it is difficult to separate the concept of the "social world" and its good from the good of the individuals who constitute this world.

Interesting comments are included in the work of three authors, published last year, which is a comparative study conducted on a global scale[26]. It is devoted to the relation of smart city societies to the values they accept. The main subject of the research were the inhabitants of the cities of Malaysia and Indonesia, whose views were confronted with the inhabitants of cities located in selected countries situated on several continents. These countries are: Australia, the United States, Germany, China, Brazil, Pakistan, Nigeria and Iran. It turns out that regardless of cultural differences in all countries, there is a trend of moving away from material values towards post-material ones[27]. The value enjoying the least recognition was politics (52.81% of the respondents). In all countries, the family was considered to be the highest value (98.87%). In further places, the value of work (89.61%) and friendship (89.49%) were indicated. Religion and free time were, respectively, indicated by 70.84% and 84.42% of the respondents. It should be noted that religion achieved the highest position in Indonesia and Malaysia, i.e. countries where Islam is the dominant religion (99.9% and 91.1% respectively). In turn, politics was indicated as a significant value in these countries by 44.2% and 51.2% of respondents. In countries outside of Asia, the greatest number of respondents agreed with the opinion that family and leisure time are values more important than others. If we consider that free time is a certain manifestation of the desire for freedom, then respondents from non--Asian countries such as Nigeria, Brazil, the United States and Germany indicate it as a value that reflects freedom to a greater extent than other values. The position of politics is highest in relation to other values in the United States and Germany. On the other hand, in these countries and in Australia, i.e. countries where the income is the highest, religion and work have the lowest positions. In the highest-income societies, in turn, values (qualities) such as tolerance, independence, determination and imagination rank high in the hierarchy. Geographical location turns out to be a relatively insignificant criterion in the choice of value. The authors of the article recognize the need for greater

[26] Lim S.B., Malek J.A., Yigitcanlar T.: Post-Materialist Values of Smart City Societies: International Comparison of Public Values for Good Enough Governance. Future Internet, Vol. 13, No. 8, 2021, pp. 1–13.

[27] By material values, the authors of the aforementioned work understand those that are related to the meeting of basic physiological needs necessary for survival and the need for security. As defined, post-material values are related to satisfying "higher order" needs built on top of the former (e.g., freedom of speech).

civic involvement, which would be manifested by a higher position of values related to the common good and its management, as one of the main conclusions resulting from the research when it comes to building smart cities areas. The technological aspect of transforming city into its intelligent form is its inherent feature, but it should not be treated as its goal in itself, but only a mean to achieve it.

These studies show preferences regarding the selection of values considered important on a global scale. They show that despite the differences resulting from different cultural conditions, income levels or geographic location, some regularities indicated above can be found. According to the author, this proves the possibility of finding an axiological foundation on which it is possible more effectively develop intelligent cities that are friendly to residents and the environment.

The author of these words proposes to refer to the Platonic triad of values which are: good, truth, and beauty supplemented with the value of freedom and justice. These values should be considered not only universal, but also fundamental to all spheres of human activity. Anastasia Seoul distinguishes two aspects of the famous triad: horizontal and vertical. The first indicates the social conditions of human development, the fullest manifestation of which is the common concern for good, truth, and beauty. The second is the transcendental dimension of these values[28]. She also refers to the words of John Paul II, who points out that, as we know from history, democracy not based on values easily turns into open or camouflaged totalitarism[29].

Freedom is one of the basic axiological and metaphysical categories that have been the subject of analyses by thinkers since ancient times. It is most often understood as the lack of enslavement and the possibility for the subject to make undetermined choices. A supporter of philosophical liberalism, Isaiah Berlin distinguishes between two types of freedom: 1. positive freedom, the so-called freedom to ... (or the right to: live, express opinions, work, etc.) and 2. negative freedom – freedom from ... (from persecution, coercion by the authorities, hunger, etc.). He characterizes both concepts of freedom in the following words: “The first of these political senses of freedom or liberty (I shall use both words to mean the same), which (following much precedent) I shall call the ‘negative’ sense, is involved in the answer to the question ‘What is the area within which the subject – a person or group of persons – is or should be left to do or be what he is able to do or be, without interference by other persons?’ The second, which I shall call the positive sense, is involved in the answer to the question ‘What, or who, is the source of

[28] It is worth remembering that good (bonum), truth (verum) and beauty (pulchrum) are referred to as transcendental, or universal properties of being. On the history of the concept of transcendentals. See, e.g., Maryniarczyk A.: Transcendentalia w perspektywie historycznej (Od arché do antytranscendentaliów). Roczniki Filozoficzne, Vol. XLIII, No. 1, 1995, pp. 139–164.

[29] Seul A.: Prawda. Dobro. Piękno. Wrocławski Przegląd Teologiczny, Vol. 27, No. 1, 2019, pp. 97–122.

control or interference that can determine someone to do, or be, this rather than that?' The two questions are clearly different, even though the answers to them may overlap"[30]. Berlin recognizes only negative freedom as its proper form. Freedom in the smart city community would fulfil two basic functions manifested primarily in the social sphere: (1) expressed in the expanding area of civil liberties and freedom of beliefs of the residents; (2) related to the positive understanding of freedom as "the right to ...". Freedom understood this way would constitute the basis of broadly conceived human rights.

In the above approach, good in the smart city project and various activities undertaken within its framework would function as a value that determines the basic goal of all forms of activity. The scope of this concept would include both the good of the anthroposphere and the entire biosphere[31].

Beauty in ancient Greek philosophy was considered inseparable from good. The implementation of a smart city project would be expressed not only in its architectural structure. Let us reach for the Greek ideal of kalokagathia (καλοκαγαθία), (Greek: καλὸς – beautiful, ἀγαθός – good), postulating harmonious human development. Its main task would be to provide people with the possibility of comprehensive development in line with their lives goals. In practice, the point is to create, for example, an education system at all levels that would solve the problems of social exclusion or unemployment. Generally speaking, the good in social (public) life is manifested in the broadly understood safety (including social one) and its protection[32]. Its purpose is to provide the individual with the possibility of comprehensive physical and spiritual development.

Truth, which is most often understood as the logical value of propositions (next to the opposite falsehood) of a specific language or, more broadly, a feature of all information expressed in a non-linguistic way (by means of images, thoughts, symbols) is also a value that guarantees order, both in our individual and social life. Truth is also an autotelic value which constitutes the ideal goal of all cognition[33]. Cognition, on the other hand, is a typically human form of existence in the world that also enables the functioning of all institutions, inter alia, scientific or political. Truth as an absolute

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[30] Berlin I.: Two concepts of liberty. In Four essays on liberty, London: Oxford University Press, 1969, p. 118.

[31] It is an extremely important issue in the conducted deliberations. Zdzisława Piątek, for example, states directly: "Replacing anthropocentrism with biocentrism is a breakthrough in this field of philosophy, which concerns the relationship of the human species to nature". See Piątek Z.: Filozoficzne podłoże zrównoważonego rozwoju. Problemy Ekorozwoju: studia filozoficzno-sozologiczne, Vol. 2, No. 1, 2007, p. 14.

[32] See on this topic, e.g. Sierpowska I.: Bezpieczeństwo socjalne jako dobro publiczne. Zeszyty Naukowe Państwowej Wyższej Szkoły Zawodowej im. Witelona w Legnicy, Vol. 16, No. 3, 2015, pp. 45–58.

[33] Lipiec J.: Przyjaźń i prawda, 2009, p.335. Available online: https://ruj.uj.edu.pl/xmlui/bitstream/handle/item/151550/lipiec_przyjazn_i_prawda_2009.pdf?sequence=1&isAllowed=y (accessed on: 5 May 2022).

(universal) value is structurally linked to other values: good, justice and freedom[34]. It is also the foundation of both individual and social life based on the principles of peace and solidarity.

Justice, which is the subject of analyses dating back to the beginnings of European culture, is linked to the ideas of equality, human dignity and democracy[35]. The meaning of this concept was most often identified with the principle of the distribution of goods and social roles as well as the law of reciprocity referring to the rule of compensating for the harm. As such, it should become an essential element, first of all, of the social structure of a smart city, but also of the effective implementation of the goals set in this concept. In the social sphere, in modern countries, justice is expressed mainly in three areas: education, health care and social assistance. The full expression of the idea of justice would be, on the one hand, its application to the entire biosphere, on the other hand, in accordance with the guiding principle of sustainable development, building a fair social environment of a smart city, economic living conditions for its inhabitants and ensuring the optimal state of natural resources also for future generations (intergenerational justice).

The above-outlined proposal to build the axiological foundation of the smart city concept requires, of course, to be developed towards specific principles of the functioning of its various components. The values mentioned above, which constitute this concept, seem to be the best answer to the question about the shape of the value system on which the three basic elements of a smart city should be based: social, economic and environmental.

1.4. Summary

The concept of a smart city is a multidimensional idea. The project of building smart cities can be treated as an exemplification of the concept of urbanized areas sustainable development. This implies, inter alia, a thesis on the common axiological basis of smart city and sustainable development. Among many definitions of a smart city, some of them emphasize the importance of technological aspects of its development, while others

[34] Dołęga JM.: Systemy wartości w zrównoważonym rozwoju. Problemy Ekorozwoju: studia filozoficzno-sozologiczne, Vol. 2, No. 2, 2007, p. 47.

[35] Wróbel P.: Postulat sprawiedliwości społecznej a idea sprawiedliwości. Studia Socialia Cracoviensia, Vol. 5, No. 1, 2013, p. 135.

emphasize social issues[36]. Each of these approaches, however, presupposes an *implicit* or *explicitly* defined system of values.

Research conducted in various countries where smart city projects are implemented in different cultural, social, economic and geographical realities shows that there is a general tendency to be observed. It is expressed in the process of departing from material values towards post-material ones. The preferred values are influenced mostly by factors such as the level of religiosity and the degree of wealth. The geographical location is relatively insignificant. One can also notice the universal values mentioned by respondents living in various regions of the world. There is also a clear tendency to rank post-material values higher by younger respondents than by mature and older people. The most important conclusion from the research is the need to build civil societies within smart cities' communities. This can be done by increasing the residents' participation in matters related to the smart cities' management. The condition for this is, however, a higher position in the hierarchy of values relating to the political inhabitants' commitment. In my opinion, the authors of the aforementioned work rightly point out that technology must be involved in the smart city construction project, but it cannot be reduced to it. Its social and axiological dimension is an equally important issue.

So far, no single axiology of sustainable development of a smart city has been developed. Most of the proposals in this regard are aimed at taking into account the three orders that constitute this concept: social, economic (economic) and environmental (ecological). The differences concern the very choice of specific values, but also their mutual relations.

At the end of these considerations, the question arises about the effectiveness of axiology in shaping the social world in which, on the one hand, actions are taken on the basis of fundamental values, and on the other hand, actions non-compliant with these values are abandoned. According to the views of great ancient philosophers such as Socrates, Plato, Aristotle and the Stoics, the task of ethics (axiology) is to lead man to happiness, which they equate with a good life. It seems that over the centuries, the tasks assigned to ethics have changed significantly. Contemporary axiological theories abandoned the ambitious task of showing people paths to happiness through moral improvement long time ago[37]. Andrzej Papuziński notices, "they influence the reality by mobilizing people, that is making them adopt a specific attitude. They generally contain three components: a long-range autotelic goal, an instrumental goal, and the means to

[36] Pichlak M.: Inteligentne miasta w Polsce – rzeczywistość czy utopia?. Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie. Vol. 127, 2018, p. 194.

[37] It is pointed out by, for example, the outstanding Polish ethicist Maria Ossowska. See Ossowska M.: Podstawy nauki o moralności. Państwowe Wydawnictwo Naukowe, Warszawa 1957.

achieve this goal”[38]. The strength of this influence, in my opinion, depends largely on the choice of values, but also on their actual implementation in the planned and undertaken activities aimed at creating a symbiosis of the social world with the environment of which it is an integral part.

It seems that the optimal proposition of an axiological foundation on which a just social order of a smart city can be built, also taking into account its economic and environmental dimensions, is a return to the classic triad: good, truth, and beauty supplemented with the values of freedom and justice. These values have the status of ideals – constitutive values on which practical values are based.

[38] Papuziński A.: The Axiology of Sustainable Development: An Attempt at Typologization (Aksjologia zrównoważonego rozwoju: próba typologizacji). Problemy Ekorozwoju/Problems of Sustainable Development, Vol. 8, No. 1, 2013, p. 18.

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Waldemar CZAJKOWSKI[1]

2. ONTOLOGY OF (SMART) CITY AND ITS PRACTICAL RELEVANT INTRODUCTORY REMARKS

As the title of this text suggests (ontology is an important part of philosophy), it is philosophical in nature. It should be stressed that the word "philosophical" should be, in the present context, regarded as closely related to such phrases as "transdisciplinary approach" or "holistic perspective". – This declaration I would like to supplement with two general remarks that should help to characterize its type and goals. The first remark concerns globalization. This word is not only defined in many ways but also (what is much more important) referred to phenomena and processes of various sorts: civilizational, cultural, economic, political, social… Due to character of this text and its limited size, it is impossible to discuss, even very briefly, this conceptual and theoretical variety: I have to limit myself to presenting this interpretation of globalization[2] that is, as I believe, most useful at this place. It should be convenient to begin this presentation with mentioning two events that happened fifty years ago: In Stockholm, from June 5–16, 1972, the United Nations Conference on the Human Environment was held. This same year, the Club of Rome (established in 1968) issued the "Limits to Growth" report. Regardless of many debates and (scientific, ideological, political – often intermingled) controversies aroused by these two events, one thing seems beyond discussion: they contributed significantly to the development of global consciousness. Considerably (though still inadequately) has increased the number of those who are aware that whole humanity faces big problems (among them those related to climate changes seem to be most widely known) that can be solved only by our common, global actions. We are also more than decades ago (though also inadequately…) aware that our species together with all the artifacts we have produced is but a part of one global (encompassing the whole Earth, and particularly – the whole life-world) system.

[1] Silesian University of Technology, Department of Applied Social Sciences – Faculty of Organization and Management, Gliwice, e-mail: wczajkowski@polsl.pl.

[2] One of the best concise discussions of this concept contains Osterhammel: Osterhammel J.: Globalization. [In:] Bentley J.H. (ed.): The Oxford Handbook of World History. Oxford University Press, Oxford 2011, pp. 89–104.

Two simple but important (and strongly interrelated) facts should account for the relevance of the perspective I have just outlined for the issues that will be addressed in this essay: Firstly, the absolute and relative number of people living in the cities is still increasing and – in the coming decades – will be (even if slower than the previous one). Secondly, cities – though have fundamentally contributed to the progress which we have experienced in various domain of our life – have no less fundamentally contributed to the generating the big problems we have to cope with. The conclusion to these observations is simple: the successful solving of the global problems depends very much on the development of cities – smart, intelligent, wise.[3]

And now my second remark. Among popular (even: fashionable) labels used for characterizing "our times" (say, the last few decades) is the term "knowledge society". Its popularity certainly reflects important civilization (social etc.) changes that have occurred over the last decades. They might be briefly and concisely characterized as "great growth of knowledge production"; growth measured by numbers – of scientists, of academic institutions, of books and journals, of congresses and symposia… Even if not all "products" of science contribute significantly to the growth of our knowledge the overall development of our knowledge should be expected – due to "gaussian" statistical regularities. If we would produce knowledge "for its own sake" only, we could be very pleased. But if we take into account the simple fact that growth of "knowledge production" is strongly connected with more prosaic interests and motivations (manifested i.a. by an increase in states expenditures on science) than with the intellectual ethos of Plato or Aristotle, we will note some paradoxical aspects of this growth. This *problematique* would deserve separate, comprehensive analysis. Here, but few short notes will be made: First, the sheer number of "scientific products" results in difficulties for those who are exclusively (or mainly) interested in applications of (scientific) knowledge ("information noise"). Second, the various factors of the growth of "knowledge production" result in progressive diversification ("balkanization") of science[4]. Various attempts to counteract this process have been undertaken – with rather limited success. Let us look at the idea of interdisciplinarity (a catchword – more or less popular since 1970s). If it is something more than a slogan, it increases rather than decreases the number of disciplines (e.g. the rise of biochemistry did not result in disappearance of more "centrally" located biological or chemical/sub/disciplines; in humanities the same might be said about historical sociology or social psychology). But

[3] To develop this remark one should discuss the Barber's ideas on the increasing significant of the role played by mayors. Barber B.: If Mayors Ruled The World: Dysfunctional Nations, Rising Cities. Yale University Press, New Haven 2013.

[4] Interesting comments on these problems and some practical proposals how to solve tincreasing hem are presented in the philosophical book of great physicist Murray Gell-Mann: Gell-Mann M.: The Quark and The Jaguar: Adventures in The Simple and The Complex. Abacus, London 1995.

is the increasing diversification of sciences and specialization of scientists a serious practical problem? I do share the opinion that the answer to this question is definitely positive. Especially – in the time of globalization: in the epoch in which humanity, eco--sphere and techno-sphere are getting elements (sub-systems) of one socio-eco-techno--system[5] we need – more and more, and for very practical reasons – knowledge about the whole system and not only about its various sub-, sub-sub- etc., systems. It is obvious that the specialist knowledge is of fundamental importance. To avoid any misunderstanding, let me avail of analogy with geography/cartography: In most practical situations we need – if any – city plans; probably less often – regional and national maps, still less – those of continents. But even the map of the whole globe is useful not only for geographical education. It might be also noted that the practical importance of world maps has been increasing in correlation to the increase of the scope of various activities (political, military, trade etc.).

Now, I would like to draw some conclusions from these two remarks: Firstly, there is no doubt that – due to a large number of factors (from the number of city-dwellers to political and cultural role of cities) – the development of cities is a key element of the development of the global civilization. Therefore, the quality of the cities development (particularly: its smartness, its intelligent character) determines significantly the ways in which are and will be solved the global problems humanity faces today and will face in the coming future. Secondly, there is also no doubt that smart/intelligent development of cities must be knowledge-based (science-supported). Thirdly, if the development of cities is to be smart/intelligent, it must be (at least in the longer perspective) holistic/sustainable[6]. Fourthly, science-supported holistic/sustainable development presupposes holistic (comprehensive, complex, systematic…) knowledge about city. And here is the point: city has – for the last century or so – become an object of studies of various scientific – social, natural, engineering – disciplines. In virtually all cases specialized sub-disciplines have developed: sociology of cities[7] and urban anthropology, geography of cities and social ecology[8], urban (regional etc.) planning and urban

[5] One of the first who introduced the concept of techno-sphere, and of anthropo-technical and socio-technical system was J. Dietrych (1907-2001) – professor of Silesian University of Technology: Dietrych J. System i konstrukcja. Wyd. Naukowo-Techniczne, Warszawa 1983.

[6] The notion of sustainability (sustainable development etc.) has been a subject of many debates and controversies. A useful overview can be found in: Tainter J.A.: Understanding sustainability through history; resources and complexity. [In:] Caradonna J.L. (ed.): Routledge Handbook of the History of Sustainability. Routledge, London 2018, pp. 40–56). A discussion of the relations between sustainability and city development is presented in Zavestoski S.: Sustainability and the reframing of the world city. [In:] Caradonna J.L. (ed.): Routledge Handbook of the History of Sustainability. Routledge, London 2018, pp. 219–232.

[7] Jałowiecki B., Szczepański M.: Miasto i przestrzeń w perspektywie socjologicznej. Wyd. Naukowe Scholar, Warszawa 2006.

[8] Pióro Z.; Główne nurty ekologii społecznej. [In:] Pióro Z. (ed.) Przestrzeń i społeczeństwo. Z badań ekologii społecznej. KiW, Warszawa 1982, pp. 7–51.

economics. City has also been one of the main objects of the study of some wider disciplines such as energy or transport engineering. There is little doubt that this specialization has had many positive consequences. But, as I have tried to argument, we do need also (and not! – instead) holistic image of city.

Having accepted this thesis, one should consider the question: how to accomplish this task – how to construct such an image? Should we commence from systematic overview of the research results achieved by all the relevant disciplines? – Such a strategy seems to be impractical: it would take too much time. And the results may be doubtful: many ideas expressed in various theoretical languages, using different terminologies… For this reason, I have decided to look for a different strategy.

The strategy I have adopted might be called "top-down" approach and contrasted with the "down-top" one. This strategy might be succinctly characterized by analogy/comparison with mathematics: in contemporary (the 20th–21st century) mathematics one starts (most often though not always) from a most abstract theory (set theory), then passes to less abstract ones (algebra, topology) to come to mathematical analysis, probability etc. To apply this strategy to a domain oriented at studying cities – real-world objects, and not mathematic objects belonging to, let us say, an ideal world – it is risky. But risk is, I am profoundly convinced, unavoidable in any sphere of human activity. And science is not an exception to this rule.

And still a note: Any science – be natural, be social – is based on some elements of general, pre-scientific knowledge. One of the tasks of a scientific discipline beginning exploration of a domain of the world is to order and precise this pre-scientific knowledge. It should be stressed that that the relevance of this knowledge depends – to a considerable extent – on some ontological peculiarities of the given domain, and in particular – on its relative stability or instability: the physical order has been stable for millenia at least; basic elements of biological order have also remained unchanged. Contrarily, the social order: for the last ten thousand years or so, it has been changing – faster and faster, and more and more profoundly. And so it has been with the cities. Analyses – much wider than possible here – would be necessary if the evolution of the cities (since their beginning some seven/eight thousand years ago were to be studied. Thus, speaking about cities I think mainly about those which have existed for the last two centuries (or a few decades more) – since the beginning of the (first) industrial revolution.

As a name for the most abstract and general part of the trans- and multi-disciplinary theory of city, I have chosen the word "ontology"[9]. This choice is by no means incidental. On the contrary, it has rather profound motivation: First, this term designates

[9] This decision has been inspired by the ideas of the prominent Polish philosopher Roman Ingarden who stressed the ontological character of his studies on art: Ingarden R. Studia z estetyki. Vol. II. PWN, Warszawa 1966.

a very important part of philosophy. And, from the point of view I accept, philosophy has in the contemporary world an important role to play. Its task is to construct sciences--based world-view(s), and – in particular – to develop language enabling "synthesizing" the main ideas/results of physics and psychology, of biology and sociology etc. into one world-view. (The two initial remarks should make clear why I regard this task of philosophy as important.) Second, various parts of ontology (sometime called "regional ontologies") try to answer two fundamental questions: (1) What is the "essence" of, say, man (or living organism, architectural work of art, society…)? (2) What is the (fundamental) structure of the given type of objects?

Having made the above remarks, I have outlined the main ideas which motivated and directed my work on this text. Now, at the very end of this section, I would like to present the structure of this text.

The next (second) section will be devoted to the ontology of cities – in the possibly broad sense of the last word. This decision assumes that something both interesting and general can be said about, say, ancient Athens, medieval Baghdad, early modern Cracow, 19th century Tokyo, 20th century New York, 21st century Shanghai, also about contemporary Zakopane or Gliwice, and about thousands other places on the Earth which existed and disappear or still exist. The third chapter will be more future--oriented, thus more "speculative": I think that the term "smart city" only to a limited degree can be referred to the cities as they exist to-day, and much more to the cities as they will probably/hopefully exist in the future. In both these sections I will regard city as "stable" object (i.e. consciously abstracting from its dynamics). In the subsequent (fourth) section the concept of development – applied to city – will be discussed. The concept of smart/intelligent development will be introduced and its relations with that of smart city will be discussed. The last (fifth) section will contain final remarks: I will summarize the results of the discussions in this text and present vistas on future researches.

2.1. Ontology of city

2.1.1. Some remarks on the notion of city

Some readers might expect at this place a definition of city. Unfortunately, I am not going either to quote one or to offer my own. This decision is a consequence of my very general methodological conviction: I believe that definition – in the precise, strict sense of this word – can be formulated only in the context of a theoretical (in particular:

conceptual) system. Avoiding rather long methodological/logical considerations – completely unnecessary here, let me suggest you considering a standard geometric definition (e.g of circle or cube) or a physical one (e.g. acceleration) – model instances of definitions.

To my knowledge, no such system exists. What are we to do then? I think that two complementary ways can be taken. First, we can use a method which is sometime called "ostensive" ("deictic") definition. The word "definition" – if used as a part of the phrase "ostensive definition" – refers to a complex (both nonverbal and verbal) behavior. Such definition we use while teaching a child some simple words: we show him/her an object and say "This is a fork (spoon, pen etc.)". We can "define" city by saying: London is a city but also, say, Zamość, Mexico City etc. (I assume as obvious that one knows a certain number of cities.) And second, we can indicate a certain number of other notions which are related to that of city. I think that the list of such notions should contain at least the following items: (social) space, territory, building, people, inhabiting… So much for now.

Being convinced that even without a formal ("scientific") definition, we know quite well what city is, and we know enough different cities, I am going to pass now to the analysis of the structural analysis of city. It will be divided into two steps. In the first – I will analyze city "from inside"; as a complex object, composed of various "strata", elements etc. In the second – I will look at city "from outside": as an element of larger systems, networks etc.

2.1.2. City as a complex system

So, let us look at city as a complex object. What kind of object is city? Figuratively speaking (and suggesting an analogy with some medieval ideas[10]), one might say that city is object of the same sort as the global system but "in miniature": it is a socio-eco--techno-system but – much smaller (compare Tokyo – the biggest city /ca.40 / with the planet population /ca. 8bln/). Having noted this structural analogy, one could ask the question about existence of systems of this kind – other than global system and cities. It seems to me that the answer is negative but the issue requires further analysis. Regardless of how large (and internally differentiated) is the class of systems of this type, one issue is beyond all discussion: the very essence of such systems demands close and strong cooperation between social, biological and engineering sciences in order to develop a comprehensive theory of such systems.

[10] The whole world was interpreter as macro-cosmos, and man – as micro-cosmos.

In the next step I would like to offer a somewhat modified and more subtle/detailed model of city. While constructing it, I will be using some ideas developed by the great French historian Fernand Braudel (1902–1985) and by the world-wide known Polish philosopher Roman Ingarden (1893–1970). At the first sight their areas of interest appear very different: Braudel is speaking about natural environment, civilizations, everyday life[11]…, Ingarden is analyzing the structure of literary, musical, architectural…works of arts. But if to look at these ideas from a still broader perspective, best – from that of the prominent German ontologist Nicolai Hartmann (1882-1950), we should note, rather easily, their formal/structural similarity. This similarity can be characterized by a single (adopted from geology) term: stratum (layer).

Now, let us briefly present the ideas grouped under the umbrella of this term. First, in some objects, say – in a painting, we can distinguish (analytically!, in a standard esthetical situation we perceive the painting as a unite whole) a certain number of strata (say – in the case of a realistic painting, e.g. – to focus our attention – in Matejko's "Battle of Grunwald" – the "purely material" stratum /i.e. the cloth and paint lumps/, the visual stratum /i.e. color spots, lines etc./, the stratum of objects /i.e. people, horses, weapons, elements of landscape etc./, the narrative structure /i.e. a pedestrian soldier is attacking a Teutonic knight/, the interpretive stratum /i.e. the Teutonic knight interpreted as Ulrich von Jungingen/, the symbolic stratum – say a vision of the history of Poland, its relations with Lithuania and Germany etc./). Second, the order in which the strata have been presented is not incidental; on the contrary, it reflects important ontological relations between the strata: the subsequent stratum can exist based on the previous one (note that this relation is transitive). Third, each of those strata is of different ontological character (physical, perceptual,…, "historiosophical") ; thus, each of them has to be analyzed with the help of different kinds of knowledge/science. Fourth, the character of the object depends not on the "lower" strata but on the "upper" ones; in the case of the painting: it is a work of art due to its "content" and artist "form", and not – due to its material foundation (though – without it – it could not exist).

As the Reader might have guessed, the above discussion was intended as a conceptual introduction to the following thesis: city is a multi-strata object. My next task is to describe the strata structure of city.

Any city is a part of the surface of the Earth, in other words – a territory[12]. The various traits of the territory are of importance[13]: First, the shape of the territory: flat or

[11] Braudel demonstrated his ideas in his own historical practice rather than presents them in an abstract form. His great work devoted to the history of the "Mediterranean world" in the 16th century – a work which starts from the geology and ecology of the region and ends with military and diplomatic events – is the best presentation of his ontology. Cf. Braudel (7) Reader interested in a short summary of his view should consult Braudel (6).

[12] The concept territory should be discussed in the context of the much more general notion of space. On its significance for architecture and urban planning cf. Szmidt (49).

mountainous (or various combinations of these two "extremal" types). Second – its "geometrical shape": circular, linear, irregular…Third, the location of the given territory on the planet: its distance from the Equator (or, to put it alternatively, from the poles), also from the oceans and seas; somewhat differently put – its location in a climatic zone.

The next stratum could be described as material/artefactual[14] one. In most cities (even in some Ancient ones, not to say about contemporary Tokyo or New York or other metropolises), this stratum is very complex. Its systematic and possibly complete description might be a subject of a separate paper. Here, I can propose but a tentative and simplified attempt at such a description. Starting from two – complementary – perspectives (on one hand: historical – based on the evolution of cities, on the other: phenomenological – based on everyday experience) we could say that various buildings (considered here just as "purely" material objects) are the main part of the material/artefactual stratum. "Empty" space – a complementation of built-up space – should be regarded as a special part of this stratum. If we assume that the word "empty" is used here not in an absolute (quasi-Democritean) sense, but as a short equivalent for "not build-up" , then we can say that roads, sidewalks, parks and gardens are elements of – so understood – "empty" space. (It should be stressed that trees, flowers, grass etc. – are its elements.) Last but – by no means – least, infrastructure. First: water. Second: energy. Third: sewage system. Fourth: transport. And fifth (most recent, but particularly important in the context of the idea of smart cities): control and information system.

Ending (or stopping) at this very moment we could speak about "dead cities" only. But genuine cities are living cities. And living cities are cities in which live people. Saying this, we pass to social ontology (a border area between philosophy and sociology). Perhaps it is an area no more complex than that encompassing two previously discussed strata but surely – much more controversial. Trying to avoid too far-reaching philosophical/sociological debates, I suggest using (at least temporarily) a model which will allow us about only three social strata of city. The first one is composed of human individuals (of women and men, of children and adults etc.). The second – of human actions (of all types: from resting – in this or that form – to working). And the third – of relations between humans and between their actions[15] (in other words: of networks connecting both humans and their actions). The notion of the third stratum demands a few commenting words: One might suppose that limiting myself only to relations between humans and their actions and giving up speaking about families, parishes, schools, offices, etc., I have omitted a very important part of social reality. But it is

[13] On territory in a historical perspective cf. Lewis (31).
[14] On artefacts in a philosophical perspective cf. Thomasson (51).
[15] Janik's book (22) on Vienna contains very interesting and instructive concrete analyses of such relations.

not so. This (rather apparent than real) omission is a consequence of the fact that I have accepted the idea that social groups, organizations and institutions can be regarded simply as special (relatively durable and relatively well defined) relations between humans/actions. It seems necessary, while speaking about this stratum, to stress the existence of a special type of human actions and special type of organizations/institutions oriented at city – at its re-construction/transformation. (More on this issue will be said in the chapter 4.).

Having introduced the strata encompassing humans (their actions, and their relations) we should return to the sphere of material objects. City can be viewed also as a great "container" of countlessly many things used by humans in course of all their actions. The spectrum of these objects extends from food and tools to its preservation and consumption, through clothes and furniture, work and play instruments, to learning and worshiping devices. – It might be discussed whether this sphere should be regarded as a part of the material/artefactual stratum or as a separate stratum. At this moment of my work I want to remain this question open.

And now I would like to discuss the issues related to the viewing city as – to use a philosophical jargon – an intentional object. Without delving into some philosophical problems – too distant from the issues tackled in this text, I will characterize the meaning of this concept by referring to an example – to the concept of painting work of art (see above the remarks on the "Battle of Grunwald"). On one hand, it is a physical object (cloth, paints etc.) On the other, it contains some content. And this content has be grasped, understood, interpreted… And understanding/interpretation of any meaningful object is impossible without someone who performs these mental actions. Formulating it in somewhat different way, we could say that a painted cloth, if kept in a museum warehouse, is a work of art only potentially, and is getting an actual work if viewed by visitors.

Let us commence with buildings. Obviously, they are – as already stressed – material objects which can be characterized by various physical parameters, of which many are of great significance from human/practical point of view (say, fire – or other – safety). But some buildings are – also – architectural works of arts[16]. Let us think about various monuments – some of them are masterpieces of sculpture; also – about "purely" artistic sculptures, including – recently – quite fashionable "artistic benches". All these objects, however differentiated, have one trait in common: they can be regarded as individual objects. It might be claimed that all such objects constitute a stratum of the city in which they are located.

[16] Some Ingarden's considerations (according to many specialists: of classic significance) are devoted just to architectural works of art. Cf. Ingarden (20) and also – Illes, Ray (19).

And now, let us shift our attention to – among others – gardens and parks. Some of them are counted – and, I believe, rightly so – as works of art. But – works of art of a special kind. They can be regarded – at least at some cases – as "second order" (i.e. composed of "first order" works – e.g. of individual sculptures; some exhibitions consisting of paintings, sculptures etc. – e.g. "Poles' Self-portrait"[17]) works. – The issues that arise here would deserve a separate and extensive discussion (based upon analyses of numerous and variegated instances). Such a discussion is not possible here. I have to limit myself to making a few short comments. Firstly: The important role played by the "empty" spaces of the city is to be noted (an interesting analogy with the role of silence in music). Secondly: the role of various panoramas – both "internal" (of particularly interesting/valuable parts of the given city) and "external" (of the natural surrounding of the city). Thirdly: the spatial (geometrical etc.) structure of the city – perhaps the most important element allowing us to regard the whole city as a single "high order" work of art.[18]

Still another stratum should be, as I suppose, distinguished. A stratum which also – like that just discussed above - consists of some intentional objects. What is the reason to distinguish it? – Should not we speak about one intentional stratum? My answer is: We should not. Why? – I suggest to start with analysis of an instance: Think about a part of the Berlin Wall. Nobody would call it "work of art". Also, almost for sure, nobody would ascribe to it a (positive) esthetical value. But, the block of concrete – especially if located in its "historically proper" place – has a historical (emotional, cognitive…) value. To make this object – or any similar – more "nice" would result in depriving it its historical value. Even some "empty" places can posses a value of this type and, according to the opinion I share, should remain undeveloped.[19]

I would like to end this sketchy discussion of the strata-structure of city with a few notes on two strata that can be regarded as composed of intentional objects – if this concept is used in a very broad (and weak) sense. One of them might be defined as "audio-space", the other as "odor-space". The objects of these two spaces might be regarded as intentional if this term is to direct our attention toward their double – objective/subjective – character.

So much as for city viewed "from inside" – as a complex multi-strata object. Now, let us pass to city seen "from outside" – as a "point" (node, vertex) of some networks.

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[17] A great exhibition in the National Museum in Cracow (1979).

[18] Remarks on the so-called Royal Track in Varsow might add some concretness to these considerations. Cf. Szmidt (49) More on these issues in Eco (10) and Porębski (43), These theoretical considerations can be supplemented by a very interesting book on Gdańsk (and is cultural/symbolic strata) – Cf. Bossak-Herbst (5).

[19] Still another type of, let's call it, symbolic stratum, discusses Kowalski (26) He also analyses this issue in the legal context of intellectual property rights.

2.1.3. City a node of networks

The most basic idea of this part of the ontology of city which analyses city as a node of networks is expressed in the plural form of the last noun: City is not a node of a single network – contrarily: it is node of number (rather large than small) of networks. Introducing the notion of centrality (and – correspondingly – of peripherality) we can say that one and the same city can be a central node in a network (say, transport one) and a peripheral one in another (say, administrative one). This plain and rather obvious remark confirms a simple but important methodological observation: ontology of city must draw from ontology of social space (of which is a part).

Let us try to characterize a certain number of networks of which cities are nodes. Cities (like villages) are territories. No (small) territory is self-sufficient[20]. Thus, any city (and today even any village) has to be connected with other territories: matter, energy and information must flow into and out of it. Therefore, city must be a node in a road and/or rail and/or air-line network. Also – of power grid and of radio/TV/internet networks.

The transport/communication networks form the material basis for social networks of exchange. Numerous factors determine the directions, scale, and forms of exchange (in a very broad sense of the word: voluntary or involuntary, equal or inequal, barter or money-mediated).

The transport/communication networks deliver also the material fundamentals for political/administrative networks. Networks of this type provide well-known and very clear (at least in comparison with some other types of network) examples of hierarchies ordering the nodes: a city is the capital – of a state, of a region (Land, voivodship etc.), of a sub-region (Kreis, county) etc. The fundamental role is also these that two types of networks (transport and communication) play also for culture – broadly understood: as patterns and styles of human behavior (from eating and sex, through recreational activities to morality, attitudes toward death etc.) To a considerable degree, one can speak about the process of cultural diffusion (from more central to more peripheral nodes) but more complex mechanisms can be also observed, for instance increase of traditionalism as reaction to abrupt and too far-reaching cultural changes.[21] At the end of this point, let us formulate a question being a variant of a much more general one –

[20] I formulate this thesis in a simplistic way. The concept of self-sufficiency is both difficult and important; particularly today: in the time of globalization. But a systematic analysis of this problem is a subject for another text.

[21] On the territory/geographical aspect of innovations (their diffusion): Asheim B., Gertler M.S.: The Geography of Innovation; Regional Innovation Systems. [In:] Fagerberg J., Mowery D.C., Nelson R.R. (eds.): The Oxford Handbook of Innovation, 2005, pp. 291–311.

a question about autonomy: of individual, of nation/state, and – of city. Is it possible (to what degree) that cities would autonomously determine their futures? A partial and tentative answer will be given at the end of the next section.

2.2. Ontology of smart city

2.2.1. City as a "living" system

At the beginning of this section I will formulate some remarks – of a relevance .to both the present and the next ones. In the previous section, I have stressed that genuine city is "living" one. It is a metaphor. But this metaphor is to suggest some analogies between city – viewed as a complex system – and living (organic) systems[22]. Let us list them and characterize them briefly.

First, both cities and living systems are dynamical systems: various movements of their parts (changes of their internal and external relations) are not incidental but are of fundamental importance for them – their "essence" depends on these movements/ changes. Second, these movements/changes (the word "processes" can be conveniently used for sequences of them) can be grouped into two classes: periodical (e.g. circulation of blood in organism, circulation of electric energy in city) and directional (e.g. spatial growth of the organism/city)[23]. The processes of types are interlinked in various ways but studying these links presupposes their analytical distinction. Third: virtually all living (both in the literally and metaphorical sense of this word) systems contain sub-systems that regulate processes – ongoing both inside the systems and between them and their environments.

These analogies suggest two complementary theses. According to the first one, all cities are – in a sense – smart cities: all cities (also villages) have regulative sub-systems of this or that sort. But, and this the second thesis, it is neither incidental nor unimportant that the concept of "smart city" has recently been gaining popularity. Following Herbert Spencer (1820-1903) and many his continuators, we can use the term "evolution" in a very general sense and apply it to very different processes – in particular: to the development of cities. Use of this term – and some analogies it suggests – should help us to understand some elements of the development of cities. Think about biological

[22] I use here some ideas of Rosnay J.: Le macroscope. Vers une vision globale. Ed. Du Seuil, Paris 1982. He speaks for instance about "metabolism of city".

[23] These formulations are – as in many other places of this text – of schematic character. In a more elaborate text we should (and could) speak about, say, degrees of periodicity/directionality.

regulative sub-systems. Even the simplest organisms (e.g. bacteria) have them. But the birth of vertebrates, then – of special sort of them: mammals, and – of special kind of mammals: humans – and all these important transformations in the history of life have been strictly connected with the development of nervous systems. Being aware of the importance of the all previous "turning points" in the evolution of biological regulative systems, we have no reason to underestimate the profoundness of this transformation that resulted in the development of human brain/mind and in result – in the development of human culture (technology, art, religion, science, law…). Using this analogy, we could say that the we live in a period of a very profound transformation in the millenia-long history of cities – perhaps the most profound, to be compared only with the very rise of cities. And just this transformation has found its manifestation in the phrase "smart city".

And the last introductory comment. In this section, I am going to analyze in some detail the (actual and possible) traits of smart cities as "stable" units (in which all processes are of periodic character); I regard the issue of city (smart) development as particularly important, and for this reason, I have decided to devote to it a separate chapter.

2.2.2. City as (self-)regulated system

Let us start sketching ontology of smart city from presentation of the simplest abstract model of regulation. According to it, we have to distinguish two elements: object of regulation (briefly: object) and subject of regulation (briefly: regulator). These elements are connected by at least one relation (or, to be more precise, a set of relations of a type); this relation can be denoted with the word "power". Such a relation exists if regulator is able to influence some states (parameters) of the object. However, assuming additionally (rejecting some "pathological" – in the human world – situations) that the regulation is an intentional/rational activity, we must add some elements to our model. First, a cognitive relation. Regulator has to have some general knowledge about the object[24] – about some its parameters; it also has to have some detailed knowledge – about the values[25] these parameters assume at the given period/moment of time. It has to have also some self--knowledge: about its possibilities to exert some influence on the object (about the scope of its power over it). Regulator must be also equipped with some criteria of choice

[24] On the problem of relations between power and knowledge Fricker M.: Rational Authority and Social Power. [In:] Goldman A.I., Whitcomb D. (eds.): Social Epistemology: Essential Readings. Oxford University Press, Oxford 2011, pp. 54–70; Goldman A.I.: A Guide to Social Epistemology. [In:] Goldman A.I., Whitcomb D. (eds.) Social Epistemology: Essential Readings. Oxford University Press, Oxford 2011, pp. 11–37.

[25] The word "value" is used here as in mathematics (a number is the value of a function at a given point) and not as in humanities (the esthetic value of a painting).

(relations of preference) between alternative possible values of manipulable/steerable parameters. This model presents what might be regarded as the "essence" of regulation. But for its applications to most practically interesting situations, it must be supplemented by two elements: a set of cognitive instruments and a set of instruments of power; without these instruments establishing the respective relations would be (very) difficult or even impossible. So much about the abstract model. Let us try to apply it to city.

City will be regarded here as object of regulation. The considerations presented in the previous chapters demonstrate that city is complex multi-strata system. Each of its sub-systems is characterized by a large number of parameters. It can be assumed that the respective numbers tend to increase. However, taking into account the very fast progress of computer and other electronic systems, we can assume that regulation of the material stratum – however difficult today – will be, slower or faster, progressing. Much more difficult seem to be the problems connected with the human/social strata. To some extent, they are connected with the processes of globalization: with massive translocation of many industries (think for instance about the situation Detroit faced in 2013 when it had to declare bankruptcy) or with migrations (think about Marseille or Paris, recently – Stockholm). Individual cities have little influence on these processes.

Now, let us pass to the concept of regulator. Who is the regulator of a city? This question should not be decided just by adopting one definition or another. Also reference to the legal/constitutional system should not be accepted[26]. The answers should be formulated as scientific hypotheses supported (as always only in a measure) by empirical research (in some cases: very difficult since certain members of the regulator can be very interested in concealing their membership in this group). It is obvious that the answers concerning Mexico City or Gliwice, Kopenhagen or Damascus… will be very different – not only personally (what is obvious) but also, so to say, structurally. It might be worth noting that the spectrum of possible answers extends between "dictatorship" (one person) and "perfect democracy" (all dwellers); it obvious that real situations can be located somewhere in-between these two rather purely logical possibilities. At this moment, I have indicated a field that deserves repeated sociological studies (social reality is constantly changing thus the similar problems have to be re-examined over and over again) – a large book might be written. Thus, I have to limit myself to a few general remarks. First, let us note that regulator is just a group of people (let us call them individual regulators). Second, this group can be divided in various ways (e.g. on the basis of material or nonmaterial resources, or – of spheres of interests etc.) into sub--groups. Third, the criteria of regulation can be more or less contradictory. Four, contradictory interests of groups of approximately equal force may result in a "paralysis" of some city sub-systems.

[26] We should avoid confusing description (of what is) with prescription (of what should be).

The effective city-regulation presupposes many factors. In the present context of two should be mentioned. First: transparency. Second: the culture of negotiations and compromise[27]. Both very difficult to be achieved. But both so important that even a small step bringing the achievements of these goals closer should be appreciated.

In the next step, let us assume that (all or some) individual regulators are a coherent (common interests and moral and other values) group. Even such a situation does not guarantee that their regulative activity will be coherent. The cognitive factors have to be taken into account. First, the general knowledge. At this moment we should return for a while to issues mentioned in the first section. There, I have emphasized the practical relevance of the ontological perspective outlined in this text. And now that claim can be additionally supported: our perception of the world (any part of it, e.g. of a city) depends on many factors, among them – on professional education. Therefore, even if we share moral values and political opinions, our perception not only of the whole Universe (national history etc.) but even of the city, in which we live cannot be identical. A holistic view on city – delivered by ontology – should facilitate (be the modesty of this word stressed) looking for a common integrated view on this very city in which we live and whose problems we are trying to solve.

Last but not least: we could say that ontology is important from the point of view of the role played by the general knowledge about cities (saying alternatively: from the point of view of questions "addressed" to a city). As regards the detailed knowledge – that concerning the given city (saying alternatively: from the point of view of answers "obtained" from the city), this depends, on one hand, on the computer/Internet based system of information about city, but – on the other – on the reliability of data. Data on material strata can be (assume optimistically) introduced to the information system automatically. But data on human/social strata must be introduced by humans. One of the fundamental concepts (and problems) of sociology appears here: trust.[28]

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[27] At this moment I would like at least to mention the concept of deliberative democracy – democracy not limited to (otherwise very important institution of) free election democracy in which debate and negotiations play important role. For such a democracy important role may play social epistemology. Goldman A.I.: A Guide to Social Epistemology. [In:] Goldman A.I., Whitcomb D. (eds.) Social Epistemology: Essential Readings. Oxford University Press, Oxford 2011, pp. 11–37. The importance of democratic procedures and culture manifests itself better if the phenomenon of conflict is taken into account. On its application in the context of urban planning: Goldman A.I.: A Guide to Social Epistemology. [In:] Goldman A.I., Whitcomb D. (eds.) Social Epistemology: Essential Readings. Oxford University Press, Oxford 2011, pp. 11–37. On the possible roles IT can play in development of democracy: Noveck B.S.: Wiki Government. How Technology Can Make Government Better, Democracy Stronger, And Citizens More Powerful. Brooking Institution Press, Washington D.C 2009.

[28] Lackey J.: Testimony: Acquiring Knowledge from Others. [In:] Goldman A.I., Whitcomb D. (eds.): Social Epistemology: Essential Readings. Oxford University Press, Oxford 2011, pp. 71–91.

2.3. Development of (smart) city

2.3.1. Cities as dynamical/evolving systems

Cities are dynamical systems. Though real processes ongoing in the cities are complex and differentiated, it is convenient – as suggested in the previous chapter – to divide them into two groups. The first one contains periodic (or *quasi*-periodic) processes, the second = directional processes. Periodical processes were discussed in the previous section. In the present section my focus will be on directional processes.

For brevity but – first of all – to suggest some intuitions, the word "development" will be used as a synonym for "directional process".

Before starting discussion of (smart) city development I will make a few remarks on the general notion of development. Firstly, it is used in many domains: in economy and psychology, in biology and sociology… Secondly, growth of an object (of GDP per capita, of individual organism, of number of members of an organization, etc. etc.) could be regarded as the simplest instance of development. Thirdly, as "genuine" development are regarded processes of qualitative (and not only quantitative) changes[29]. This formulation would deserve a longer debate – impossible here. I limit myself to indicating the relevance of the category of innovation[30] and to invoking some close/related adjectives (used to characterize some changes) such as "profound", "essential", "important", "structural"… Taken together with the opposition "qualitative – quantitative" they should create intuitions allowing to grasp the meaning of the term "development' – without using a formal definition.

Let us continue for a while the discussion of the general (ontological) notion of development. In a schematic way, we can distinguish two types of development: spontaneous (not regulated, not planned) and planned (not spontaneous, regulated). You can easily see that economic both economic development and improvement of an individual's language competence can be spontaneous or planned, both the growth of an organization and solving of some scientific problems…

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[29] At this point a reference to the (at the first sight: academic, but in fact – ideological and political) debates on the difference between economic growth and economic development. These concepts, most often applied to states, can be undoubtedly used in the case of cities: Bornstein D.: How To Change The World: Social Entrepreneurs and The Power of New Ideas. Oxford University Press, Oxford 2007; Edquist Ch.: Systems of Innovations: Perspectives and Challenges. [In:] Fagerberg J., Mowery D.C., Nelson R.R. (eds.): The Oxford Handbook of Innovation, pp. 181–208.

[30] Among various types of innovations one should direct one's attention to the notion of organizational innovation. Lam A.: Organizational Innovation. [In:] Fagerberg J., Mowery D.C., Nelson R.R. (eds.): The Oxford Handbook of Innovation, pp. 115–147; Osborne D., Gaebler T.: Reinventing Government. How The Entrepreneurial Spirit Is Transforming The Private Sector. Penguin, London 1992.

In the present point I am going to concentrate on the spontaneous development of cities[31]. The planned development will be discussed in the next section.

The development of cities has undoubtedly been associated with the demographic processes and especially with the growth of population. In this context two interrelated facts should be mentioned: First: the growth of population was for a long time very slow (the size of world population is estimated for 16th century at 0.5 billion and the threshold of 1 billion was trespassed about 1820). Second: until the first industrial revolution (ca. 1760–1840) virtually all societies were agricultural with 80–90% of population living in villages. Since this revolution both the absolute and relative size of urban population has been increasing. This demographical process started the territorial expansion of the cities. Among other factors, it was supported by the gradual liquidation of city walls (resulting from some military and political developments).

Fundamental role has also been played by the accelerated development of technology. Two domains should be mentioned at least here: that of – both public and private – transportation (note the important role played by bicycle – a relatively simple invention), and that of energy – the great and differentiated role.

So much about the development of the material stratum of cities. Now, let us say some words about their human/social stratum. Before the industrial revolution cities were inhabited mainly by merchants and artisans. In the 19th century, cities started to become places in which were concentrated two new great and important social groups: working class (or, more broadly, proletariat – comprising those working in services) and "white collars" (from intellectuals to petty clerks). Cities (especially great ones) have become territories on which develop various more or less formal organizations co-creating civil society.

And the third group of strata, let us call it shortly – cultural. Artistic aesthetic values of buildings and their complexes were appreciated even in ancient times, thus little is to be added here. But there are social/cultural phenomena – not identical but very close to the artistic ones. I think here about cultural property or monuments but also about cemeteries (Arlington, Pere Lachaise…) or even ruins (Hiroshima Peace Memorial)… These strata has been developing since the end of 18th century. This development has been to a large degree determined by a complex of processes that might be summarily called "discovery of History/Past" – processes connected, among others, with the development of nationalisms of which historical memory was/is an important part.

[31] One of the best discussions of the interactions between development of cities (in Europe) and other macro-processes – in the long perspective (990–1992): Tilly Ch.: Coercion, Capital, and European States. Blackwell, Cambridge (Mass.) 1992.

Summarily, the development of cities has mainly been an effect of various pressures and emerging possibilities to react to them. But approximately at the same time (in 19th century) ideas of planned development of cities begun to come into existence. This process become intensified in the 20th century, and precisely to this issue, I will now turn.

2.3.2. The idea of "Smart City" in a historical perspective

As we remember, the industrial revolution that profoundly influenced the development of cities began in the second half of 18th century. It was also a period in which the Enlightenment ideas were gaining wide popularity in almost all of Europe. Of course, the Enlightenment was a very complex (even contradictory) phenomenon. However, if we want to indicate its most central and important idea, we should – I believe – invoke the concept of progress. This concept groups a number of more specific ideas; among them – the idea of conscious, intentional construction of social reality. This idea concretized in many ways and inspired various practical city/urban activities[32] (such as those of R. Owen). It also inspired different concepts for urban development. Let us mention some of those that have been implemented. We can start from Ebenezer Howard's idea of garden city (Wetwyn, UK; Nowa Huta, Poland…) through those of Le Corbusier ("Cite radieuse", Marseille), Karl Ehn (Vienna's municipal housing), Oscar Niemeyer's Brasilia, to Auroville – inspired by Mirra Alfassa and designed by Roger Anger.

The rise of the idea (ideas) of Smart City is, I think, to be viewed best in the perspective briefly sketched above.

The name "Smart City" has its predecessors: "Wired Cities" and "Intelligent Cities". The first term seems to have lost its popularity. The second is still in use; for instance, this year (2022) in November, intelligent Cities Exhibition and Conference will be held in Cairo.

Individual decisions of some city authorities (Los Angeles, Singapore) are regarded as first steps towards smart city, but dynamic development of the idea and practice of smart city started at the beginning of the 21st century. A large paper might be devoted to a systematic description of this development. Therefore, but a few sample information will be provided here. A few completely new cities – designed as smart cities – have been built. Perhaps most famous is Masdar (Abu Dabi, United Arab Emirates) – built in

[32] A very interesting analysis of the relations between social, cultural etc. processes and the development of urban ideologies and practices contains Wujek: Wujek J.: Mity i utopie architektury XX wieku. Wyd. Arkady, Warszawa 1986.

the years 2006–2010 Interestingly, the project has been supported by both the US government and Greenpeace. Some already existing cities have applied for official recognition as smart city. It is possible due to the establishing the international norm ISO 37120[33] (first edition 2014, second – 2018). It is also very interesting that almost from the very outset of the process of development of smart cities, this process has been accompanied by various organizational initiatives of international character. To mention initiative Smart Cities Council (established in 2012). The ten years or so that have passed since the beginning of their activities is perhaps too short period to formulate overbearing opinions. On the other hand, today, having observed the rapid development during the post-war decades, we have become aware of various pathologies characterizing international organizations (from UN to sport federations). Is it possible that organizations supporting smart development of cities will be smart too.

A few words should also be said about the role of sciences and academia in the development of smart cities. In this moment, a few institutions active on this field exist. Among them, the MIT Smart Cities Lab seems to be most concentrated on these issues.

In 2018, Institution of Engineering and Technology (UK) launched the "Smart City" Journal.

Ending this part of these considerations, I would like to say some words about an interesting fact: Analyzing the relatively short period of the development of smart cities, some experts have distinguished three types of smart cities (or three phases of their development). According to contemporary habits, one says about City 1.0, City 2.0, and City 3.0:

The City 1.0 is one in which information technologies are used to regulate material infrastructure of the city (transportation, energy etc.).

The term "City 2.0" is applied to those cities which widely use IT to collect various types information about cities and to use them to city governance.

The notion of City 3.0. refers to those cities which enlarge using IT to various forms of social (including political) life.

Using the ontological analyses presented in the previous sections, one could say that one can note a trend toward interpreting the second part of the phrase "smart city" (i.e. the word "city") in more and more comprehensive way (i.e. encompassing all strata and sub-systems of city): as a human community availing for its development sophisticated technologies.

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[33] Midor K., Płaza G.: Norma ISO 37120 – nowe narzędzie do oceny i porównania inteligentnych miast. [In:] Jonek-Kowalska I., Kaźmierczak J.(eds.): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 189–202. According to this paper, three Polish cities (Gdynia, Warszawa, Kielce) have received certificates.

2.4. Final remarks

Let me commence these final remarks with re-invoking a widely accepted thesis: The process of urbanization will be continued – for a few decades at least. More and more people will live in cities. More and more cities will become megacities. – If so, solving the global problems, facing the global challenges, achieving the global goals (grouped under the one-word slogan "sustainability") – all this depends to a great and ever greater extent on the development of the cities.

And cities are becoming more and more complex[34]. Thus, steering their development is getting more and more difficult. And possibly effective steering should be knowledge-based (it is a necessary condition, by no means – a sufficient one). Based – on what knowledge? The shortest answer: both on practical (drawing from personal experience) and theoretical/academic (drawing from books, seminars, lectures etc.) knowledge; their complementarity should be emphasized. [35]

A note on the role of IT in the distribution of practical knowledge[36]. First: its role in building world-wide network(s) of mayors (deputy mayors etc.), activists of city movements etc. – network(s) enabling exchange of the practical knowledge. Second: its role in "objectivization" of the practical knowledge in the form of permanently accessible (and supplemented) knowledge bases. Incidentally, quite a dose of academic knowledge is necessary to design such bases.

And now, a few words on academic knowledge[37]. The great part of such knowledge exists in the verbal form ("great part" – since we are today aware of the role of so-called "tacit knowledge"[38]) – in the form of (sets of) theorems, hypotheses etc. These linguistic

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[34] On the relations between theory of complexity and that of smart city: Kowalska-Styczeń, A.: Badanie złożonych zjawisk społecznych w kontekście inteligentnego miasta. [In:] Jonek-Kowalska I., Kaźmierczak J. (eds.): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 137–147. More generally and complexity Mainzer K. Thinking in Complexity. The Computational Dynamics of Matter, Mind, and Mankind. Springer, Berlin 2004; Gell-Mann M.: The Quark and The Jaguar: Adventures in The Simple and The Complex. Abacus, London 1995.

[35] This distinction is also of schematic/instrumental character. Systematization of practical knowledge is one of the tasks of academic knowledge. As am interesting instance of such studies can serve the book of Kurowski: Kurowski S.: Warszawa na tle stolic Europy. Wyd. KUL, Lublin 1987. More generally on these relations: Kuzior A.: Zastosowanie Modelu Quintuple Helix w projektowaniu Smart Sustainable City. [In:] Jonek-Kowalska I., Kaźmierczak J.(eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 15–26.

[36] Brey Ph., Hartz Soraker J.: Philosophy of Computing and Information Technology. [In:] Meijers A. (ed.): Philosophy of Technology and Engineering Sciences. Elsevier, Amsterdam 2009, pp. 1341–1409.

[37] Polish experiences in the development of cities-academia relations analyze: Jonek-Kowalska I., Kaźmierczak J.: Ocena potencjału relacji miasto -uczelnia w zakresie kreowania inteligentnych miast w Polsce. [In:] Jonek--Kowalska I., Kaźmierczak J. (eds.): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 27–38.

[38] On tacit knowledge (and its applications in engineering sciences): Nightingale P.: Tacit Knowledge and Engineering Design.[In:] Meijers A. (ed.): Philosophy of Technology and Engineering Sciences. Elsevier, Amsterdam 2009, pp. 351–374.

items are composed (as all sentences) of words. Some of them play an auxiliary role, some – central, fundamental. These words receive special names – such as theoretical concepts/notions or categories. Their role can hardly be overestimated (can you imagine contemporary science without such concepts like "atom", "electro-magnetic field", "gen", "ecosystem", "intelligence", "market"…?). Therefore, an important part of theoretical work in sciences is about developing theoretical/scientific languages: about making the concepts more precise, and about analyzing the relations between concepts. The second activity might be conveniently characterized as investigating a (part of a) conceptual network. The first step in such investigations is to describe "conceptual surrounding" of a concept; in other words: enlisting the concepts that seem to be related (in a significant way) to a concept of particular interest to us.

Here, of such particular interest is obviously the concept of smart city. And, as suggest the analyses in this text, its "conceptual surrounding" comprises a few groups of concepts. First, general ontological concepts (such as system, stratum, process, development etc.). Second, concepts belonging to "regional" ontologies: to the ontology of technology (such as techno-sphere, technological system, internet of things, technology assessment[39] etc.) and to the social ontology (such as community, collective action etc.). Third, epistemological concepts (information, knowledge – explicit and "tacit" etc.). Fourth – such, very important, sociological concepts as social capital[40] and intellectual capital[41]. And, last but not least, fifth group – of "ideological" concepts. It contains such notions as sustainability[42], society 5.0, industry 4.0. – A systematic study of this conceptual network is a task to be undertaken in another text.

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[39] A very good succinct (and based on author's practical experience as the director of the German TA office) presentation of the main ideas of TA: Grunwald A.: Technology Assessment: Concepts and Methods. [In:] Meijers A. (ed.): Philosophy of Technology and Engineering Sciences. Elsevier, Amsterdam 2009, pp. 1103–1146.

[40] On creating social capital in smart cities: Osika G.: Connexity jako element koncepcji Smart City – analiza wybranych aspektów na przykładzie polskich miast [In]: Jonek-Kowalska I., Kaźmierczak J. (eds.): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 123–136.

[41] On creating intellectual capital via organizational learning: Mazur S., Olejniczak K.: Rola organizacyjnego uczenia się we współczesnym zarządzaniu publicznym. [In:] Olejniczak K.(ed.): Organizacje uczące się. Wyd. Naukowe „Scholar", Warszawa 2012, pp. 25–60; Olejniczak K.: Model organizacyjnego uczenia się dla administracji publicznej [In:] Olejniczak K.(ed.): Organizacje uczące się. Wyd. Naukowe „Scholar", Warszawa 2012, pp. 166–201.

[42] On this notion in historical perspective: Tainter J.A.: Understanding sustainability through history; resources and complexity. [In:] Caradonna J.L. (ed.): Routledge Handbook of the History of Sustainability. Routledge, London 2018, pp. 40–56. On the idea of sustainable development and the social (political etc.) changes necessary to actualize it: Robinson J.A., Maggs D.: At the crossroads: sustainability and the twilight of the modern world. [In:] Caradonna J.L. (ed.): Routledge Handbook of the History of Sustainability. Routledge, London 2018, pp. 387–40. As an interesting instance of various conceptual links can serve the notion of sustainable architecture: Baweja V.: Sustainable architecture: a short history. [In:] Caradonna J.L. (ed.): Routledge Handbook of the History of Sustainability. Routledge, London 2018, pp. 273–295. Conections between sustainability and city development analyzes Zavestoski: Zavestoski S.: Sustainability and the reframing

Let me add that – from the point of view I do share – any debates on priority of more theoretically or more empirically oriented studied are but waste of time. Both philosophical (epistemological) analyses and historical studies have demonstrated – beyond any reasonable doubt – that development of all scientific disciplines is a very complex process in which theoretical speculation, construction of instruments, logical analysis, experiments etc. interact. There is not reason to suppose that in the case of city studies should by otherwise.

But ontology of (smart) city is significant not only for the development of academic knowledge about (smart) cities. It is important also (or even: first of all) from the practical point of view: Smart development of a city presupposes existence of strategies and plans. As it is in the case of any complex system, also cities should have strategies and plans of different generality/specificity; among them – most general and perspective. And just for such strategy knowledge provided by ontology (I speak here about a type of knowledge – in any discipline one can find theories, conceptions etc. of different value, philosophy/ontology is no exception to this rule.) seems to be most significant. But even in the case of less general strategies, ontology has at least two roles to be played. First, preparation of general and perspective strategy may take a rather long time, therefore some partial strategies/plans must be prepared. But to make a possibly optimal decision as to what strategy is to be prepared most urgently one must have knowledge of the city as a whole. – Ontology of city may serve as an instrument to assess/evaluate this knowledge (its completeness/incompleteness etc.). Secondly, ontology can also serve as a kind of "map of knowledge" – indicating which part of academic knowledge is most relevant for the diagnosis and solving this or that practical problem. And third, not only choosing a solution to the given problem but even the selection/definition of the "most urgent" ("most important" etc.) problem can be a matter of controversies and manipulations.[43] The perspective offered by ontology may help to make such debates more factual and rational.

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of the world city. [In:] Caradonna J.L. (ed.): Routledge Handbook of the History of Sustainability. Routledge, London 2018, pp. 219–232.

[43] The idea of smart city is – from the point of view I share – closely connected with the idea of deliberative democracy. Gutmann A., Thompson D.: Why Deliberative Democracy? Princeton University Press, Princeton 2004; Healey P.: Collaborative Planning. Shaping Places in Fragmented Societies. Bloomsbury Publishing, London 2005. Very close to the notion of deliberative democracy is that of participative democracy. On this notion and its applications Rożałowska B.; W stronę Human Smart City – praktyka partycypacji obywatelskiej w polskich miastach. [In]: Jonek-Kowalska I., Kaźmierczak J.(eds.), Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp.147-158; Sadik-Khan J., Solomonow S.: Streetfight: Handbook for an Urban Revolution. Penguin London 2016. On epistemological foundations of deliberative democracy: Zollman K.J.S.: The Communication Structure of Epistemic Community. [In:] Goldman A.I., Whitcomb D. (eds.) Social Epistemology: Essential Readings. Oxford University Press, Oxford 2011, pp. 338–350.

Let me end these final remarks, and thus – the whole text, with a comment on the slogan of environmentalists, anti and alter globalists, and many others concerned with the future of the humanity: “Think globally, act locally”. I hope that this text implements this postulate in a double way. First, it is about such development of cities which takes into account the global problems and contributes to their solution. Second, it tries to consider how science could help cities to make their development more sustainable.

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Anna LESSAER-KENTZER[1]

3. THE SMART CITY AND SMART URBANISM: USING THE MASTER PLAN METHOD IN THE PLANNING AND DESIGN PROCESS OF IMPLEMENTING SMART URBANISM SOLUTIONS

3.1. Introduction

What is a Smart City from an urban planning perspective? How are urban spaces created? Is there room for creativity and outside-the-box solutions in the processes of creating these spaces? Or are we focusing too much on purely utilitarian and functional elements within the Smart City and forgetting about other aspects?

Changing demographics and rapid technological advances have significantly affected urban development. The concept of the Smart City has been thought of for several years as the intersection between technology and information technology tools and the needs of society. In the pursuit of improving the quality of life and the working processes of urban systems, one of the most important factors is not considered that a city is created in a specific space and time. Today's ubiquitous technology significantly affects all areas of our lives. However, it cannot fully predict human behaviour or the consequences that a progressive increase in the use of smart technology will have. By relying on the "intelligence" of technological solutions, we significantly restrict the influence of human skills on shaping urban spaces. As Czeslaw Bielecki notes: "Why, at a time when no one was talking about urban planning, has a public space been created in which we can implement our revolutionary smart cities strategies? Meanwhile, in the projected chaos of forms pushing each other in the queue for fame, this turns out to be much more difficult. Today, it is more common for us to write dissertations on cities for people and happy cities than on how to build them. However perfect our city software may be, architects are all about hardware"[2].

[1] Silesian University of Technology, Facultyy of Architecture, Gliwice, e-mail: anna.lessaer-kentzer@polsl.pl
[2] Bielecki Cz.: Archikod. Narodowy Instytut Architektury i Urbanistyki, Warszawa 2021.

3.2. Aim, scope and research method

The aim of this chapter of the monograph is to try to fill the research gap concerning the insufficient consideration of planning and design processes in the concept of the Smart City. In view of the need for cities to adapt to changing conditions and expectations, the omission of the role of urban design may result in an intensification of spatial and functional conflicts, while other demands of the Smart City are implemented. In this way, the objectives will be achieved in a city that is gradually losing its individual structure. In order to identify what a Smart City is from an urban planning perspective, the author analyses the impact of demographic growth on urban development, along with the characteristics and factors that constitute the criteria for evaluating a Smart City. At the same time, the author points to the need to introduce an additional area of activity within the concept of the Smart City, which takes into account the process of creating urban space in a creative and non-standard approach, which she defines as Smart Urbanism. In the methodology adopted, this term refers to a range of urban planning and design activities that technology cannot replace. A search of publications and scientific studies related to the theory of urban and spatial planning was used to verify the research hypotheses to determine whether a relationship exists between the variables being studied. Based on these variables, conclusions on the features and characteristics of Smart Urbanism within the framework of the Smart City concept were derived. The issues addressed in Smart Cities are interdisciplinary and are related to current challenges within priority research areas.

The analysis covers the historical period from 1950 to 2021 and the projected period up to 2060. The research, in which the analyses were carried out, focuses on showing the relationship between demographic growth, the Smart City, and urban design, as well as the phenomenon of technological development and its impact on social and spatial change. In the chapter, the author deals with theoretical issues and global phenomena without reference to Polish conditions.

The structure of the chapter identifies four issues. The first part is an analysis of demographic growth as one of the factors influencing changes in the structure of the city. The aim of this section is to highlight the need for concrete measures to stop urban sprawl. In the second part, the concept of the Smart City is discussed, taking into account its features and contributing factors, as well as a framework for assessing its effectiveness. Critical observations are aimed at identifying the subsequent research

gap, which, according to the author of this chapter, is the omission of the creative urban design process in the structure of the Smart City concept. In addition, this section emphasises that planning and design activities have been and should continue to be at the heart of the city's development, which should be enhanced through Smart Urbanism. To this end, the third part of the chapter answers a number of questions related to the concept of Smart Urbanism. By verifying the functioning definition, analysing the impact of the development of global technologies on urban design as well as creative planning and design processes, the author redefines the concept of Smart Urbanism. The author defines its characteristics and features, providing a clear record within the current areas of activity of the Smart City. The last part of the chapter refers to operational measures that can fulfil the demands of Smart Urbanism. The author introduces the concept of the Smart Masterplan, which aims to show, guide and redefine the Masterplan development process. The fourth part represents only a fragment of the research conducted by the author on the Masterplan Method. The selected scope and the adopted form of the chapter are aimed at indicating the basic directions of activities in the context of integrating planning and design processes within the concept of the Smart City. The chapter ends with preliminary conclusions.

3.3. World population growth and the shrinking of Europe

Since the mid-18th century there has been a significant increase in the world's population. Over the last 70 years, the population has grown from 2.5 billion (in 1950) to 7.7 billion (in 2019). With a sustained growth trend of 1-2 per cent per year, the population will have exceeded 10 billion by 2060[3]. As the world's population grows, the proportions of the population living in rural and urban areas are changing. In 1950, less than 30% of the world's population lived in cities. In 2007, the numbers of urban and rural dwellers were almost equal, and in 2050, according to estimated statistics, the proportion compared with 100 years previously will be reversed in favour of urban dwellers[4] (see Figure 3.1). This means that spatial, infrastructural, environmental, social, and economic problems in cities will escalate unless a long-term development perspective is adopted.

[3] Cilluffo A.: World's population is projected to nearly stop growing by the end of the century, Pew Research Center, 17.06.2019, online: https://www.pewresearch.org/fact-tank/2019/06/17/worlds-population-is-projected-to-nearly-stop-growing-by-the-end-of-the-century (accessed: 25 April 2022).

[4] Ritchie H., Roser M.: Urbanisation, Our World in Data, published: 09.2018, revised: 11.2019, online: https://www.ourworldindata.org/urbanization [accessed: 25 April 2022].

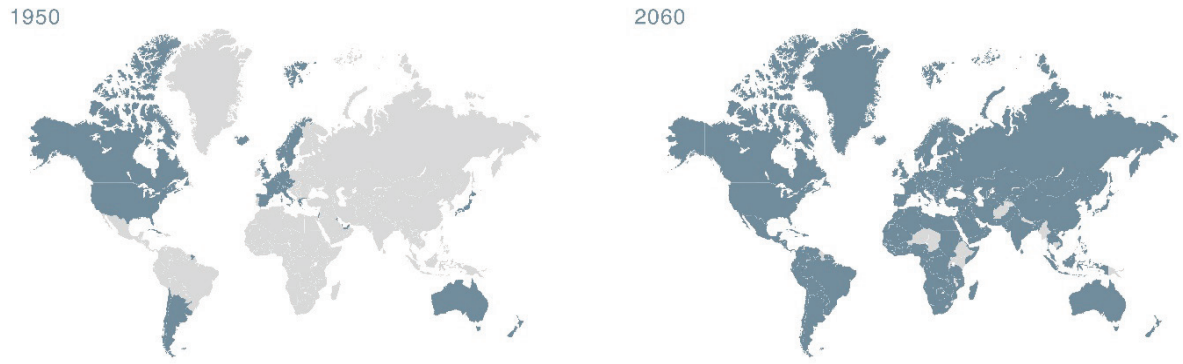

Fig. 3.1. Diagram showing the share of the population living in urban and rural areas in the 1950s and 2060s. "Urban majority" means that more than 50% of the country's population lives in cities. The scheme is based on estimates up to 2016 in conjunction with the UN forecasts until 2050

Rys. 3.1. Schemat przedstawiający udział ludności mieszkającej na obszarach miejskich i wiejskich w 1950 roku i 2060 roku. „Większość miejska" oznacza, że ponad 50% ludności kraju mieszka w miastach. Schemat opiera się to na szacunkach do 2016 roku w połączeniu z ONZ prognozy do 2050 roku

Source: Own elaboration based on https://ourworldindata.org/urbanization, 2022 r.

The growth of the world's population has a significant impact on the environment. Progressive climate change is one of the greatest challenges facing the world today. It directly affects people's lives and economies. Global population growth, as a trend, is only one of the drivers of climate change that lead to increased greenhouse gas emissions, flooding, reduced agricultural productivity, increased variability in water availability, seawater intrusion, increased coastal erosion, pressure on resources, an ever expanding economy, and increasing urbanisation[5]. Of these challenges, urbanisation is the one primarily faced by the world's major cities. As a result of development pressures, adjacent peri-urban open landscape areas are being occupied that previously played a significant role in providing biodiverse habitats, guaranteeing ecosystem services and maintaining environmental quality. The process of urban sprawl is not only inconducive to improving the environment, but also creates many new functional-spatial conflicts. Unfortunately, economic issues (such as abundant land supply), effectively divert attention from the long-term consequences of this process[6]. For European cities, stopping urban sprawl is particularly important because, contrary to global trends, Europe is ageing. This process began several decades ago and is results in a declining proportion of people of working age. According to Eurostat, 20.3% of the European Union population was expected to be aged 65 or over

[5] H. Hussain Mari I., Hussain Z.: Climate Change in Pakistan: Govt Efforts to Reduce the Climate Change Threats, European Journal of Innovation in Nonformal Education. Vol. 1, No. 1, Belgium 2021.

[6] Mortoja G., Yigitcanlar T.: Are climate change, urbanization and political views correlated? Empirical evidence from South East Queensland, Urban Climate, Elsvier, 2022.

in 2019, and this will be an increasing trend[7]. Cities will have to adapt to a changing society and its needs. Excessive and ill-considered urbanisation of successive areas may in the long term result in a loss of continuity of the functional and spatial structure of the city.

3.4. Smart city: improving quality of life through technological development

Urban communities are changing rapidly. To a large extent, this is due to ongoing technological developments that are breaking new ground. The question is no longer whether something can be done, but in what time frame it can be done and at what cost. Optimising processes and increasing efficiency are objectives that are found in every industry. Due to technology, such objectives have become standard practice. Changing environmental conditions are evident in urban areas. They do not only concern the development of information and communication technologies, but also the next industrial revolution, the constraints caused by the pandemic and the war in Ukraine. In recent years, the concept of the Smart City has become an answer to a number of questions related to the city in its broadest sense, whose areas of activity are being elaborated on more and more each year. At the same time, the emergence of new interpretations over the past decades has meant that we have a number of notions of "Smart".

The introduction of the concept of the Digital City (City Network) was one of the first references to the Smart City, which referred to the presentation and sharing of information about the ICT (Information and Communications Technology) used on the city website. This process was linked to, among other things, the development of city marketing as well as the creation of electronic information and service layers in cities[8]. Anthopoulos, in "Understanding Smart Cities – A tool for Smart Government or an Industrial Trick?", cites the case of Amsterdam as the city where the idea of the Digital City was first introduced in 1994. The stimulus then came from a desire for dialogue between the public and politicians. As a result, the scale of public participation, as well as the use of the Internet, has been a success. The potential of using technological solutions to address certain societal needs was recognised[9]. To this day, Amsterdam is considered

[7] Eurostat, Archive: Struktura ludności i starzenie się społeczeństwa, Eurostat Statistic Explained, 20.07.2021, online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Struktura_ludności

[8] Aurigi A.: Making the Digital City. The Early Shaping of Urban Internet Space, Routledge Taylor&Francis Group, 2005.

[9] Anthopoulos L.G.: Understanding Smart Cities: A Tool for Smart Government or an Industrial Trick?. Public Administration and Information Technology, Vol. 22, Springer, 2017.

one of the smartest cities[10]. This case has also inspired other urban centres and contributed to the emergence and development of the concept of the Smart City.

So far, there has been no established definition of a Smart City. This concept is treated in a multivalent manner. In the 1990s, the Smart City focused on the role of transport infrastructure[11]. In 2007, Giffinger et al. compiled the "Smart cities: Ranking of European medium-sized cities", in which, on the basis of an analysis of 70 European cities, they selected six areas of activity (Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, Smart Living), within which we can say that a Smart City is functioning well[12]. In later years, definitions began to include the role of human capital, and so Caragliu et al. commented that city is smart "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance"[13].

In simple terms, a Smart City is a set of ideas, procedures and concepts based on the principles of inclusion, innovation, resilience, equality, and social cooperation that can "provide a specific answer to changing conditions and expectations in the environment"[14].

In a different scope and perspective, the phenomenon of Smart Cities is seen by the United Nations Economic Commission for Europe (UNECE) and the International Telecommunication Union (ITU), who redefine the concept of Smart City to the term Sustainable Smart City, placing it in the context of the idea of sustainable development. In their view, a Sustainable Smart City is "an innovative city that uses ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects"[15].

The global initiative, United for Smart Sustainable Cities (U4SSC) was established to build an international platform for sharing information to help manage cities. It supports the development of policies and strategies that encourage the use of digital

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[10] Smartcity: 2020 Smart City Winners: IESE's Top 10 By Dimension, Smart City Press, published: 22.07.2020, online: https://smartcity.press/top-10-smart-cities-of-2020/, [accessed: 30 April 2022].
[11] Caragliu A., Del Bo Ch., Nijkamp P.: Smart cities in Europe, Journal of Urban Technology, Vol. 18, Taylor&Francis, London 2011, pp. 65–82.
[12] Giffinger R.: Smart cities – Ranking of European medium-sized cities, Centre of Regional Science, Vienna UT, 2007.
[13] Caragliu A., Del Bo Ch., Nijkamp P.: Smart cities in Europe, Journal of Urban Technology, Vol. 18, Taylor&Francis, London 2011, pp. 65–82.
[14] Bitkowska A., Łabędzki K.: Koncepcja inteligentnego miasta – definicje, założenia, obszary, Marketing i Rynek/ Journal of Marketing and Market Studies, Vol. XXVIII, No. 2/2021, Polskie Wydawnictwo Ekonomiczne, Warszawa 2021, pp. 3–11.
[15] UNECE, Sustainable Development Goals, Sustainable Smart Cities, online: https://unece.org/housing/sustainable-smart-cities, [accessed: 30 April 2022].

technologies to facilitate the transition to smart, sustainable cities. The U4SSC is coordinated by the International Telecommunication Union (ITU), the United Nations Economic Commission for Europe (UNECE) and United Nations Habitat (UN--Habitat) and is further supported by 14 UN bodies16. In 2017, Collection Methodology for Key Performance Indicators for Smart Cities was published. This document was created to develop key performance indicators for Smart Sustainable Cities. The methodology developed is intended to help cities achieve their sustainability goals and become smarter and more pleasant. The indicators included in the study formed the basis of the Smart Sustainable City Index, which is intended to help assess and sustain the city[17].

Activities in the wider field of the Smart City are very broad. Numerous definitions of a Smart City show that researchers interpret the concept using individual approaches, and rankings and reports define their individual criteria. In addition, the interdisciplinary nature of the issue makes it the subject of research by scientists from different fields and scientific disciplines. In the literature, there are also several models that represent a synthesis of the Smart City strategy. In "Smart cities: Ranking of European medium-sized cities" a classification into six activity areas was adopted (see Figure 3.2), these being Smart Economy, Smart People, Smart Governance, Smart Living, Smart Environment, Smart Mobility[18]. Anthopoulos, on the other hand, defines eight areas of activity several years later: Smart Infrastructure, Smart Transportation, Smart Environment, Smart Services, Smart Governance, Smart People, Smart Living, Smart Economy[19]. Analysing both lists, an evolution of the concept of the Smart City is evident, as well as its areas of activity. Certain sectors, due to the changing environment, are the subject of numerous studies, leading to a more detailed description of the issues, and resulting in an additional subdivision within the category, or specific new areas of activity. These activities show that the idea of the Smart City is flexible enough to accommodate further development.

[16] U4SSC, online: https://u4ssc.itu.int/about/ [accessed: 25 April 2022].
[17] Collection Methodology for Key Performance Indicators for Smart Sustainable Cities, United 4 Smart Sustainable Cities, Geneva 2017.
[18] Giffinger R.: Smart cities – Ranking of European medium-sized cities, Centre of Regional Science, Vienna UT, 2007.
[19] Anthopoulos L.G.: Understanding Smart Cities: A Tool for Smart Government or an Industrial Trick?. Public Administration and Information Technology, Vol. 22, Springer, 2017.

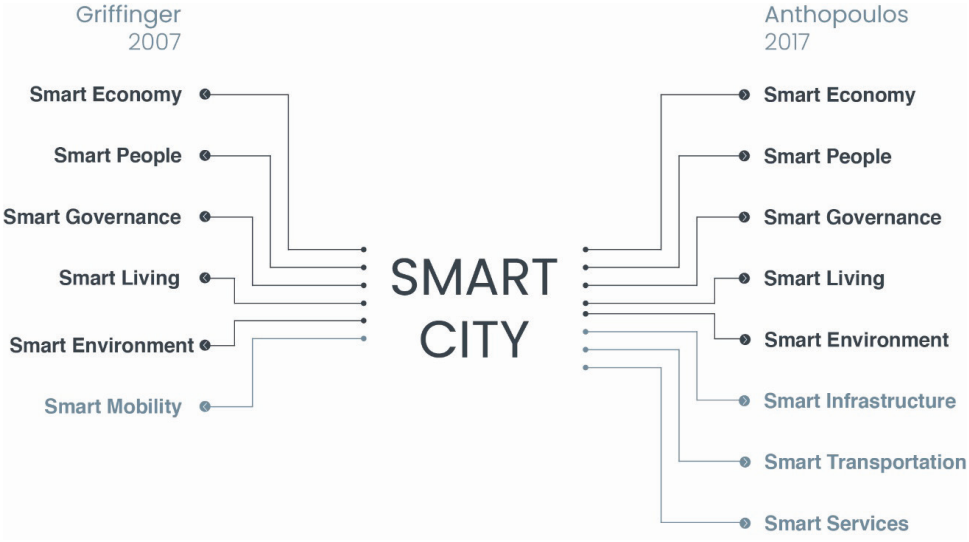

Fig. 3.2. Diagram showing the areas of Smart City activity. Comparison of Griffinger and Anthopoulos research.

Rys. 3.2. Schemat przedstawiający obszary aktywności Inteligentnego Miasta. Porównanie badań Griffingera i Anthropoglots

Source: Own elaboration based on Anthopoulos L.G.: Understanding Smart Cities: A Tool for Smart Government or an Industrial Trick? and Giffinger R. et al.: Smart cities: Ranking of European medium-sized cities.

When talking about the Smart City, it is important to note that individual countries define success factors individually. In the European Union, for example, Intelligent Transport and Communication is identified as the most developmental factor[20]. Cities strive with their policies and management to achieve as many indicators as possible in order to be identified as a Smart City, which is currently considered one of the most effective tools for creating competitive advantage.

There is no doubt that the idea of the Smart City is a leading trend in contemporary urban management. Objectives within each area of activity can be transparently defined, implemented and reviewed. These activities drive technological, economic, political, and social development. However, they omit an area that the author believes is crucial – the planning and design of multi-scale urban space, in terms of imaginative creative activities. The Smart City benchmarks are based too much on purely utilitarian and functional elements forgetting the unique city-forming processes that technology cannot replace. The author believes that the existing areas of activity should be supplemented by one more area, which is Smart Urbanism. This is possible because of the open form of interpretation of the Smart City and the constant evolution of the areas of activity that it engages in its strategy.

[20] Hollands R.: Will the smart city please stand up? Intelligent, progressive or entrepreneurial?. City 2008, Vol. 12, No. 3, pp. 303–320.

3.5. Smart urbanism: shaping the city in the digital age

Smart Urbanism is a relatively new concept. Increasingly, this phrase is presented as an answer to future urban planning challenges[21], but there is a lack of both theoretical insight and empirical evidence to assess this phenomenon. As noted by Marvin et al. "Smart urbanism is emerging at the intersection of visions for the future of urban places, new technologies and infrastructures. Promoted by international organisations, the corporate sector and national and local governments alike, the dominant vision is of the meshing of intelligent infrastructure, high-tech urban development, the digital economy and e-citizens. Discourses around smart urbanism are deeply rooted in seductive and normative visions of the future where technology stands as the primary driver for change"[22].

While our understanding of Smart Cities is growing, awareness of the opportunities and implications of using new technologies in urban planning is limited. Kitchin et al. point out that "There is a powerful political and economic lobby advocating the development of smart cities. The arguments forwarded by this lobby propose that smart city initiatives will lead to more efficient, effective, sustainable, resilient, safe and secure cities"[23].

Given the pace of development and the popularity of the mechanisms that form the elements of Smart Cities, it is necessary to develop a methodology for Smart Urban Planning aimed at analysing, as well as creating, a multifaceted physical urban context and subjecting it to critical evaluation. It must be taken into account that cities are not directly comparable to each other and that we are dealing with archetypes of space that have emerged over centuries, shaping inner and outer, private and shared, as well as ennobled and everyday spaces in our cities. However, it should be remembered that the physical image of the city is not a democratic space; it only gives this impression because it is a stage for democratic action. Referring to Tadeusz Wróbel's Brief History of Town Building[24], which refers to ancient Greece, he writes: "The town developed gradually around or at the foot of the acropolis, and its characteristic element was the agora, the square, the marketplace, where buildings intended for public use were concentrated; their number, purpose and size increased as the organisation of the polis progressed and the population grew". An urban space was created for the inhabitants and included a clear

[21] Marvin S., Luque-Alaya A., McFarlane C.: Smart Urbanism. Utopian vision or false down?. Routledge, New York 2016.
[22] Marvin S., Luque-Alaya A., McFarlane C.: Smart Urbanism. Utopian vision or false down?. Routledge, New York 2016.
[23] Kitchin R., Lauriault T.P., McArdle G.: Smart Cities and the politics of urban data [In:] Smart Urbanism. Utopian vision or false down?. Routledge, New York 2016, pp. 17–33.
[24] Wróbel T.: Zarys Historii Budowy Miast, Zakład Narodowy Imienia Ossolińskich, Wrocław 1971, p. 20.

layout of the structure in the space. The design logic that can be observed in most historic city centres was upheld: a logic that has been broken, resulting in today's spatial conflicts, which are the result of disconnected actions that required immediate decisions and hurried implementation.

The question arises as to whether the same mistake is not being repeated today. Do the spatial conflicts we face not result from attempts to solve current problems, to achieve isolated objectives and to meet utilitarian expectations? Is the package of measures and procedures being developed, dubbed the Smart City, not another attempt to hastily respond to newly identified problems? For example, is the idea of the 15-minute city (creating places of activity in the immediate vicinity) not consistent with descriptions from 50 years ago, and a practice known for centuries? When creating Smart Cities, why are there no smart spatial actions using practical knowledge drawn from experience? Overlooking the City, which "constitutes a centre on its own scale i.e., the essence of the city remains the same, but its strength changes depending not only on the size of the city but also on certain characteristics inherent in it"[25], and talking about realising the Smart City concept, is only a temporary response to current problems and the collection of user information.

A Smart City should not be perceived only through the lens of technological solutions. Technology should be a means to shape amenable urban spaces. The success of the Smart City is as much dependent on the skills of human resources as it is on the modern technologies that include planning and design, digital citizenship, data literacy, implementation and management26. The role of developing human resources in connection with the Smart City is at times overlooked. Often, there is too much focus on the mere gathering and processing of information, without it being translated into project objectives. An increasing number of cities have detailed analyses obtained by means of, for example, scanning buildings, drone measurements, compilation of databases with spatial information, as well as 3D printouts. Unfortunately, these materials are very often developed without any commonly established method for their further development and use. What is forgotten is that these are neither methods nor products but tools for further work. Additional problems resulting from the maintenance of programmes and extensive licences sometimes limit further development of this sector. As a result, cities have information for the sake of having it, or the requirement to have it.

In the opinion of the author, Smart Urbanism is the process of creating space by analysing and creating the multifaceted physical urban context and subjecting it to

[25] Szymańska D.: Urbanizacja na świecie. Wydawnictwo naukowe PWN, Warszawa 2007.
[26] Smartcity: 2020 Smart City Winners: IESE's Top 10 By Dimension, Smart City Press, published: 22.07.2020, online: https://smartcity.press/top-10-smart-cities-of-2020/, [accessed: 30 April 2022].

critical evaluation. At the urban planning level, the space of the Smart City should improve and enhance the user's perception of the city. Every city is different, each with its own unique structure resulting from individual cultural, social and environmental patterns. In a Smart City, Smart Urbanism is that which maintains a multi-scale planning and design continuum composed of hierarchical systems and structured spatial elements. Technology should support planning activities and inform the expertise of urban planners. However, it should not be the dominant factor.

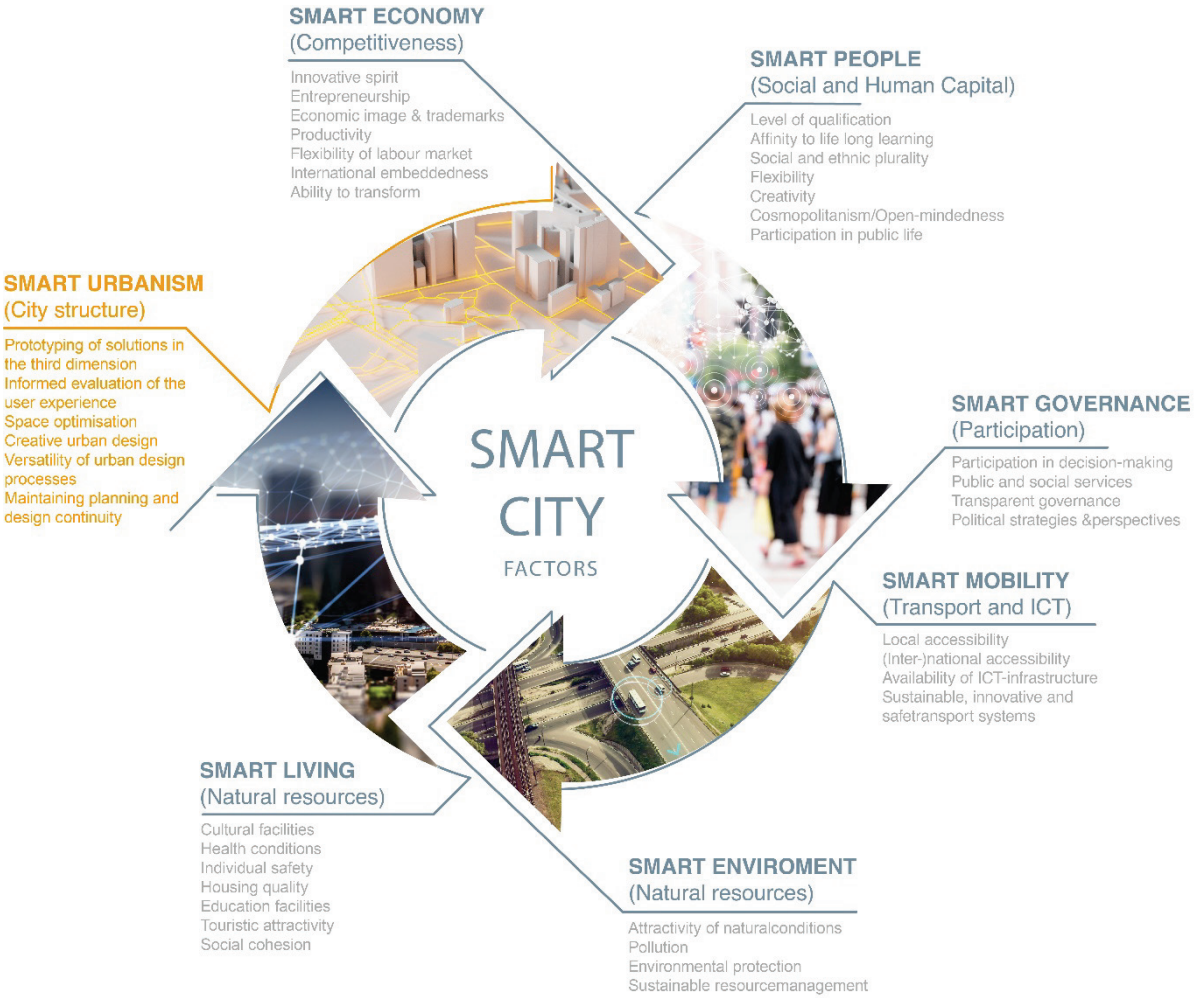

Fig. 3.3. Diagram showing the features and factors that form the framework for the assessment of a Smart City, taking into account an additional factor in the form of Smart Urbanism
Rys. 3.3. Schemat przedstawiający cechy i czynniki, tworzące ramy do oceny Miasta Inteligentnego z uwzględnieniem dodatkowego czynnika w postaci Inteligentnej Urbanistyki.
Source: Own elaboration based on the diagram from the report Smart cities. Ranking of European medium-sized cities, 2022 r.

The Smart City concept is a set of interdependent systems formed by the areas of its activity. Successful integration of a large number of mechanisms requires openness and

standardisation[27]. It is possible to try to embed Smart Urbanism as an integral part of the concept by defining standardised characteristics that fit into the established characteristics and descriptions of the areas of activity of the Smart City (see Figure 3.3). In the opinion of the author, the methodology of Smart Urbanism should be based on principles and features that coincide with the workflow of planning and design processes. In the author's opinion, these are:

- Prototyping of solutions in the third dimension – problem solving from the perspective of the third dimension should become standard practice at the urban design stage. New technologies provide us with a lot of information about the city, enabling us to design and verify design solutions in real time.
- Informed evaluation of the user experience – the use of behavioural analyses of the users of a space makes it possible to design factors that influence specific behaviours and stimulate pro-social processes.
- Space optimisation – balancing creative and technological elements. Searching for optimal spatial solutions for the implementation of the guidelines within the Smart City concept and forecasting the effects of their implementation.
- Creative urban design – the design of city spaces taking into account a range of components, for example: view sequences, compositional axes, landscape interiors or public spaces, which significantly affect the user's perception of the city.
- Versatility of urban design processes – the introduction of an operational tool implementing the principles of Smart Urbanism will make it possible to react dynamically to changes resulting from other areas of Smart activity.
- Maintaining planning and design continuity – composed of systems of hierarchical and structured spatial elements.

Smart Urbanism requires the development of a range of supporting measures. Given today's expectations and standards, Smart Urbanism must be made "versatile". This is a difficult task, given the complex, interdisciplinary nature of the problems. The development of new and systematisation of existing, design methods, taking into account the opportunities offered by technological development, cannot only improve the design process, but also provide real opportunities to respond to dynamic changes arising from other areas of Smart activity. The Masterplan Method is one of the tools implementing the principles of Smart Urbanism, which can combine strategic and operational activities as part of project implementation.

[27] Naydenov K.: Smart Cities – The future of urban planning, 5th International Multidisciplinary Scientific Conference on Social Sciences & Art SGEM 2018.

3.6. Masterplan as a planning and design process for implementing the principles of smart urbanism

Early references to the Masterplan began to appear in the first half of the 20th century. In his book “The Master Plan”, Edward M. Basset explores the potential of the Masterplan as a tool to assist town planning committees. Using the term “plastic”, he repeatedly stresses that the Masterplan should be flexible and be a reference tool, allowing for verification of solutions and implementation of changes. He points out that the Masterplan should not be adopted by any legislative body and, as a flexible, coordinated study, should become a recommendation for further planning activities. In order to have for it an advisory function it should show elements such as streets, parks, sites for public buildings, public utilities, and pierhead and bulkhead lines.[28] The analysis of the literature shows that no further attempts have been made to redefine the Masterplan in the context of its written form, scope or role in the spatial planning system. Basset's statement that “although all perceive the need of a plastic master plan there is a constant tendency to pass legislation that will ossify it. As soon as this takes place the plan loses its usefulness as a reference map”[29] appears to be exceedingly relevant to contemporary spatial planning. Probably, because of the fact that the document was not embedded in the planning and design structure, the Masterplan was interpreted freely and its role was marginalised by depriving it of a formal record. However, this does not mean that studies under the name of Masterplans have not been produced over the years. They have been, but the lack of initial guidelines has resulted today in an extensive spectrum in the format of the document itself, as well as its name.

In retrospect, the open and fluid form of the Masterplan record, as well as its free interpretation, is an asset, since it did not limit the creators' creativity. As a result, we now have a number of case studies that can serve as a starting point for further research. Furthermore, technological developments make it possible to introduce a new qualitative and substantive standard for planning and urban design reports. The author presents the concept of the Smart Masterplan, understood as a document written according to the Masterplan Method, implementing the principles of Smart Urbanism (see Figure 3.4)

[28] Basset E.M.: The Master Plan. WM. F. Fell CO., Printers Philadelphia, 1938.
[29] Basset E.M.: The Master Plan. WM. F. Fell CO., Printers Philadelphia, 1938.

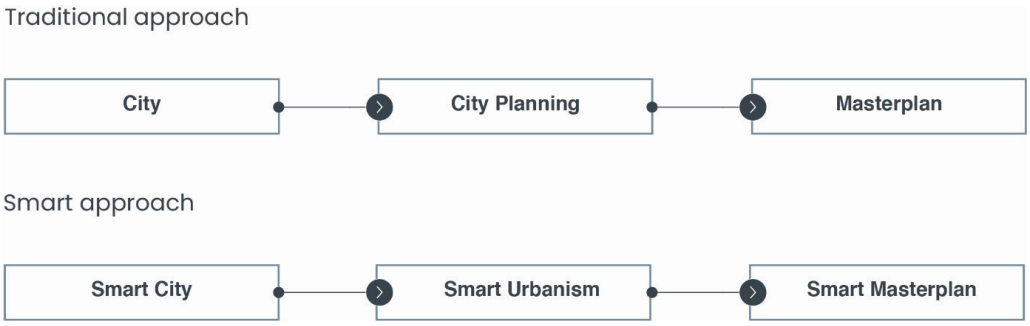

Fig. 3.4. A diagram showing the traditional approach in creating urban space and the intelligent approach
Rys. 3.4. Schemat przedstawiający podejście tradycyjne w tworzeniu przestrzeni miejskiej i podejście inteligentne
Source: Own elaboration, 2022.

The Masterplan method, being a clear record of the Smart Masterplan, is the subject of current research and analysis by the author of this chapter. In the Masterplan Method, the author explores ways to realise the objectives of Smart Urbanism within the concept of the Smart City by defining a model for interdisciplinary cooperation and identifying planning and design application possibilities. Urban planning work can implement design activities as part of operational activities. The use of third--dimension technologies to solve spatial and functional problems plays an important role. However, prototyping spatial solutions in the form of a 3D printout makes it possible not only to verify the decisions made, but also to acquire a real, more attractive and accessible shape, one that is tangible at the design stage.

A Masterplan drawn up in accordance with the Masterplan Method can effectively integrate spatial planning with urban and architectural design. At the same time, it is intended to increase the efficiency of planning processes by systematising the basic form of the provision and indicating the key activities that determine the success of an investment. The Masterplan Method also aims to develop an analytical framework (see Figure 3.5), drawing on the project lifecycle management methodology, based on goal definition, analysis, planning, design, financing, and the application, modification and verification of solutions.

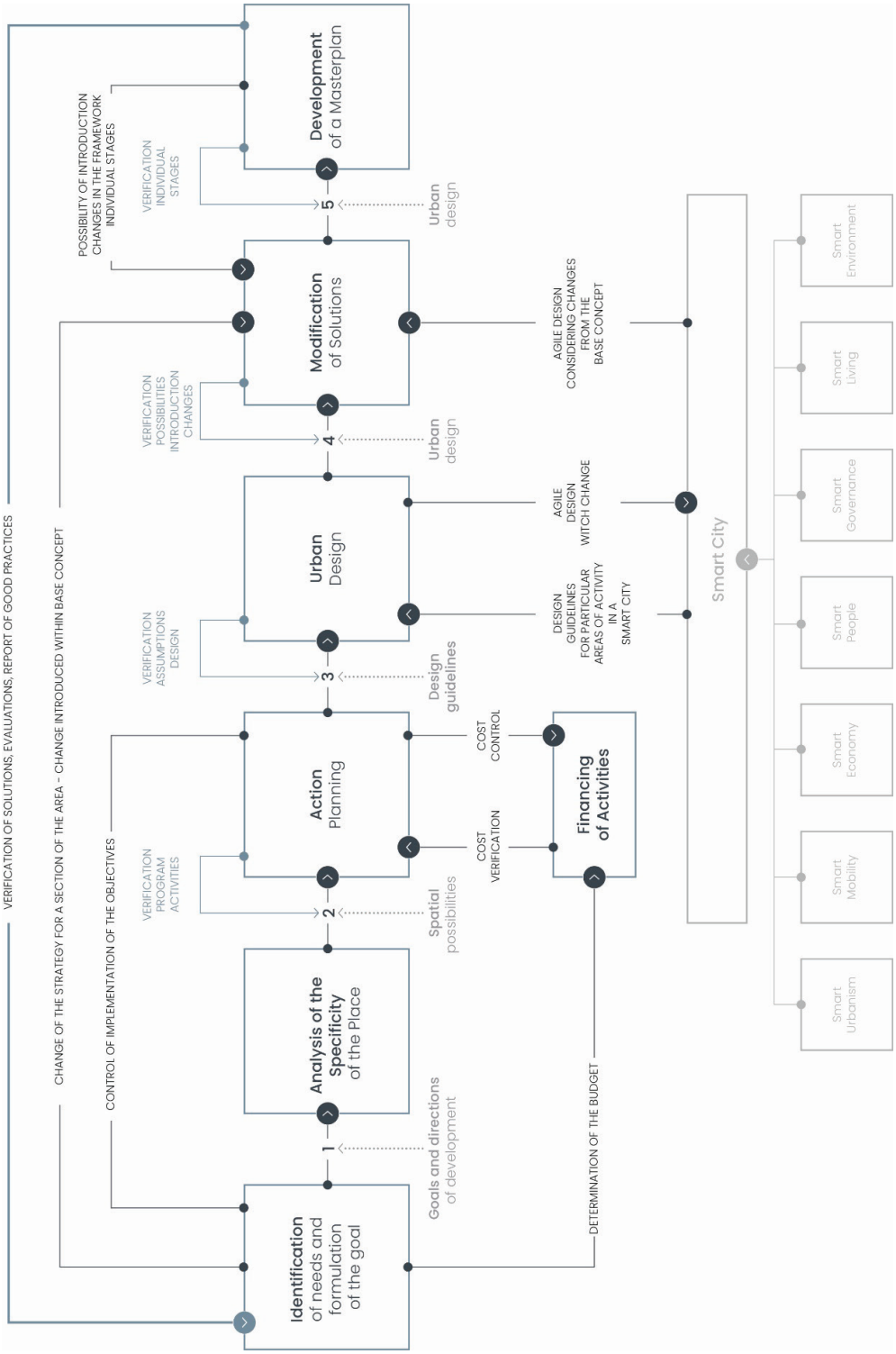

Fig. 3.5. Initial scheme of activities within the Masterplan Method.
Rys. 3.5. Wstępny schemat działań w ramach Metody Masterplanu
Source: Own elaboration, 2022

3.7. Preliminary Conclusions

The concept of the Smart City has become disconnected from individual spatial features and the qualities of the place (a place understood geographically, but also as a place for specific urban activities). Without changes, concerning not so much a broad spatial policy, but more detailed urban planning and architectural strategies, cities will deteriorate. Most of them will lose their unique character, which is currently disappearing in areas outside the city centre. With population growth, migration, emigration, an ageing population, and the unification of urban activities, it will be increasingly difficult to "return" to creating places.

Developments in technology have significantly influenced the ability to use behavioural analysis in conjunction with spatial design. The use of extensive databases and digital mapping resources should become an integral part of the creative process which, enriched by 3D spatial models and local vision, can have a real impact on the quality of city space and thus on the quality of life of its inhabitants. Technology should be supportive. Numbers and parameters generated from analysis and human behaviour cannot replace the creative design process.

Smart Urbanism would appear to be a combination of a vision for the city, employing new technologies as well as a continuation of spatial design practices. It is an opportunity to embed planning and design activities within the Smart City concept.

If the process of creating Smart Urbanism is kept within purely strategic activities without further translation into operational activities, it will not be effective. It is important that political, economic, environmental and social issues are only a backdrop for the activities of Smart Urbanism. These factors cannot be ignored but should act as guidelines in the subsequent design process. It is at the stage of creative space-shaping that city matters should be decided. In the opinion of the author, Smart Urban Planning should refer to both technological solutions and human resource competence. Integration into the existing city structure or elimination of "bland" places is not possible through digitisation. It is the design process that makes it possible to stimulate pro-social processes, thanks to which the residents identify with the space, feel safe, and thus care about their immediate surroundings.

This chapter provides an introduction to further research and analysis of Smart Urbanism, as well as an introduction to the Masterplan Method. Changes in approach to space-shaping are necessary, and this is evidenced by the current marginalisation of urban design issues within the Smart City concept, which will certainly continue and be expanded upon in the coming years.

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Grażyna OSIKA[1]

4. AMBIENT DESIGN AS A SOCIAL INNOVATION FOR SMART CITIES OF SOCIETY 5.0

4.1. Introduction

If we wanted to predict how human civilization will develop in the future, considering technological and social issues, the most obvious solution would be cities, managed in the spirit of social concepts, which are currently referred to as Society 5.0. Why cities? Because the accumulation of people in one place gives birth to a huge potential for action. We discovered this truth in the history of mankind quite early; some even believe that cities are the greatest technical invention of human being[2], which became possible thanks to the increase of the organizational capacity of man. The tasks of the system, which is the city, are to ensure safety and prosperity of its inhabitants. The condition for the realization of this assumption is to maintain the balance of the system. It is not surprising that, in view of the growth of the world population, this invention is considered the best solution, making urbanization one of the dominant social trends[3]. The city as a system allows for easier access to resources, health care, education, cultural goods, and also offers greater opportunities to obtain work than rural areas. Today, cities are seen as an opportunity to create a more sustainable environment in which, thanks to human cooperation and advanced technologies, it will be possible to increase harmony

[1] Silesian University of Technology, Faculty of Organization and Management, Department of Applied Social Sciences, Zabrze, e-mail: grazyna.osika@polsl.pl.

[2] Rose J.F.P.: Dobrze nastrojone miasto. Czego współczesna nauka, pradawne cywilizacje i ludzka natura mogą nas nauczyć o przyszłości życia w mieście Krakter. Kraków 2019.

[3] See: Weizsäcker E.U. von, Wijkman A.: Ejże! Kapitalizm, krótkowzroczność, populacja i zniszczenie planety. Raport Klubu Rzymskiego, Instytut Badań Stosowanych Politechniki Warszawskiej, Warszawa 2018; Osika G. Connexity jako element koncepcji Smart City – analiza wybranych aspektów na przykładzie polskich miast. [In:] Jonek-Kowalska I, Kaźmierczak J. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 123–136; Kowalska-Styczeń A.: Badanie złożoności zjawisk społecznych w kontekście inteligentnego miasta. [In:] Jonek-Kowalska I., Kaźmierczak I. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 137–146.

between man and nature[4]. We are talking about a specific concept of the city, the so--called Smart City (SC). In this vision of the future, humanity lives mainly in cities where a large part of the processes involved in its functioning are automated, and thus a high level of optimization of management is achieved. But managing is, above all, to follow some general plan, to direct activities according to a previously adopted development strategy. Why is it assumed that this vision should be the concept of Society 5.0? Because in this social concept there is a broader view of the human being, the social environment, and the directions of development to which we can aspire thanks to technology, which, as it is assumed in this vision, will make it possible to experience universal well-being to a greater extent. As defined, "Society 5.0 attempts to balance economic development with the resolution of social and environmental problems. […] is a society in which advanced IT technologies, Internet of Things, robots, artificial intelligence, and augmented reality are actively used in everyday life, industry, healthcare, and others spheres of activity, not primarily for economic advantage but for the benefit and convenience of each citizen"[5], each resident of the SC.

If the concept of Society 5.0, assumes that the society is to be a cyber-physical system in which advanced IT technologies are actively used on a daily basis to improve the quality of life, hence the term human-centered society[6], and urbanization as a social megatrend means that it is in cities that the assumptions of the Society 5.0 concept will be realized, so SC is an integral part of the vision of a human-centered society, it is its specification. But it is necessary to be more specific: how do we plan to do it, what methodology can we adopt?

It is well known that living in a city generates several negative psychological effects which, in consequence, may result in social instability, reducing the quality of life of the city inhabitants. That is why it is so important to also include this aspect in the realization of the SC and Society 5.0 assumptions. Therefore, we can say that we are currently in the brainstorming phase, that is, generating ideas on what concrete steps can serve the implementation of the visions described above. The present discussion should be treated as one of the conceptual sketches in this brainstorming, which in the future will require a deeper analysis and critical reflection, but for now, using conceptual analysis[7], it is only

[4]Rose J.F.P.: Dobrze nastrojone miasto. Czego współczesna nauka, pradawne cywilizacje i ludzka natura mogą nas nauczyć o przyszłości życia w mieście Krakter. Kraków 2019.
[5]Breque M., Nul De L., Petridis A.: Industry 5.0, Towards a sustainable, human-centric and resilient European industry. Policy brief, European Commission, Brussels 2021.
[6] Skobelev, P. O., & Borovik, S.: On the Way From Industry 4.0 to Industry 5.0: From Digital Manufacturing to Digital Society. Industry 4.0. Vol. 2, No. 6, 2017, pp. 307–311. Available on-line: https://pdfs.semanticscholar.org/dd06/76ec0c1f225900fff0729b516a075e195d8a.pdf?_ga=2.83915353.1395171908.1591124780-70997457.1591124780 [accessed on: 22 April 2022].
[7] Conceptual analysis is a scientific method that seeks to combine existing theoretical approaches in order to develop new insights from them, which can then be empirically verified, see:

about outlining the general assumptions of the proposal. The idea suggested for consideration is to use ambient design, understood as social innovation, to design an optimal urban environment, within SC, taking into account the concept of Society 5.0. The description will include the key definition and the relationship between them to understand the essence of the proposal.

4.2. Society 5.0, Smart city, ambient design – key definitions

Outlining the essence of the concept proposed herein requires an initial definition and a preliminary definition of the main concepts through which the main problem area will be delineated. According to the assumptions contained in the "Introduction", first the idea of Society 5.0 and SC should be presented, then the denotation ranges for the notion of ambient design should be described in order to finally show what theoretical and practical meaning may result from the realization of the concept of Society 5.0 and SC.

4.2.1. Society 5.0 – Definition

The prototype of the Society 5.0 concept was Japan's strategy for the development of technology and innovation announced in 2016 entitled "Comprehensive Strategy on Science, Technology and Innovation for 2016"[8], at which time the crucial assumptions mentioned earlier were established. "The basic schema of Society 5.0 is that data are collected from «real world» and processed by computer, with the results being applied in the real world. […] Society 5.0 will feature an interactive cycle in which data are gathered, analyzed, and then converted into meaningful information, which is then applied in the real world: moreover, this cycle

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Furner J.: Conceptual Analysis: A Method for Understanding Information as Evidence, and Evidence as Information. Archival Science, Vol. 4, 2004, pp. 233–265; Gilson L.L., Goldberg C.B.: Editor's comment: So, what is a conceptual paper?. Group & Organization Management, Vol. 40. No. 2, 2015, pp. 127–130; Jaakkola, E.: Designing conceptual articles: four approaches. AMS Rev, Vol. 10, 2020, pp. 18–26 . Available on-line: https://doi.org/10.1007/s13162-020-00161-0, [accessed on: 12 March 2022]; Stuart M.T.: Philosophical Conceptual Analysis as an Experimental Method. [In:] T. Gamerschlag, D. Gerland, R. Osswald&W. Petersen (eds): Meaning, Frames and Conceptual Representation. Dűsseldorf: Dűsseldorf University Press, 2015, pp. 267–292; Dickson A., Hussein E.K., Adu-Agyem J.: Theoretical and Conceptual Framework: Mandatory Ingredients of A Quality Research, "International Journal of Scientific Research", Vol. 7, 2018, pp. 438–441.

[8] See: Society 5.0. A People-centric Super-smart Society, Hitachi-UTokyo Laboratory Springer, Tokyo 2018. Arsovski S.: Quality of Life and Society 5.0, International Quality Conference 13 IQC Quality Research, 2019. Available on-line: http://www.cqm.rs/2019/papers_iqc/81.pdf [accessed: on 22 March 2022]. Gladden M.: Who will Be the Memebers of Society 5.0? Towards an Anthropology of Technologically Posthumanized Future Societies. Social Science. Vol. 148, No. 8(5), 2019, pp. 1–39.

operates at society-wide level”[9]. This conception of society is often defined as “a human-centred society that balance economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space”[10]. It is also sometimes referred to as “supersmart society” or “human-driven society”[11], pointing to a strong technological orientation on the one hand, but also aiming at social well-being. As emphasized in the introduction, the technological feature of society 5.0 is very important because in this vision, society is to be a cyber-physical system, it is the society “where the advanced IT technologies, IoT, robots, an artificial intelligence, augmented reality (AR) are actively used in people common life, in the industry, health care and other spheres of activity”[12] but not only for the progress, rather for the benefit and well-being of each person. Matthew E. Gladden makes us aware that “the human being who are members of Society 5.0 will also find their bodies, mind, and daily life experience transformed through the application of futuristic technologies. New types of medical devices, […] robotics, AI, and the Internet of Things will have a great impact on not only people’s lifestyle and on their way of being but also on the foundation of its existence”[13]. Carolin Narvaez Rojas and others call this type of society a 'system of systems' [14], based on a complex information infrastructure made up of leading technologies such as IoT, Big Data, and AI linked together, while the primary source of information is a network of sensors used to compile large amounts of data-aggregated, these are then processed by artificial intelligence algorithms and serve as 'tools' to diagnose the state of things and then as a resource of information and knowledge, up to predictions and design of specific social changes. The technologically established process of moving from the knowledge of “what is” to “how it happened that it is” and “what can happen in the future”, and finally “how to precisely program the change” is to become, according to the assumptions of the

[9] Deguchi A., Hirai Ch., Matsuoka H., Nakano T., Oshima K., Tai M., Tani Sh.: What is Society 5.0?. [In:] Hitachi-UTokyo Laboratory(H-UTokyo Lab.) (eds.): Society 5.0. Springer, Singapore 2020. Available on-line: https://doi.org/10.1007/978-981-15-2989-4_1, [accessed: on 17 April 2022].

[10] Society 5.0. Overcoming Societal Challenges and Co-creating the Future Though Digitalisation and Unity in Diversity, Breda University, SAP, Breda 2020. Society 5.0. A People-centric Super-smart Society, Hitachi--UTokyo Laboratory Springer, Tokyo 2018.

[11] See: Society 5.0. A People-centric Super-smart Society, Hitachi-UTokyo Laboratory Springer, Tokyo 2018. Onday O.: Japan’s Society 5.0: Going Beyond Industry 4.0. Bus Eco J, Vol. 10, 2019, pp. 1–6.

[12] Skobelev, P. O., & Borovik, S.: On the Way From Industry 4.0 to Industry 5.0: From Digital Manufacturing to Digital Society. Industry 4.0. Vol. 2, No. 6, 2017, pp. 307–311. Available on-line: https://pdfs.semanticscholar.org/dd06/76ec0c1f225900fff0729b516a075e195d8a.pdf?_ga=2.83915353.1395171908.1591124780-70997457.1591124780 [accessed: on 22 April 2022].

[13] Gladden M.: Who will Be the Memebers of Society 5.0? Towards an Anthropology of Technologically Posthumanized Future Societies. Social Science. Vol. 148, No. 8(5), 2019, pp. 1–39.

[14] Rojas C.N.; Penafiel G.A.A.; Buitrago D.F.L.; Romero C.A.T.: Society 5.0: A Japanese Concept for a Superintelligent Society, “Sustainability”, No. 13/6567, 2021. Available on-line: file:///Users/gra/Downloads/sustainability-13-06567.pdf. [accessed: on 29 April 2022].

concept of Society 5.0, a basic form of social activity allowing, on the grounds of accumulated data, to work out optimal solutions from the point of view of possibilities of improving the quality of life. This principle applies both to the physical infrastructure but also to social activities. In this sense the technological potential becomes the foundation of society's flexibility and the measure of its adaptability. This applies to every type of environment in which human beings function, from urban infrastructure with intelligent processes of energy, water, and transport networks, through the organization of production processes, agriculture, to the organization of leisure and emergency response. This digital transformation is expected to change many aspects of society, including private life, public administration, industrial structure, and employment, through the use of cyberspace and their integration with physical spaces. Therefore, the Society 5.0 model brings with it a number of changes that open up opportunities to create new systems and processes. These changes are technological, but also economic, geopolitical, social, and mental. The focus on the human being as the central element of change allows us to combine technological development with economic growth while giving hope for a sustainable future. This new concept of society aims to focus on the human to balance the deployment of Big Data Technologies, the Internet of Things, and Artificial Intelligence with the resolution of major problems of society such as: competitiveness, productivity, connection, and wellbeing – all these on the basis of achieving the maximization of human use of the ongoing technological transformation, digitization.

4.2.2. Smart City – Definition

In its broadest sense, Smart City is associated with the use of digital technologies such as the Internet of Things (IoT), cloud-based analytical and calculation systems based on Big Data, the application of solutions based on artificial intelligence (AI), and deep machine learning enabling the automation of all processes related to the functioning of the city[15]. SC researchers point to a lack of unanimity as to how the term itself should

[15] See: Ahvenniemi H., Huovila A., Pinto-Seppa I., Airaksinen M.: What are the differences between sustainable and smart cities?. Cities, Vol. 60, 2017, p. 234–245; Appio F.P., Lima M., Paroutis S.: Understanding Smart Cities: Innovation ecosystems, technological advancements, and societal challenges. Technological Forecasting & Social Change, Vol. 142, 2019, pp. 1–14; Jonek-Kowalska I.: Zrównoważony rozwój inteligentnych miast. Dotychczasowe osiągnięcia i nowe wyzwania. Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie, Vol. 118, 2017, pp. 237–246; Jonek-Kowalska I., Kaźmierczak J., Kramarz M., Hilarowicz A., Wolny M.: Introduction To The Research Project Smart City: A Holistic Approach. 2018. Available on-line https://www.sgemsocial.org/index.php/jresearch-article?citekey=Jonek-Kowalska201819101112 [accessed on: 28 January 2022); Kaźmierczak J.: SMART CITY jako obszar wyzwań edukacyjnych, [w:] Wyzwania

be defined[16], but this helps to realize that the concept of smart city itself is not homogeneous. The formerly dominant approach strongly emphasized the technological aspect and is now increasingly complemented by social elements[17]. However, considering a number of definitions, it is possible to identify some common significant aspects that allow us to grasp the most crucial points for the concept itself, such as efficiency, environmental considerations and innovation[18]. Efficiency can be understood as the ability of a city to provide effective public and private services to all actors of urban life, such as citizens, businesses, non-profit organizations, etc. In this context, the main function of a smart city is to create public value for its inhabitants. In the case of environmental considerations, it is about protecting it and preventing its degradation mainly in areas such as energy consumption, water and air pollution, traffic congestion, rapid urban sprawl reducing the amount of green space. In this context, a smart city is a city that cares about the quality of its environment, including that of future generations. Therefore, the definition of SC should take into account integrative approaches reaching a compromise between the needs of all city stakeholders and taking the improvement of the quality of life in a city, including environmental factors understood in a broader

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i uwarunkowania zarządzania inteligentnych miast, Wydawnictwo Politechniki Śląskiej, Gliwice, 2020. Available on-line: https://www.researchgate.net/publication/339285514_Chapter_SMART_CITY_jako_obszar_wyzwan_edukacyjnych [accessed on: 28 January 2022]; Kidyba M., Makowski Ł.: Smart City. Innowacyjne rozwiązania w administracji publicznej a zarządzanie inteligentnym miastem, Wydawnictwo Wyższej Szkoły Bankowej w Poznaniu, Poznań 2018; Kummitha R.K.R., Crutzen N.: How do we understand smart cities? An evolutionary perspective. Cities. Vol. 67, 2017, pp. 43–52; Patel Y., Doshi N.: Social implication of smart city. Procedia Computer Science. Vol. 155, 2019, pp. 692–697.

[16] See: Kuzior A.: Zastosowanie modelu Quintuple Helix w projektowaniu Smart Sustainable City. [In:] Jonek-Kowalska I, Kaźmierczak J. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp.15–26; Kummitha R.K.R., Crutzen N.: How do we understand smart cities? An evolutionary perspective. Cities. Vol. 67, 2017, pp. 43-52; Kummitha R.K.R.: Smart cities and entrepreneurship: An agenda for future research, "Technological Forecasting & Social Change", 149, 2019, pp. 1–10; Patel Y., Doshi N.: Social implication of smart city. Procedia Computer Science. Vol. 155, 2019, pp. 692–697; Preharaj S., Han H.: Cutting through the clutter of smart city definition: A reading into the smart city perceptions in India. City Culture and Society. Vol. 18, 2019, pp. 1–10; Sojda A., Owczarek T., Wolny M.: Smart City w ujęciu zorientowanym na dane – Polska w bazie Eurostat. Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie. Vol. 30, 2018, pp. 557–566; Calzada I., Cowie P.: Beyond Smart and Data-Driven City-Regions? Rethinking Stakeholder-Helixes Strategies, Regions. The Voice of The Membership, Vol. 308, No. 4, 2017, pp. 25–28.

[17] See: Rożałowska B., Macełko M.: Miasto jako organizacja ucząca się. O znaczeniu idei inteligentnego miasta (obywatela) w społeczeństwie informacyjnym. Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie, Vol. 79, 2015, pp. 279–283; Rożałowska B.: Smart Citizen – społeczności miejskie w procesie budowania „inteligencji" miasta. Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie. Vol. 95, 2016, pp. 430–440; Rożałowska B.: The Functioning of Smart City in the Context of Global City Ranking, Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie, Vol. 146, 2020, pp. 413–425; Osika G. Connexity jako element koncepcji Smart City – analiza wybranych aspektów na przykładzie polskich miast. [In:] Jonek-Kowalska I, Kaźmierczak J. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 123–136; Kowalska-Styczeń A.: Badanie złożoności zjawisk społecznych w kontekście inteligentnego miasta. [In:] Jonek_Kowalska I., Kaźmierczak I. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 137–146.

[18] Dameri R.P., Rosenthal-Sabroux C. (eds.): Smart City: How to Create Public and Economic Value with a High Technology in Urban Space. Springer, Cham-Heidelberg-New York–Dordrecht–London 2014.

perspective, as the goal of its activities[19]. In the conception of SC, technology inevitably takes a central place as it provides the tools for realization of the previous assumptions, but the innovations that arise from it also have a social character, and they are social innovations[20]. The areas that are emphasized in the context of applying technological solutions are: smart administration, smart energy, smart buildings, smart transport solutions, smart urban infrastructure, smart healthcare and smart citizens[21]. Technology infrastructure, on the other hand, includes: Internet of Things (IoT), which allows to make contact "anytime", "anywhere", "with everything" through technical identification and high performance mobile technology (5G), using among others systems such as GSM, WiFi, Bluetooth, ZigBee, Z-Wave, beacons, femtocells, wireless sensor networks, etc. It becomes possible to continuously transfer data on the Internet[22]. The acquired data is then aggregated in databases and constitutes a valuable resource that enables its further processing depending on the needs, i.e., the so-called Big Data (BD). BD analyses play a key role in SC management, because they create new decision-making potential, and the choices made in management actions with a high level of risk are supported by information derived from data provided and processed in real time. In addition, these processes allow us to develop procedures of action, algorithms, which can be successfully used in analogous situations. A great advantage of tools based on Big Data is their universal application within all functions typical for the management process, i.e. planning, organizing, directing, and controlling, whose effectiveness increases with the application of the so-called artificial intelligence (AI), another key SC technology. AI solutions are important from the point of view of being able to use the acquired data and transform it into meaningful information allowing one to manage the entire city infrastructure in a coordinated way[23]. Taking into account the above findings, we can assume that the concept of SC fits into the general assumptions of Society 5.0, as indicated both by its goal, i.e. building an environment focused on the well-being of its members/citizens, and in terms of the tools that are planned to be used for this purpose. But the realization of these intentions requires the consideration of concrete ideas, in this

[19] Patel Y., Doshi N.: Social implication of smart city. Procedia Computer Science. Vol. 155, 2019, pp. 692–697; Osika G. Connexity jako element koncepcji Smart City – analiza wybranych aspektów na przykładzie polskich miast. [In:] Jonek-Kowalska I, Kaźmierczak J. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 123–136.

[20] See: Osika G. Connexity jako element koncepcji Smart City – analiza wybranych aspektów na przykładzie polskich miast. [In:] Jonek-Kowalska I, Kaźmierczak J. (eds): Inteligentny rozwój inteligentnych miast. CeDeWu, Warszawa 2020, pp. 123-136; Osika G.: Social Innovation as a Support for Industry 4.0. Scientific Papers of Silesian University of Technology, Organization and Management Series. Vol. 141, 2019, pp. 289–301.

[21] Patel Y., Doshi N.: Social implication of smart city. Procedia Computer Science. Vol. 155, 2019, pp. 692–697.

[22] See: Patel Y., Doshi N.: Social implication of smart city. Procedia Computer Science. Vol. 155, 2019, pp. 692–697; Kidyba M., Makowski Ł.: Smart City. Innowacyjne rozwiązania w administracji publicznej a zarządzanie inteligentnym miastem, Wydawnictwo Wyższej Szkoły Bankowej w Poznaniu, Poznań 2018.

[23] Patel Y., Doshi N.: Social implication of smart city. Procedia Computer Science. Vol. 155, 2019, pp. 692–697.

discussion it is proposed to pay attention to the potential inherent in ambient design, as a form of, as Karl R. Popper called it "piecemeal social engineering"[24] allowing one to improve reality in small steps, using "tailor-made" solutions.

4.2.3. Ambient Design as Social Innovation

Implementation of the Smart City idea within Society 5.0 and determining the optimal way of solutions based on their assumptions require a series of technical but also social innovations, because the latter are the condition for widespread adoption of technology underlying the planned changes. While innovation is proposed to be understood as a purposely designed change which has the characteristics of novelty[25], this novelty may relate to products, manufacturing methods, management methods, etc. From the point of view of these considerations, social innovations are of key importance, because this is how we can treat the necessary transformations of cities and society that can serve the implementation of the visions described above. It is widely accepted that social innovations include social transformations; new forms of organizational management; new forms of entrepreneurship; new products, services, and programs aimed at satisfying social needs, as well as activities that strengthen the position and improve the efficiency of social institutions[26]. The cited classification, on the one hand, shows how wide the scope of this concept is, and, on the other hand, very concretely locates the object of innovation, because each time the emerging novelty concerns the community and the realization of the needs of its members[27]. As Rabeh Morrar and others point out, "the concept of social innovation denotes the processes and factors that lead to a sustained positive transformation to the […] society […]. It is defined as an innovative solution to the increasing challenges facing society, one that is more effective, more efficient, more sustainable, or more equitable than existing practices"[28]. Hence, "innovation is every novel change, while social innovation is such an novel change, that remodels the manner of community functioning, that is, it establishes a new manner of relations, new structure, it reconfigures the course of social processes, it creates new

[24] Popper K.R. and Gombrich, E.H.: The Open Society and Its Enemies, Princeton University Press, Princeton, New Jersey 2013.
[25] Baruk J.: Zarządzanie wiedzą i innowacjami, Wyd. Adam Marszałek, Toruń 2006.
[26] Wronka-Pośpiech, M.: Innowacje społeczne. Pojęcie i znaczenie. Studia Ekonomiczne. Zeszyty Naukowe, Vol. 212, 2015, pp. 124–136.
[27] Osika, G.: Social Innovation as a Support for Industry 4.0. Scientific Papers of Silesian University of Technology, Organization and Management Series. Vol. 141, 2019, pp. 289–301.
[28] Morrar, R., Arman H., Mousa S. : The Fourth Industrial Revolution (Industry 4.0): A Social Innovation Perspective. Technology Innovation Management Review, Vol. 7, No. 11, 2017, pp. 12–20.

behavior patterns etc."[29]. At the core of social innovation is the knowledge potential and cultural capital of a community[30], and the essence of these is to improve the quality of life of community members. Such controlled changes can only occur through conscious design, so the design process itself seems crucial to the results obtained, which we can define as planning, shaping the course of performance of some activity with the intention of realizing wanted, anticipated goal; thus, it is a conscious effort made to establish a meaningful order[31]. But if we want to design according to the vision contained in the SC and Society 5.0 concepts described above, we cannot focus on single solutions, rather we should take a comprehensive approach in the spirit of 'ambient design', according to Latin etymology – ambient means to surround, encompassing[32]. Developing this concept, we can define ambient design as the conscious shaping of elements of the environment in order to achieve the most optimal, quality of life, experience of 'being in a certain environment', and similarly, of 'being in a certain city', 'being in a certain society'.

4.3. Ambient design – Efficiency Ranges

Researchers studying the determinants of well-being in cities point to the need for a holistic approach to the problem and the remedial actions applied[33], thinking in terms of the overall environment rather than intervening in the form of separate solutions. Therefore, the transformation of cities in the spirit of ambient design seems promising, as it takes into account a holistic perspective. In design processes, incorporate everything that surrounds me, that makes up the way I experience a place, a neighborhood, a city. Jonathan F.P. Rose proposes to call this experience a 'cognitive ecosystem', which, according to the research he cites, is a prerequisite for both mental and physical health. He defines it as "the mental landscape in which people think, feel, and interact with the

[29] Osika, G.: Innowacje społeczne jako wsparcie dla inteligentnych specjalizacji – uwarunkowania komunikacyjne. Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska, Vol. 95, 2016, pp. 369–38.
[30] Nicholls, A., Murdoch, A.: Social Innovation. Blurring Boundaries for Reconfigure Markets, PLAGRAVE &MACMILLAN, New York 2012.
[31] Papanek V.: Design For The Real World. Human Ecology and Social Change, Thames &Hudson, London 2006.
[32] Latinitum. Latin dictionary, https://latinitium.com/latin-dictionaries/?t=lsn2163,do31 [accessed on: 4 May 2022].
[33] See: Montgomery Ch.: Happy city. Transforming our lives through urban design, Farrar, Straus, and Giroux, New York 2013; Rose J.F.P.: Dobrze nastrojone miasto. Czego współczesna nauka, pradawne cywilizacje i ludzka natura mogą nas nauczyć o przyszłości życia w mieście Krakter. Kraków 2019; Whyte W.H.: The Social Live of Small Urban Spaces, Project for Public Space, New York 1980; Romice O., Thwaites K., Porta S., Greaves M., Barbour G., Pasino P.Urban Design and Quality of Life, [In:] G. Fleury-Bahi, E. Pol, O. Navarro (eds.): The Handbook of Environmental Psychology and Quality of Life, Springer 2016 (e-book), pp. 241–271.

world," as he further states, "it interacts with and is itself modified by social networks"[34]. In turn, as Montgomery's research shows, it is well-established social networks that form the basis of experienced well-being in a city, which is why urban management should focus on building social capital[35]. In the design process, then, ambient design takes an ecosystem perspective, where it is about creating a symbiotic place that works and is tailored to its inhabitants, rather than one-size-fits-all solutions that are for everyone, and therefore for no one. We are talking, of course, about technical innovation, which is the core of SC, but also about social innovation, which is even asking to incorporate existing cultural context. This is the first reason why there are grounds for recognizing its usefulness in the urban design process, SC uses digital technology, but its application should be focused on human wellbeing.

And while 'ambient' itself points to the content of the design, helping to realize the idea of a human-centered living environment. The second part of the phrase reveals the method that should be used to do so. As indicated earlier, to design is to consciously shape, to attempt to bring about order with the hope that the project will be successful, but these actions do not take place in a vacuum. In this case we are given methods that have been already developed. First, as Victor Papanek points out, design should be "an innovative, hugely creative, cross-disciplinary tool responsive to the true needs of men[36]. The essence of good design is functionality, which, while being a direct response to needs, is also a complex of factors such as method includes tools, materials, processes; association means family & early environment, education, and culture; aesthetics i.e. gestalt, perception, eidetic & biosocial 'givens'; need namely survival, identity, goal formation; telesis means nature, society, technological bias; use understanding as tool, as communication, as symbol. "The function complex […] appears at each of the six aspects, indicating the soft-hard, feeling-thinking, intuitive-intellectual mix, which determines each of these six evaluative criteria"[37]. Using Papanek's proposed approach in urban design processes, we gain:

- the possibility of applying a very specific methodology of action from the field of design processes;
- possibility of choosing the scale of social action from micro- through meso- to macro-;

[34] Rose J.F.P.: Dobrze nastrojone miasto. Czego współczesna nauka, pradawne cywilizacje i ludzka natura mogą nas nauczyć o przyszłości życia w mieście Krakter. Kraków 2019.
[35] Rose J.F.P.: Dobrze nastrojone miasto. Czego współczesna nauka, pradawne cywilizacje i ludzka natura mogą nas nauczyć o przyszłości życia w mieście Krakter. Kraków 2019.
[36] Papanek V.: Design For The Real World. Human Ecology and Social Change, Thames &Hudson, London 2006.
[37] Papanek V.: Design For The Real World. Human Ecology and Social Change, Thames &Hudson, London 2006.

- change of the action formula from general strategies to the so-called “piecemeal social engineering”, i.e., creation of “tailor-made” environmental, social innovations;
- maximization of adaptation activities – thanks to the adjustment of the scale, methods, and assumed effects;
- high probability of optimization of action.

4.4. Conclusions

As was pointed out in the introduction, the realization of the assumptions of Society 5.0, which involves a very specific way of designing future cities, must not only concern a series of technical innovations, but also include social innovations allowing to ensure a high quality of life of citizens. That is why it was considered so important to take this aspect into account in the implementation of both the SC and Society 5.0 assumptions. The present discussion should be treated as a conceptual sketch, as evidenced by the research method used conceptual analysis. Obviously, this sketch will require deeper analysis and critical reflection in the future, but also extensive development in relation to methodological approaches and their further application. The idea proposed to be considered was the use of ambient design, understood as social innovation, to design an optimal urban environment, within the SC framework, taking into account the concept of Society 5.0. In the description, the key definitions and the relations existing between them were taken into attention, which allowed one to understand the essence of the proposal and its validity in the discussed context. It seems that the presented treatment of social innovation as an environmental project is supported both for conceptual reasons and indications of a pragmatic nature.

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Mateusz PIEGZA[1]

5. REPURPOSING EMPTY SPACES AS A PART OF MUNICIPAL PROGRAMS FOR URBAN REGENERATION

5.1. Introduction

The challenges of the housing sector in Poland have been overlooked in the public debate, and the answer to the question "what is the shortage of flats in Poland?" evokes strong emotions. Estimates from 2016 indicate that the deficit is nearly 800 thousand housing units[2]. In the following years, the number of housing units in Poland grew dynamically. According to GUS (Polish Central Statistical Office) data, in years 2016–2022 954,970 flats were handed over for use[3] In 2021, Poland had the highest number of new dwellings built per capita in the EU countries[4]. It should be stressed that the vast majority of investments are commercial projects with flats at market prices, not available to middle or low income earners. What also made impact was a result of Russian invasion on Ukraine, which began on 24th February 2022: nearly 3 million Ukrainians fled to Poland. It is estimated that nearly half of them will stay there permanently[5]. This immigrant influx has significantly exacerbated the shortage of affordable housing, which the author estimates, as of today, at 600 thousand flats.

The situation outlined above has forced the implementation of unprecedented temporary housing solutions. Polish families invited Ukrainians at their homes, municipalities converted sports buildings into collective housing, NGOs developed their own programs to provide housing for refugees. However, there is a lack of systemic solutions to build long-term housing solutions. In a letter to the Prime Minister of the

1 Silesian University of Technology, Faculty of Architecture, Department of Theory, Design and History of Architecture, e-mail: Mateusz.piegza@polsl.pl.
2 Twardoch A.: Systemy do mieszkania, Wydawnictwo Bęc Zmiana, Warszawa 2019.
3 https://demagog.org.pl/wypowiedzi/ile-mieszkan-oddano-do-uzytku-w-ciagu-ostatnich-pieciu-lat/?cn-reloaded=1 [access: 04.05.2022].
4 Raport Property Index 2021: „Jak mieszkają Europejczycy I ile ich to kosztuje", Delloite [źródło:https://www2.deloitte.com/pl/pl/pages/real-estate0/articles/raport-property-index-2021.html [access: 04.05.2022].
5 https://300gospodarka.pl/news/uchodzcy-z-ukrainy-w-polsce-liczba [access: 04.05.2022].

Republic of Poland dated 17.03.2022, a group of experts associated in the Rental Foundation points out, among others: the need to increase the stock of available housing, which is possible through adaptation of vacant public resources (communal resources owned by municipalities, State Treasury and State Treasury companies resources)[6]. In 2021, Habitat For Humanity Poland Foundation commissioned to the Institute for Urban and Regional Development (IRMiR) counting public vacant housing stock. According to the report, local authorities reported 817 buildings and 6201 dwellings as vacant. It needs to be noted that 255 out of 13,000 respondents (municipalities, state-owned companies, receivers, housing communities) sent data for the report which constitutes less than 2% response rate[7]. A full picture of the number of vacant units (both public and private) is expected as a result of the Census 2021, in the second half of 2022. The analysis of statistical data leads to the conclusion that repurposing public vacant units is one of the methods for reducing the deficit of affordable houses in Poland.

The aim of this paper is to analyse the literature on the subject – mainly expert studies prepared by the Institute for Urban and Regional Development; to analyse selected Polish local regeneration programs for Polish cities and then to determine the potential and barriers for the adaptation of vacant buildings as part of municipal renewal programs. The paper is enriched with illustrations depicting examples of projects implemented within the framework of regeneration programmes.

5.2. State of the research

There are numerous Polish studies on the renewal practices of Polish cities and containing an evaluation of processes on a national scale[8]. Items describing implemented regeneration programs in selected European countries[9] can also be found. Experts indicate that municipalities rarely choose housing projects for implemented renewal programs[10]. The analysis of the sources led to the conclusion that due to the rarity of

[6] https://ryneknajmu.org/list-rady-frn-do-premiera-rp [access: 04.05.2022].

[7] Jadach-Sepioło A., Tomczyk E., Wysocki K., Milewska-Wilk H.: Pustostany w gminach i możliwości ich przekształcenia w mieszkania dostępne cenowo dla osób niezamożnych, Instytut Rozwoju Miast i Regionów, Warszawa 2021.

[8] Jadach-Sepioło A., Sobiech-Grabka K.: Bariery rozwoju przedsiębiorczości na obszarach rewitalizacji – badanie skuteczności podejmowanych interwencji, raport z badań statutowych, Szkoła Główna Handlowa, Warszawa 2017.

[9] Bryx M., Jadach-Sepioło A. Rewitalizacja miast w Niemczech, seria „Rewitalizacja miast polskich", Vol. 3, Instytut Rozwoju Miast, Kraków, Warszawa 2009.

[10] Guzik R.: Rewitalizacja miast w Wielkiej Brytanii, seria „Rewitalizacja miast polskich", Vol. 1, Instytut Rozwoju Miast, Warszawa 2009.
Mróz A. Rewitalizacja w praktyce. Modele rozwiązań jako rezultaty konkursu Modelowa Rewitalizacja Miast i pilotaży w zakresie rewitalizacji, Krajowy Instytut Polityki Przestrzennej i Mieszkalnictwa, Warszawa 2018.

implementation, building adaptation as an element of regeneration for increasing the housing stock of municipalities is not sufficiently exposed.

"Report on the State of Polish Cities. Regeneration" prepared by the Institute for Urban and Regional Development in 2019 includes a chapter "Regeneration and housing" by Alina Muzioł-Węcławowicz, PhD[11]. The author presents the stages of the renewal process in Poland since 2004; she points out the available tools that improve the process; links between regeneration programs and available EU funds (mainly European Regional Development Fund, RPO 2014–2022). The content is enriched with a review of selected regeneration programs implemented by cities such as Szczecin, Bydgoszcz, or Warsaw. In the conclusion Muzioł writes: "Housing projects – contrary to obvious logic and actual needs – still do not play a fundamental role in regeneration process. The renewal of housing stock is still at the stage of being interesting good practices and experiments, while mass actions are necessary to complete the process in a foreseeable perspective (15 years)" (Mync 2018)[12].

This study complements the above mentioned paper with an analysis of the regeneration programs of municipalities which had not been included in the study.

The acquired knowledge will allow to refer to the conclusions pointed by PhD Muzioł-Węcławowicz and to determine a wider group of possibilities and barriers for the popularization of adaptation of the existing tissue for the benefit of increasing the housing stock of Polish cities.

5.3. Methods and materials

This study was conducted in Poland in March-April 2022. The following methods were applied: historical-interpretative, logic argumentation and case study. Selected, adopted by Polish municipalities renewal programmes with housing component were analysed which were not described by Muzioł-Węcławowicz, which is: *Local Regeneration Programme for years:*

a) "Wrocław Local Regeneration Programme for years 2005–2006 and 2007–2013"[13],
b) "Jelenia Góra Local Regeneration Programme for years 2008–2013"[14],

[11] Muzioł-Węcławowicz A.: Rewitalizacja a mieszkalnictwo [In:] Jarczewski W., Kułaczkowska A. (eds.): Raport o stanie polskich miast Rewitalizacja, Instytut Rozwoju Miast i Regionów, Warszawa 2019.

12 Mync P.: Problematyka mieszkaniowa w programach rewitalizacji – perspektywa praktyka, materiały V Kongresu Rewitalizacji, Lublin 2018.

[13] Lokalny Program Rewitalizacyjna na lata 2005–2006 i lata 2007–2013 miasta Wrocław, Resolution of the City Council of Wroclaw, Vol. XLIV/2969/05, Wroclaw 2005.

[14] Lokalny Program Rewitalizacyjny Miasta Jelenia Góra na lata 2008–2013, Resolution of the City Council of Jelenia Góra, Vol. 341.XXXV.2013, Jelenia Góra 2013.

c) "Leszno Local Regeneration Programme for years 2010–20015"[15],
d) "Grajewo Municipal Regeneration Programme for years 2017–2027"[16].

Due to the subject matter of the paper, it seems appropriate to introduce the reader to the term "vacancy"/"empty space". GUS defines vacancy as follows: "a dwelling in which at the time of the statistical survey no person was registered (for permanent or temporary residence) or no person lived, even temporarily, without registration"[17]. A different definition was adopted by the IRMiR during a study conducted for the Habitat Foundation, which was mentioned earlier: "a definition of vacancy was established as a premises or building unused for the last 12 months". In the following part of the research, the abbreviation LRP is used, which means Local Revitalization Program.

5.4. Case study

5.4.1. Wrocław

Wrocław is a city with poviat rights (Polish administrative district) located in south-western Poland, the seat of local government of the Lower Silesian Voivodeship. As of 2019 the population of the city was 641,929. On December 8th 2005 the City Council of Wrocław adopted the document "Local Regeneration Program for 2005–2006 and 2007–2013", and then, on April 21st, 2016, "Local Regeneration Program for 2016–2018". This analysis concerns the former document. It specifies the area for the planned regeneration activities, i.e. 6500 ha, which is 22% of the total area of the city. Analytical works carried out before the creation of the target horizontal regeneration programs showed the following, among others: neglect in the renovation of buildings and structures owned by the city, excessive exploitation of the city, the need to revitalize the Old Town area, lack of coordination of individual regeneration projects from the past. The first part of the LRP for the years 2005–2006 and 2007–2013 lists the strategic objectives for regeneration of the city. None of them refers directly to increasing the housing stock. Selected ones, i.e. improvement of housing stock standards, restoration of the lost value of properties, adaptations of buildings for economic, social and cultural

[15] Lokalny Program Rewitalizacyjny Leszna na lata 2010–20015, Resolution of the City Council of Leszno, Vol. XLII, No. 504, Leszno 2010.
[16] Gminny Program Rewitalizacji Miasta Grajewo na lata 2017–2027, Resolution of the City Council of Grajewo, Vol. XLVII, No. 370, Grajewo 2018.
[17] Niezabitowska E.D.: Metody i techniki badawcze w architekturze, Wydawnictwo Politechniki Śląskiej, Gliwice 2014.

purposes, correspond with it indirectly. The program lists 10 categories of actions, including four related to the residential tissue, i.e.: tenement houses, small-town development areas, pre-war housing estates and areas of block housing. In the LRP, justification for each group and a list of expected effects was provided. Actions aimed at renewal of the substance of buildings, thermal efficiency improvement of buildings, improvement of housing conditions, exposure of historical values, change of functions of common parts were assumed. Adaptation of vacant buildings for housing purposes was not mentioned[18].

In Annexes 2 and 3 to the LRP, 341 regeneration projects were planned, of which 80 were related to adaptation of residential buildings, i.e.: 30 renovations of tenements, 5 renovations of multi-family residential buildings, 40 renovations of multi-family buildings, 4 service and residential buildings, and 1 other type. For most of them, buildings thermal efficiency improvement, replacement of installations, replacement of roofs, change of the function of first floors or entire buildings to non-residential functions were assumed. Project descriptions do not indicate that the purpose is to adapt vacant buildings to additional housing functions. Figure 5.1 presents a photograph of the façade of the tenement houses located at 5-6 Grodzka Street, which were carried out within the LRP.

Fig. 5.1. A tenement with flats in Wrocław at Grodzka 5–6 street after renovation within the LRP in years 2005–2006. Archives from 2008. Source: https://polska-org.pl/742054,foto.html [access: 05.05.2022]

Rys. 5.1. Kamienica mieszkalna zlokalizowane we Wrocławiu przy ul. Grodzkiej 5–6 po renowacji, zrealizowanej w ramach LPR 2005–2006. Zdjęcie archiwalne z roku 2008. Źródło: https://polska-org.pl/742054,foto.html [dostęp: 05.05.2022]

[18] Lokalny Program Rewitalizacyjna na lata 2005–2006 i lata 2007–2013 miasta Wrocław, Resolution of the City Council of Wroclaw, Vol. XLIV, No. 2969, Wroclaw 2005.

5.4.2. Jelenia Góra

Jelenia Góra is a city with poviat rights located in south-western Poland, in Lower Silesian Voivodeship. In 2020, the population of the city was 78,335 inhabitants. In recent years, the City Council of Zielona Góra has adopted two revitalization programs: “LPR of the City of Jelenia Góra for 2008–2013” and “LPR of the City of Zielona Góra for 2015-2023”. The first one was analysed. The area designated for regeneration occupies 196.5 ha, which constitutes 1.8% of the total area of the city. The following challenges were outlined: degradation of urban areas, destructive phenomena and processes in the economic, spatial and social sphere, population decline, high poverty rate, lack of a coherent long-term regeneration policy for the city, punctual revitalization activities .

The main goal in LRP of Jelenia Góra for 2008–2013 has been defined i.e.: counteracting marginalization of socially, economically, and spatially degraded area of Jelenia Góra. Specific goals were: increasing the quality of space of degraded areas, improving housing conditions of the population of the degraded area, counteracting social and economic isolation of inhabitants of the degraded area of the city. The LRP assumed the implementation of 17 projects, 10 of which concerned the improvement of housing conditions. The scope of the vast majority of them concerns modernization of roofs, staircases, buildings thermal efficiency improvement, replacement of windows, strengthening of structural parts of the building. A sample project is shown in Figures: 5.2. Housing projects of the LPR did not assume adaptation of unused buildings for housing purposes and renovation of unoccupied housing units in the indicated buildings. The actions indicated in the LRP focused on improving housing conditions and the aesthetics of buildings, rather than expanding the city's housing stock[19].

[19] Lokalny Program Rewitalizacyjny Miasta Jelenia Góra na lata 2008–2013, Resolution of the City Council of Jelenia Góra, Vol. XXXV, No. 341, Jelenia Gra 2013.

Fig. 5.2. Regeneration of a tenement in Jelenia Góra at Złotnicza 4, photo before and after and elevation improvement. Source: https://docplayer.pl/57963534-Renowacja-budynkow-przy-ul-zlotniczej-2-4-6-8-10-w-jeleniej-gorze.html [accessed: 08.05.2022]

Rys. 5.2. Rewitalizacja kamienicy mieszkalnej w Jeleniej Górze przy ul. Złotniczej 4, zdjęcie przed oraz projekt elewacji. Źródło: https://docplayer.pl/57963534-Renowacja-budynkow-przy-ul-zlotniczej-2-4-6-8-10-w-jeleniej-gorze.html [dostęp: 08.05.2022]

5.4.4. Leszno

Leszno is a city with poviat rights located in the western part of Poland, in Wielkopolskie Voivodeship. In 2020 the population of the city was 62,854 inhabitants. Two horizontal regeneration documents have been developed in Leszno, i.e.: "LPR of Leszno for 2010–20015 and Municipal Regeneration Programme of the City of Leszno for 2017–2027". The first one was analysed. The areas indicated for renewal where the highest level of poverty was found, located in the city centre, were determined. The main problem of the specified area was identified as: "progressive spatial degradation, combined with an intensification of social problems". The LRP does not state the ratio of the area to the city area. It is estimated to be 1–2%. The main aim of the LRP was to: "Improve the functionality of the Old Town area of Leszno in terms of local and sub-regional service for city residents, tourists and entrepreneurs". It is to be achieved through numerous activities divided into three groups: spatial, economic, and social. Two of the activities of the first group are related to the adaptation of residential buildings, i.e.: "Renovations of residential buildings also with internal installations and surroundings, including yards and playgrounds in the strict area of the Old Town and residential blocks of parts of the Prochownia and Grunwald estates located in the area indicated for revitalization" and "Thermal efficiency improvement of residential and public buildings". Descriptions of LRP tasks do not assume adaptation of unused flats, buildings or increase of housing resources of the municipality[20].

[20] Lokalny Program Rewitalizacyjny Leszna na lata 2010–20015, Resolution of the City Council of Leszno, No. XLII/504/2010, Leszno 2010.

The discussed LRP, due to financial constraints, assumed 19 projects including 2 which covered improving condition of residential buildings i.e.: "Conservation works, renovation of façades and roofs of buildings with architectural value and historical significance of the Old Town in Leszno that are in the register of monuments" and "Repair of buildings that constitute the housing stock of the City of Leszno". As mentioned before, these projects did not concern adaptation of vacant buildings. No specific action was proposed for a considerable part of the identified needs. Figure 4 shows the façade of a former vinegar factory in Leszno. The building was presented in the LRP, in the section "Spatial conditions and problems of the area to be renewed", where its new function was defined as residential. Ultimately, its regeneration was not proposed.

Fig. 5.3. Former vinegar factory building intended for residential building as per LRP. Source: "Leszno LRP for years 2010–2015"
Rys. 5.3. Budynek fabryki octu w Lesznie przeznaczony mocą LPR na funkcje mieszkaniową. Źródło: „LPR Leszna na lata 2010–20015"

5.4.4. Grajewo

Grajewo is a city with poviat rights located in northeastern Poland, in Podlaskie Voivodeship. In 2021, the population of the city was 21,614 inhabitants. In 2017, the City Council of Grajewo adopted the "Municipal Revitalization Program of the City of Grajewo for 2017–2027", which was relocated for housing projects. The document indicates a regeneration area, overlapping significantly with the city centre, with an area of 76.37 ha, which is 4% of the city area. Some challenges for the area are formulated as follows: high unemployment and poverty rate; migration and aging of the population;

low attractiveness of the area for entrepreneurs; noise pollution; perception of the city centre as unattractive and dangerous[21].

In the Grajewo Municipality Regeneration Program, the renewal mission was set as follows: "to regenerate the Grajewo city center". In order to achieve it, four objectives were set, one of which concerns housing issues, i.e.:

a) an active, integrated society, acting for the benefit of the community of the regeneration area;
b) reduced scale of negative social phenomena in the regeneration area and increased social cohesion;
c) increased economic activity of the regeneration area and entrepreneurship of the regeneration area residents,
d) public spaces: attractive and adjusted to different groups of users of the regeneration area and functional, safe and aesthetic urban space;
e) active institutions and inhabitants of the regeneration area,
f) improved quality of housing space in the regeneration area.

The Grajewo Revitalisation Program assumed 29 projects of various types, 10 of which were housing projects. All of them concern thermal efficiency improvement of complexes or single multifamily residential buildings. The scope of works includes most often: completion of central heating installation and heat substation, completion of hot water installation, building elevation, staircase renovation or roof covering replacement. These projects are focused on improving living conditions, not on enlarging communal housing stock.

5.5. Conclusions

The research results of selected regeneration programs which take into account housing projects, especially adapting vacancies are shown in Table 5.1. In the analysed documents housing projects were included, however, they did not include repurposing empty spaces (buildings, houses). Most of the actions concerned improving housing conditions of inhabited flats i.e. buildings thermal efficiency improvement, exchanging windows, roofs or modernization of construction elements. Only for one among four LRPs, Leszno, a potential of adapting unused non-residential buildings to houses was determined. Due to budget restraints, such project was not brought to life.

[21] Gminny Program Rewitalizacji Miasta Grajewo na lata 2017–2027, Resolution of the City Council of Grajewo, No. XLVII/370/18, Grajewo 2018.

Table 5.1

Analysis of selected regeneration programs with housing projects

Program name	Indication in vacancies potential diagnosis	Total number of assumed projects	Number of housing projects	Number of housing projects on adapting vacancies
LRP for years 2005–2006 and 2007–2013 city of Wrocław	No	341	80	0
LRP Jelenia Góra for years 2008–2013	No	17	10	0
LRP Leszno for years 2010–2015	Yes	19	2	0
Municipal program for regeneration of city of Grajewo for years 2017–2027	No	29	10	0

Repurposing vacant spaces is not taken into account in diagnosis elaborated for regeneration programs despite the fact that inhabitants indicate such actions as desired. Municipalities are more willing to build new housing stock than to transform an existing space due to operational costs, ability and financing availability. What is more, this method is not considered as the proper one on central level for example in National Housing Programme. Muzioł also stresses limited availability of financial instrument in previous European Funds. All these barriers cause that municipalities resign from realizing adapting vacancies projects in regeneration programmes.

It is recommended to broaden research on regeneration programs to include housing projects which are based on adapting empty spaces into residential space. It would also be beneficial to revise assumptions for the available (e.g. Subsidy Funds by BGK) and planned (e.g. subprograms for the EU Funds 2021–2027) methods of financing renewal programs for municipalities and related entities to include such solutions. IRMiR report findings made for Habitat[22] indicate a great potential of vacancies in public resources, which should be taken into consideration.

[22] Jadach-Sepioło A., Tomczyk E., Wysocki K., Milewska-Wilk H.: Pustostany w gminach i możliwości ich przekształcenia w mieszkania dostępne cenowo dla osób niezamożnych, Instytut Rozwoju Miast i Regionów, Warszawa 2021.

DOI:10.34918/87366

Paulina GAMA MARQUES[1]

6. NATURE-BASED SOLUTIONS FOR URBAN WATER MANAGEMENT: ANALYSIS OF HOUSING ESTATES IN GDAŃSK, GDYNIA, AND WARSAW

6.1. Introduction – living with nature

Rapid urbanization has highlighted the importance of optimalization of usage and management resources in buildings and their surroundings. One of the biggest, current trends in smart cities is management of storm water that is the common goal as well for adaptation and mitigation to the climate changes. IPCC rapports don't give much hope, the growth of the global temperature is a fact and should be expected[2]. The need for innovative and natural approach is big. The one based on natural-based solutions (NBS) is especially interesting, what is proved on international and European background. Firstly, it was defined by International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"[3]. Second definition comes from European Commission and says that those solutions are „inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience."[4]. What's more NBS could have real impact on mitigation and provide 30% of cost-effective mitigation of climate change, that could help to keep to meet the Paris Agreement goal of limiting warming to below 2°C above preindustrial levels[5].

[1] Silesian University of Technology, Faculty of Architecture, Department of Urban and Spatial Planning, Gliwice, e-mail: paulina.gamamarques@polsl.pl.

[2] IPCC WGII Assessment Report, Climate Change 2022: Impacts, Adaptation and Vulnerability. Summary for Policymakers.

[3] IUCN global standards for nature-based solutions, https://www.iucn.org/theme/nature-based-solutions/resources /iucn-global-standard-nbs [access: April 2022].

[4] European Commission nature-based solutions, https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en [access: April 2022].

[5] Griscom B.W., Adams J., Ellis P.W., Houghton R.A., Lomax G., Miteva D.A., Schlesinger W.H., Shoch D., Siikamäki J.V., Smith P., Woodbury P., Zganjar C., Blackman A., Campari J., Conant R.T., Delgado C., Elias P.,

NBS for addressing water management within cities among others include bioswales, retention and detention basins (or bioretention cells/filters), (constructed) wetlands, rain gardens, permeable pavements, riparian vegetation strips and green roofs[6]. Basic advantages consider protection and reducing surface runoff[7]. The effectiveness of NBS for urban water management depends on the type and design of the NBS and the local conditions. Small-scale NBS have been found to reduce run-off by 30–65 % for porous pavements, up to 100 % for rain gardens or up to 56 % for infiltration trenches[8]. In terms of mitigation various advantages are expected from NBS considering shaping optimal microclimate, reducing heat wave[9], and regulating thermal comfort[10]. Holistic approach is very important that is not only "nature-oriented" but as well "human-oriented"[11]. That means that NBS should provide benefits for people and biodiversity[12]. Researchers proved that blue and green infrastructure has positive impact on wellness, mental health[13] and reconnects people with nature[14].

Although knowledge about methods of rainwater management systems is increasing, the realizations not always achieved to replicate hydrological conditions of pre--development landscape[15]. Unfortunately, due to the IPCC report lots of adaptation

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Gopalakrishna T., Hamsik M.R., Fargione J.: Natural climate solutions. Proceedings of the National Academy of Sciences, 2017, Vol.114, No. 44, pp. 11645–11650, https://doi.org/10.1073/pnas. 1710465114.

[6] EEA Report, No. 01/2021, Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction.

[7] Wagner I., Zalewski M., Krauze K.: Błękitne aspekty zielonej infrastruktury. [In:] Zrównoważony rozwój – Zastosowania, 2013, No. 4, pp. 144–155; Januchta-Szostak A.: Modular water squares (MWS) in Poznań – people-friendly solutions for rainwater management, Journal of Sustainable Architecture and Civil Engineering, 2015, Vol. 3, No. 12, https://doi.org/10.5755/j01.sace.12.3.12659.

[8] EEA Report, No. 01/2021, Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction.

[9] Prenner F., Müller H., Stern P., Holzer M., Rauch H.P., Kretschmer F.: Suitability pre-assessment for decoupling in-sewer captured streams to support urban blue and green climate adaptation measures, Journal of Water and Climate Change, 2022, Vol.13, No. 4, pp. 1748–1764, https://doi.org/10.2166/wcc.2022.458.

[10] Prenner F., Müller H., Stern P., Holzer M., Rauch H.P., Kretschmer F.: Suitability pre-assessment for decoupling in-sewer captured streams to support urban blue and green climate adaptation measures, Journal of Water and Climate Change, 2022, Vol. 13, No. 4, pp. 1748–1764, https://doi.org/10.2166/wcc.2022.458; Graça M., Cruz S., Monteiro A., Neset T.S.: Designing urban green spaces for climate adaptation: A critical review of research outputs, Urban Climate, 2022, Vol. 42: 101126, https://doi.org/10.1016/j.uclim.2022.101126.

[11] EEA Report, No. 01/2021, Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction; Kabisch N., Frantzeskaki N., Hansen R.: Principles for urban nature-based solutions, Ambio, 2022, Vol. 51, pp. 1388–1401, https://doi.org/10.1007/s13280-021-01685-w

[12] Kabisch N., Frantzeskaki N., Hansen R.: Principles for urban nature-based solutions, Ambio, 2022, Vol. 51, pp. 1388–1401, https://doi.org/10.1007/s13280-021-01685-w.

[13] Wuijts S., de Vries M., Zijlema W., Hin J., Elliott L.R., van Breemen L.D., Enrico Scoccimarro, Roda Husman A.M, Külvik M., Frydas I.S., Grellier J., Sarigiannis D., Taylor T., Gotti A., Nieuwenhuijsen M.J., Hilderink H.: The health potential of urban water: Future scenarios on local risks and opportunities, Cities, 2022, Vol. 125: 103639, https://doi.org/10.1016/j.cities.2022.103639; Liu H.Y., Jay M., Chen X.: The role of nature-based solutions for improving environmental quality, health and well-being, Sustainability, 2021, Vol. 13: 10950, https://doi.org/10.3390/su131910950.

[14] Kabisch N., Frantzeskaki N., Hansen R.: Principles for urban nature-based solutions, Ambio, 2022, Vol. 51, pp. 1388–1401, https://doi.org/10.1007/s13280-021-01685-w.

[15] Parris K.M., Amati M., Bekessy S.A., Dagenais D., Fryd O., Hahs A.K., Hes D., Imberger S.J., Livesley S.J., Marshall A.J., Rhodes J.R., Threlfall C.G., Tingley R., van der Ree R., Walsh Ch.J., Wilkerson M.L.,

projects leads in fact to the maladaptation and can have negative impact on the environment in long term perspective[16]. The concept of nature is both socially mediated and historically specific. The idealistic framing based on goodness, protectiveness of nature renders nature as a powerful political tool. It causes the risk of false implementations of unnatural solutions[17]. Greenery in an inseparable element of contemporary campaigns which promote new houses. Renderings and advertisements show much more greenery than if it had actually been planted later and most do not meet the NBS criteria[18].

The following research tries to verify whether trend of rainwater management on contemporary housing estates in Poland is present. Do proposed solutions meet NBS criteria and can be observed there increase of rainwater capacity?

6.2. Review method

The main goal of the research was to analyse contemporary housing estates in terms of nature-based solutions of rainwater management system (RMS). Three housing estates were selected in the cities that execute the Adaptation plans for climate changes. Due to the research goal, the main selection reason was the time of the housing's construction. All of the selected fragments of estates were planned, constructed and released in XXI century and are advertised by developer as sustainable or caring for ecosystems. Thus, the main question is how it is accomplished. Is it just a marketing or real design solutions?

Description of the RMS was divided into four stages.

In the first stage overall, evaluation of the area division into use was made. Additionally, green area was divided into more precise sections to better verify the efficiency of the RMS. The evaluation is based on surface inventory of the area during in-situ research.

Second stage was to verify the terrain profile. It is crucial for shaping the rainwater retention because, due to the gravitation water can be directed to the lower parts and

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Williams N.S.G.: The seven lamps of planning for biodiversity in the city, Cities, 2018, Vol. 83, pp. 44–53, https://doi.org/10.1016/ j.cities.2018.06.007.

[16] IPCC WGII Assessment Report, Climate Change 2022: Impacts, Adaptation and Vulnerability. Summary for Policymakers.

[17] Osaka S., Bellamy R., Castree N.: Framing "nature-based" solutions to climate change, WIREs Climate Change, 2021, Vol. 12, No. 729, https://doi.org/10.1002/wcc.729.

[18] Gałecka-Drozda A., Wilkaniec A., Szczepańska M., Świerk D.: Potential nature-based solutions and greenwashing to generate green spaces: Developers' claims versus reality in new housing offers, Urban Forestry & Urban Greening, 2021, Vol. 65:127345, https://doi.org/10.1016/j.ufug.2021.127345.

additionally filtered. Diagrams are created using geoportal.gov. The terrain profile refers to the ground levels before buildings construction.

The third stage describes RMS for every estate. Considered RMS is defined as elements infiltrating, temporary retaining or infiltrating and temporary retaining rainwater that are connected together by the water flow. All of elements are composed from basic components parts. The crucial thing in system evaluation is to identify component parts and elements which are presented in two tables. First table is about identified component parts (i.e., surfaces, type of greenery, methods of water directing, irrigation methods). Second table shows typology of elements used in RMS. Elements and components were identified during in-situ research.

Fourth stage presents the typical element of the system. The working mechanism, including water sources, its flow and direction, is presented on the photographs. That is a base for further efficiency evaluation.

6.3. Green meridian housing estate (Gdańsk)

6.3.1. Description of the researched area

Housing estate is located in the southern part of the city Gdańsk in the suburbs, about 8 km away from the city center. It is close to the express road S7 that connects four Polish agglomerations: Tri-City, Warsaw, Kielce, and Krakow. In 2018 the construction has started. There are 13 building already put into use, 17 building are about to be put into use in April, 2022, and two buildings are being planned[19]. Buildings have three or four levels. There are designed on the ground car parking spaces.

The study covers the area of 39,000 m^2 It consists of 12 buildings, six parking areas, two playgrounds and one herbarium (Fig. 6.1). Communication infrastructure at the research fragment takes 34% and buildings 13% of a total area. Rest 53% stands for permeable areas which in details are open green areas (10%), private gardens (20%) and rainwater gardens with plants up to 1m height (70%) (Fig.6.2).

[19] https://korter.com.pl/zielony-poludnik-gdansk [access: April 2022].

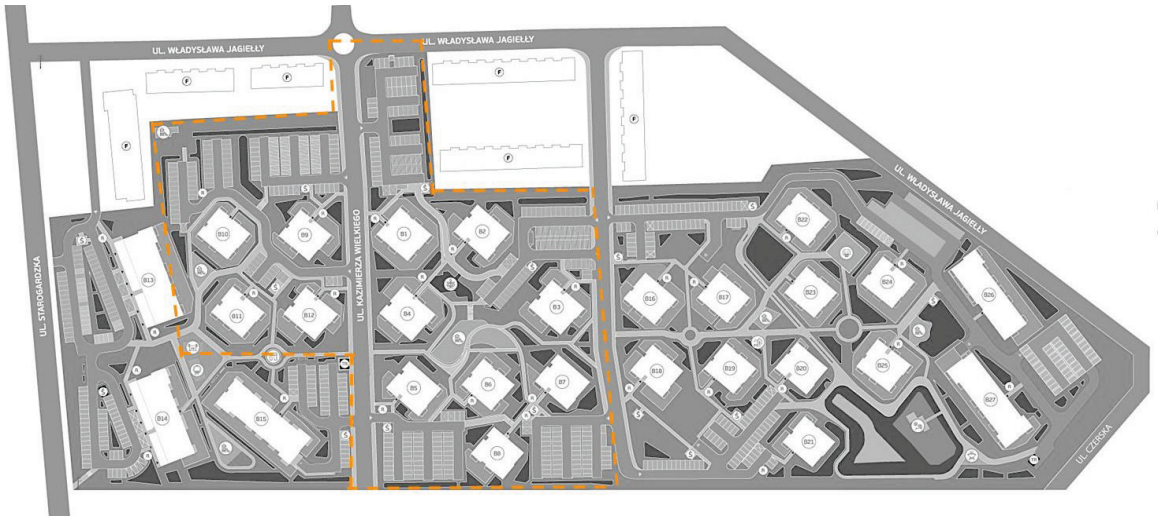


Fig. 6.1. Gdańsk, the plan of Green Meridian housing estate, chosen fragment
Rys. 6.1. Gdańsk, plan osiedla Zielony Południk, wybrany fragment
Source: https://www.eurostyl.com.pl/pl-pl/trojmiasto/lista-inwestycji/zielonypoludnik?city=trojmiasto.

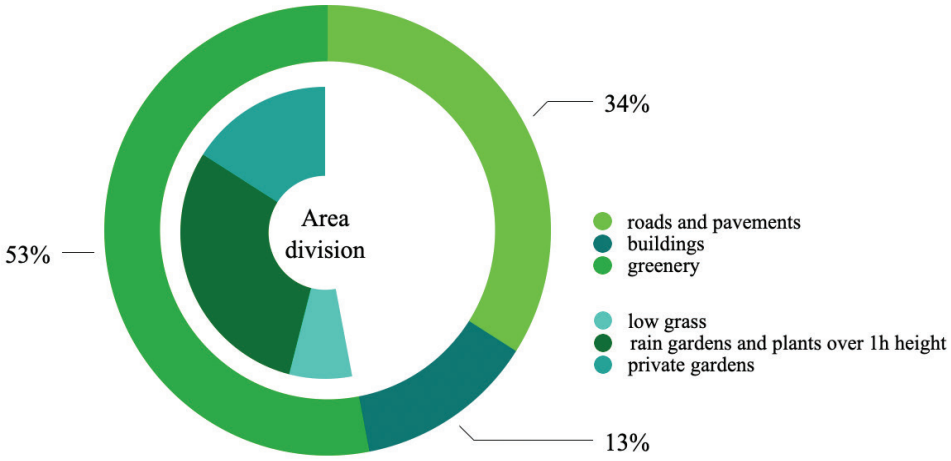


Fig. 6.2. Area division at Green Meridian housing estate
Rys. 6.2. Podział terenu na osiedlu Zielony Południk

6.3.2. Digital terrain model and terrain profile

The area of the housing estate is not plain what can be noticed on the digital terrain model (Fig. 6.3A). Darker colour stands for higher parts and lighter colour stands for lower parts. The terrain profile (Fig.3.3B) shows in detail how the topography of the research area looks like. Total length of measure is 583 m. The length of the sections up is 227 m. The length of the sections down is 356 m. Highest point is at 59 m and lowest at 44 m what gives 15 m of height difference.

Topography of the area took prime part in shape of RMS at the estate. The areas placed lower are used as surface retention elements and are the places for major raingardens.

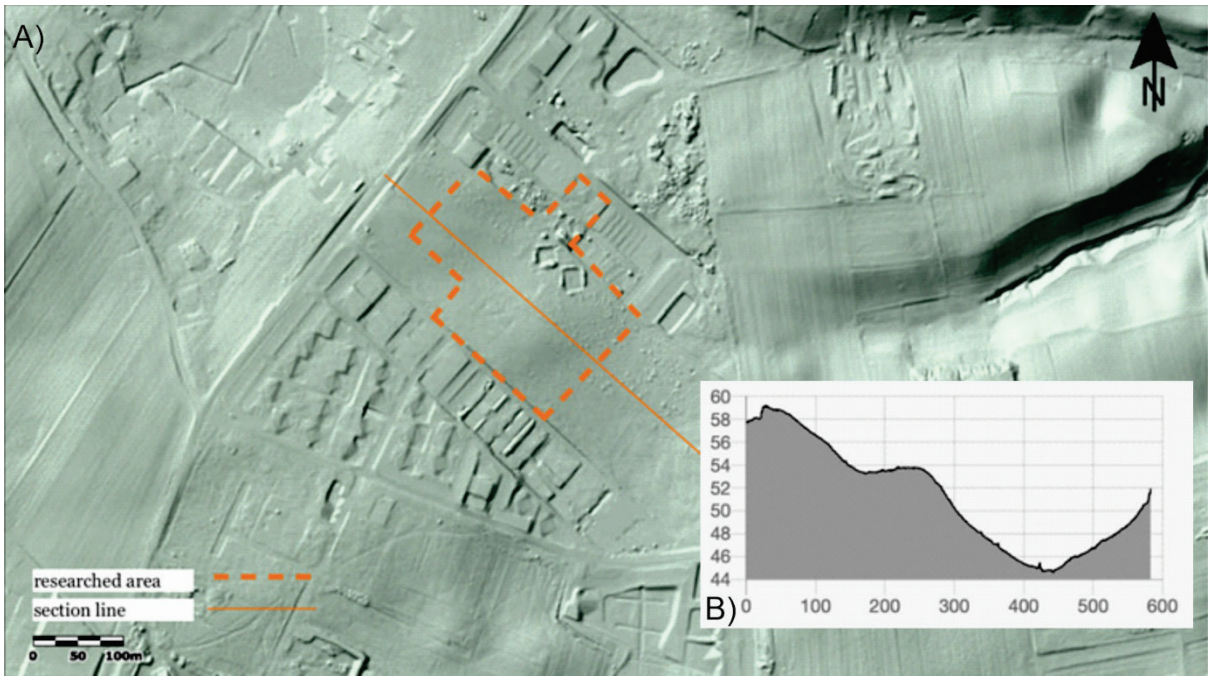


Fig. 6.3. Digital terrain model (A) with terrain profile (B), housing estate Green Meridian
Rys. 6.3. Numeryczny model terenu z przekrojem profilu, osiedle Zielony Południk
Source: geoportal.com

6.3.3. Rainwater system

The base elements of an RMS are raingardens in different sizes and shapes. They collect rainwater from the roofs of residential buildings and water from surface runoff from impermeable surfaces. Due to the high differences, rainwater by gravity is directed into bigger raingardens. The direction of water flow is manipulated by a system of open troughs and lowering curbs. The RMS component parts are different types of greenery i.e.: low grass, plants over 1 m and trees with crown diameter around 1.5 m. Majority of greenery, including trees, are very young that gives an impression of a little green space. In this case area of the parking, some roads, pavements and greenery excluding private gardens is the area of functioning RMS. Some of the roads has additional sewage overflow on the surface.

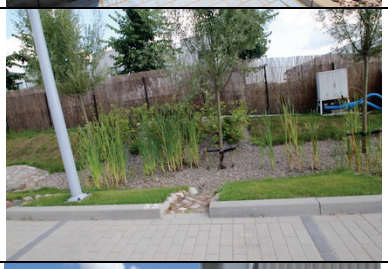
The table 6.1 shows recognized basic component parts of RMS.

Table 6.1

Component parts of the rainwater system

Category	Type	Picture, Foto PGM 2021
Greenery	Low grass	
	Greenery over 1m hight	
	Trees – crown diameter about 1.5 m	
Surfaces	Impermeable – jointless concrete bricks	
	Permeable – gravel, stones	
Method of directing the water	Hights differences	

continue table 6.1

Method of directing the water	Open channels	
	Gaps in the curbs	
Irrigation method	Rainwater from the roofs	
	Rainwater from the surface runoff	

Author's photography, 2021.

The following breakdown shows typology of elements of RMS (Table 6.2). Rainwater gardens in different shapes and forms are the base for the strategy for this system.

Table 6.2

Elements of rainwater system

S	A	Picture	Name and main goal	Description
SR	6		Small (< 2 m^2) raingarden - infiltration	Element collecting water from surface runoff from the pavement. A small cavity, lined with crushed stone, equipped with an emergency overflow above the cavity. Accompanying greenery.
BR	17		Big (> 2m^2) raingarden – temporary water basin - temporary retention of bigger amount of water	An element that collects water from surface runoff from pavements and roads. It functions as a temporary water reservoir during heavy rains. Troughs made of larger stones to direct the water. Emergency overflow above the depression. Accompanying greenery.
LR	3		Linear raingarden – temporary water basin - temporary retention	An element that collects water from the roofs of buildings and from the surface of impermeable pavements. It functions as a water reservoir during heavy rains. Emergency overflow above the depression. Accompanying greenery.

continue table 6.2

GN	6		Green niche – infiltration and short time retention	An element that collects water from the roofs of residential buildings and from the surface of impervious sidewalks. It functions as a temporary water reservoir during heavy rains. Emergency overflow above the depression. Accompanying greenery.
SB	9		Support basin – infiltration and temporary retention	Water directed by underground pipes from different areas. Filled with rain water during heavy rains. Bottom covered with layer of stones to increase infiltration and improve aesthetics. Collect overflow from other connected gardens.
LT	3		Linear trough	Water collected from the salad surface of the parking. Later directed with the underground pipe to the nearest rain garden.
LN	3		Linear niche – infiltration	Water collected from the roof. Niche filled with plants.

continue table 6.2

PR	5		Raingarden along parking – temporary retention	Niche collects water from the parking. Water is directed by open channel. Equipped with emergency overflow. Accompanying greenery.

Author's fotographies, 2021. S-symbol. A-amount.

6.3.4. Description of a typical solution

Rainwater garden is the RMS typical element (Fig. 3.4). The basin is located on the lower level what allows to collect the rainwater from higher parts. Water is directed by open channels and by gravity into desired basin. In this case, raingarden collects water from pavements, parking area, and roof. The bottom of the basin is filled with gravel, which improves the aesthetics of the tank after drying. Rain gardens are not green enough, which makes the gravel visible. In general, there seems to be few greeneries.

Fig. 6.4. Typical element of rainwater system at the Green Meridian housing estate – raingarden
Rys. 6.4. Typowy element system gospodarowania wodą deszczową na osiedlu Zielony Południk – ogród deszczowy
Source: author's photo, 2021.

There was no existing green, so the visible green is new plantings. It is necessary to repeat the research in the period of several years, when the greenery grows and fills the interior of the basin.

6.4. Beaufort's housing estate (Gdynia)

6.4.1. Description of the researched area

Housing estate is located in Gdynia, in the northern part of the city in the district Pogórze, about 9 km away from the city center. The construction of the estate started in 2017. Concept consists of 20 buildings with inner courtyards and recreational sport zone in the entrance of the concept, 16 buildings are put in use, 12 buildings are about to be put in use in 2022 and five buildings are still in the planning process[20]. Designed buildings are two or three levels tall. There are designed both underground and on the ground car parking spaces. The study covers the area of 47 700 m^2. It consists of skate park, sport pitch, 14 buildings, three playgrounds, herbarium and flower valley (Fig. 6.5). Roads and pavements account for 37%, buildings for 17% and permeable surfaces for 46% of the total researched area. Permeable surfaces are divided into low grass (10%), private gardens (17%) and raingardens and plats up to 1m (73%) (Fig. 6.6). It is worth to notice that due to the underground parking some of the plants grow on the flat roofs. It is estimated that majority of the greenery from the courtyards are above parking.

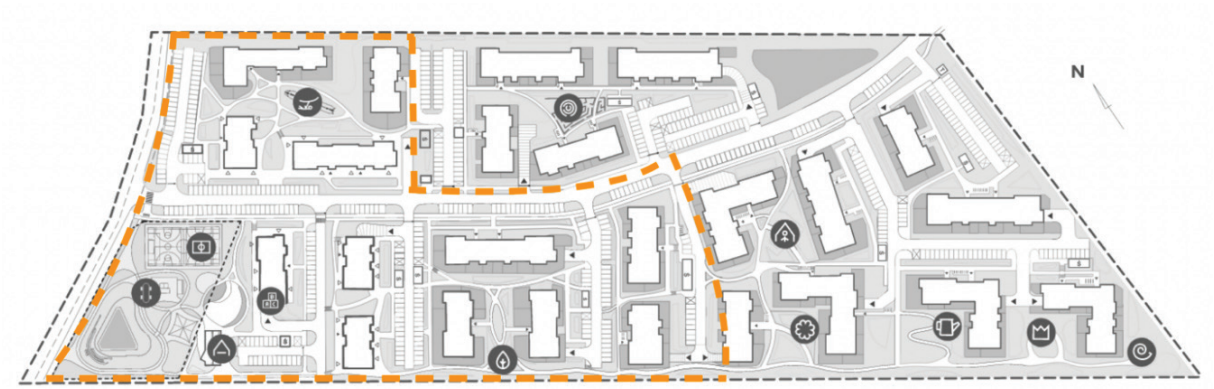


Fig. 6.5. Gdynia, the plan of Beaufort's housing estate, chosen fragment
Rys. 6.5. Gdynia, plan osiedla Beuforta, wybrany fragment
Source: https://boldshift.io/case-study/euro-styl/.

[20] https://korter.com.pl/osiedle-beauforta-pogorze [access: April 2022].

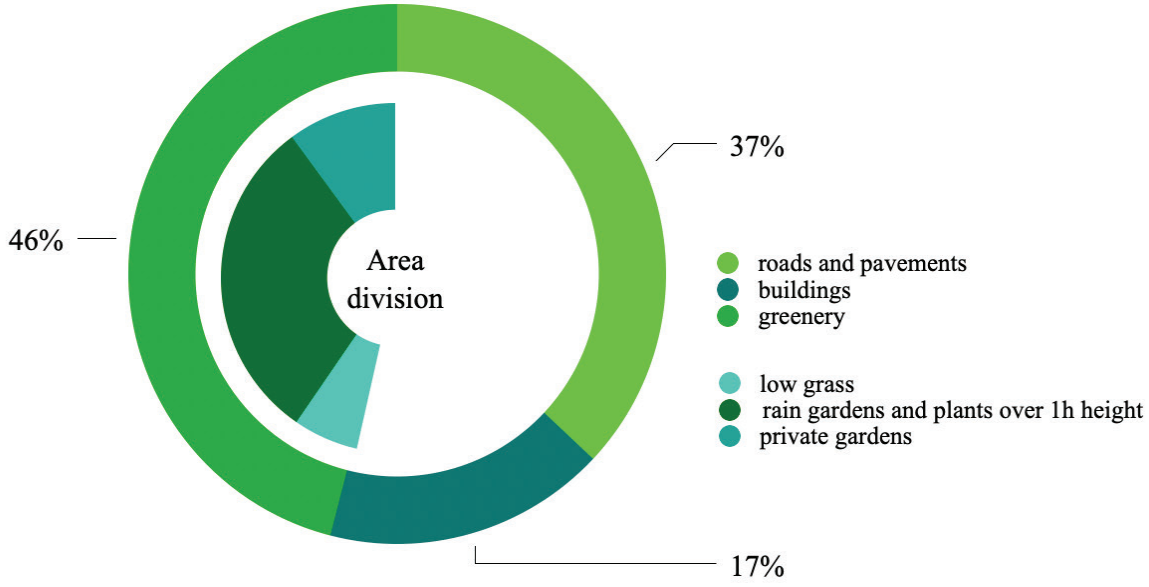


Fig. 6.6. Area division at Beaufort's housing estate
Rys. 6.6. Podział terenu na osiedlu Beuforta

6.4.2. Digital terrain model and terrain profile

The researched area is plane. The digital terrain model (Fig. 6.7A) doesn't show much darker grey colour that could testify about big high differences. Differences approximately 1m in height can be noticed on the terrain profile (Fig. 6.7B). Total length of measured area is 546,13 m. The length of the sections up is 273,1 m and the length of the sections down is 273 m. The highest point is at 69 m, the lowest point at 68 m.

The topography of the area changed due to architectural project and underground parking. The area above parking is lifted about 1.5 m up what causes a slope. In result green courtyards are greenery on the car park slab in fact what is not an issue in this particular case because water is directed through open channels and underground pipes to other parts of the area, where can be easily infiltrated.

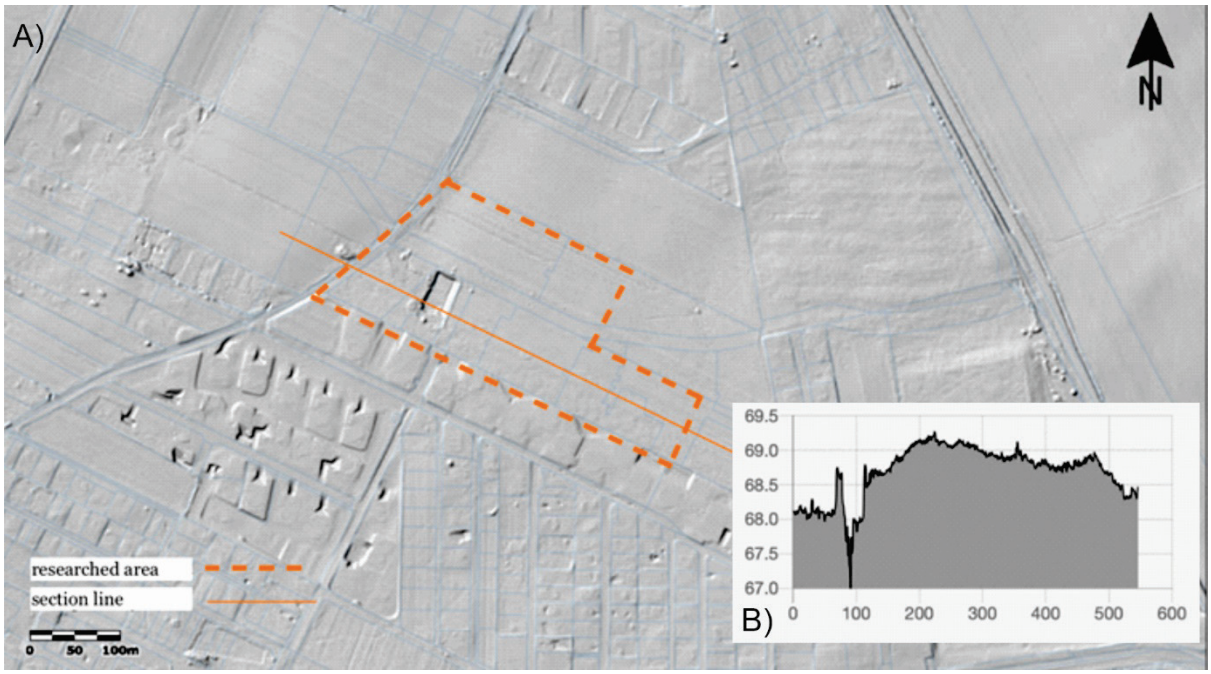


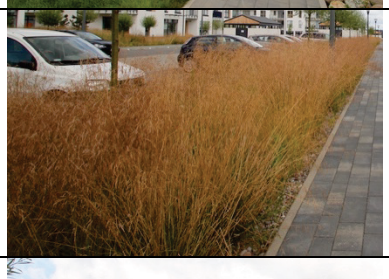
Fig. 6.7. Digital terrain model (A) with terrain profile (B), Beaufort's houisng estate
Rys. 6.7. Numeryczny model terenu (A) z przekrojem profilu (B), osiedle Beauforta
Source: geoportal.com.

6.4.3. Rainwater system

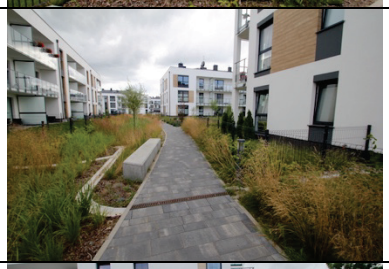
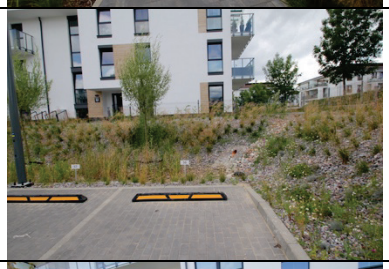
The RMS of the estate is based on rain gardens collecting rainwater from the roofs of residential buildings and water from surface runoff from impermeable surfaces. The direction of water flow is manipulated by a system of open troughs and lowering curbs. Additionally, a retention reservoir has been designed as a flood control reservoir. It was placed on the main access road to the estate together with the recreation and sports area. The slopes of the land were created due to the underground garages. The component elements of this RMS are (Table 6.3): different types of greenery, impermeable, partly permeable, and permeable surfaces, various methods of directing the water (open channels, underground pipes, high differences), and natural irrigation methods.

Table 6.3

Component parts of elements of the rainwater system

Category	Type	Picture, Foto PGM 2021
Greenery	Low greenery	
	Greenery up to 1 m	
	Trees – crown diameter around 1.5 m	
Surfaces	Impermeable: asphalt	
	Impermeable: concrete bricks without the phase	
	Permeable: gravel various sizes	

continue table 6.3

Method of directing the water	Slight drops of hights	
	Open channels, underground pipes	
Irrigation method	Surface runoff from the impermeable surfaces	
	Rainwater from the roofs	

Author's photography, 2021.

The following breakdown shows the typology of elements of RMS (Table 6.4) . This RMS strategy is based on various shapes and form raingardens, troughs and emergency water pound that support the system in case of overflooding.

Table 6.4

Elements of rainwater system

S	A	Picture	Name and main goal	Description
LT	4		Linear trough along communication infrastructure – infiltration with temporary retention	Linear niche accompanying communication infrastructure. Gathering water from the surface runoff and water directed from different areas by underground pipes. Bottom filled with gravel.
SR	6		Small (<2 m^2) raingarden – infiltration	Small basin placed along pedestrian paths. With greenery. With emergency overflow directing access of rainwater to the sewage system or others parts. (Possibly above underground parking)
IR	14		Inner courtyard raingarden – temporary retention	Larger depression in the inner courtyard. Gathering water runoff from pedestrian paths. With emergency overflow directing access of rainwater to the sewage system. (Possibly above underground parking)
IRR	7		Inner courtyard raingarden – temporary retention	Various size basins in the inner courtyard. Gathering water runoff from pedestrian paths, rainwater from the roofs and water directed with open channels from different areas. With emergency overflow directing access of rainwater to the sewage system or other parts. (Possibly above underground parking)
PT	12		Trough along parking – temporary retention	Gathering water runoff from pedestrian paths and parking, rainwater from the roofs and water directed with underground pipes from different areas With emergency overflow directing access of rainwater to the sewage system.

continue table 6.4

MI	8		Micro linear infiltration	Part filled with gravel catching and infiltrating water from roof.
GP	6		Small (<2 m^2) green pocket – short time retention	Green basin along pedestrian path. Catching access water from surface runoff. (Possibly above underground parking)
EP	1		Emergency water pond – retention	Big retention reservoir design as an emergency pound that retain and slowly infiltrate water during extremely heavy rains. Protection against downpours.

Author's fotographies, 2021. S-symbol. A-amount.

According to the designer, the main goal of rain gardens is to water surrounding greenery. Due to that, there is no need to use additional artificial infiltration systems. Greenery of the inner courtyards is, in fact, the green roof that has certain water capacity because of fixed soil thickness. The water is directed by underground pipes into bigger raingardens where can be naturally infiltrated. I n this case green roofs have an impact of the microclimate of the space because of medium high greenery and retained water.

Fig. 6.8. Typical element of rainwater system at the Beaufort's housing estate – raingarden
Rys. 6.8. Typowy element systemu gospodarowania wodą deszczową na osiedlu Beuforta – ogród deszczowy
Source: author's photo, 2021.

6.5. Mickiewicz housing estate (Warsaw)

6.5.1. Description of the researched area

The estate is located in Warsaw, northern part of the city in the district Bielany. About 7 km away from the center. Construction of the estate started in 2018. All of eight buildings are already put in the use. Buildings have six levels. On the area of the estate there are both on the ground parking and underground, two level parking[21]. Estate has BREEM certificate and several architectural awards e.g., *Architectural Award of the Mayor of the Capital City of Warsaw 2020 for the best housing estate, the Green Eagle of the Rzeczpospolita daily for pro-ecological activities, the National Labor Inspectorate Award "Build safely", a distinction in the "Accessibility Leader 2020" competition organized by the Association of Friends of Integration and the Society of Polish Town Planners.*

[21] https://korter.com.pl/osiedle-mickiewicza-warszawa [access: April 2022].

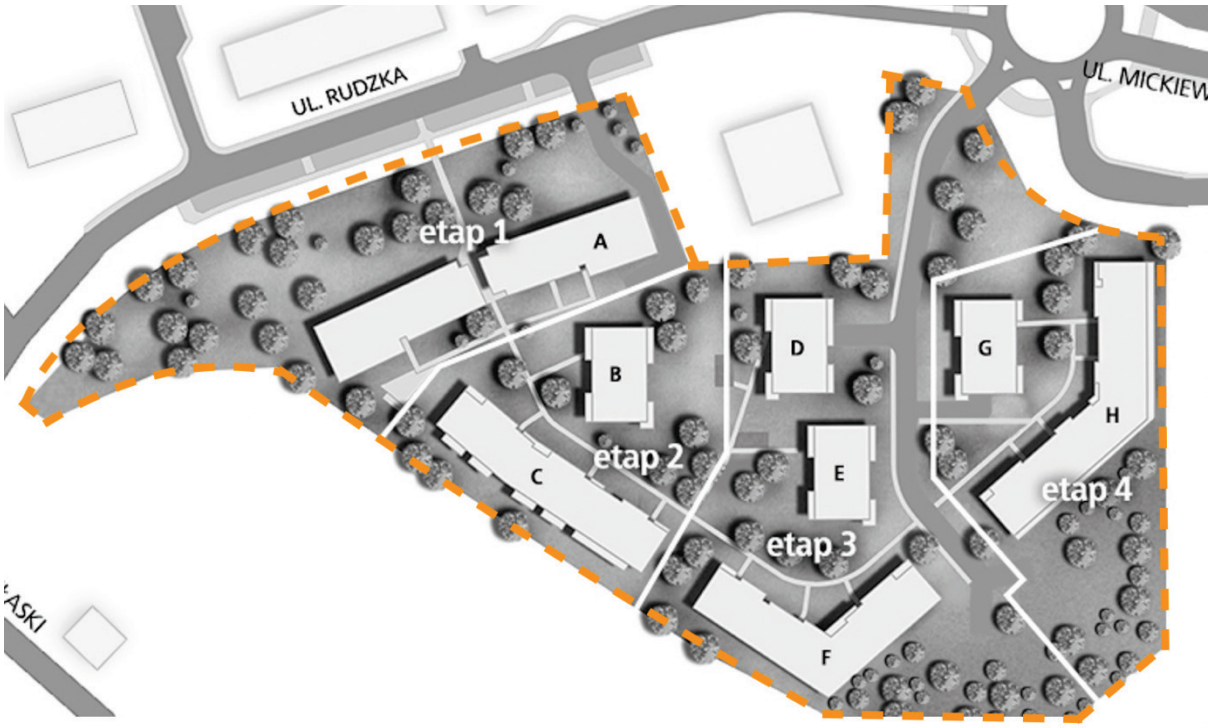


Fig. 6.9. The plan of Mickiewicz housing estate, chosen fragment
Rys. 6.9. Plan osiedla Mickiewicza, wybrany fragment
Source: https://mieszkaj.skanska.pl/nasze-projekty/osiedle-mickiewicza/osiedle-mickiewicza-iii/.

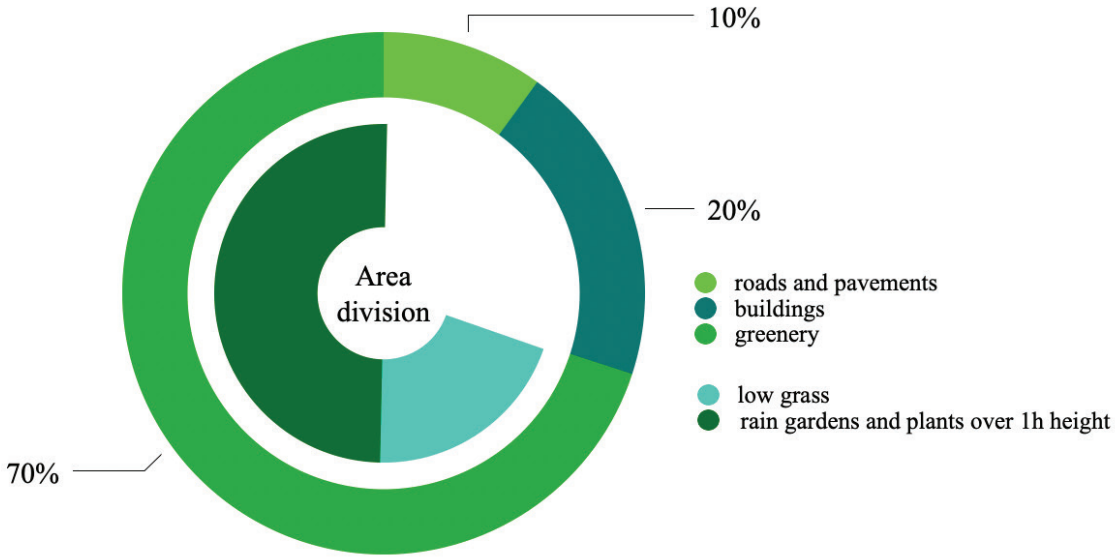


Fig. 6.10. Area division at Mickiewicz housing estate
Rys. 6.10. Podział terenu na osiedlu Mickiewicza

The study covers area of 25 000 m^2. It consists of eight buildings and inner recreational area (Fig. 6.9). Roads and pavements account for 10%, buildings for 20% and permeable surfaces for 70% of the total researched area. Permeable surfaces are divided into low grass (70%) and greenery up to 1m and trees (30%) (Fig. 6.10).

It is worth to notice that high value of permeable surfaces is due to unique design of fire safety infrastructure. The access for emergency vehicles is designed by adding about 3 m of geogrid belt along 2 m pavements made of concrete bricks without a phase. It is the only example on area with existing mature trees preserved during construction.

6.5.2. Digital terrain model and terrain profile

The area of the estate is flat, which can be seen on the numerical terrain model (Fig. 6.11A) generated from the geoportal. The terrain profile (Fig. 6.11B) shows maximum 1.5 m differences in hights. The total length of measured area is 169 m. Total length of sections up is 85 m, total length of sections down is 84 m. The highest point is at 85 m, and the lowest point at 83 m, what gives about 1.7 m difference in height. That difference in height shown on the profile can be observed on the side as slight depression with greenery.

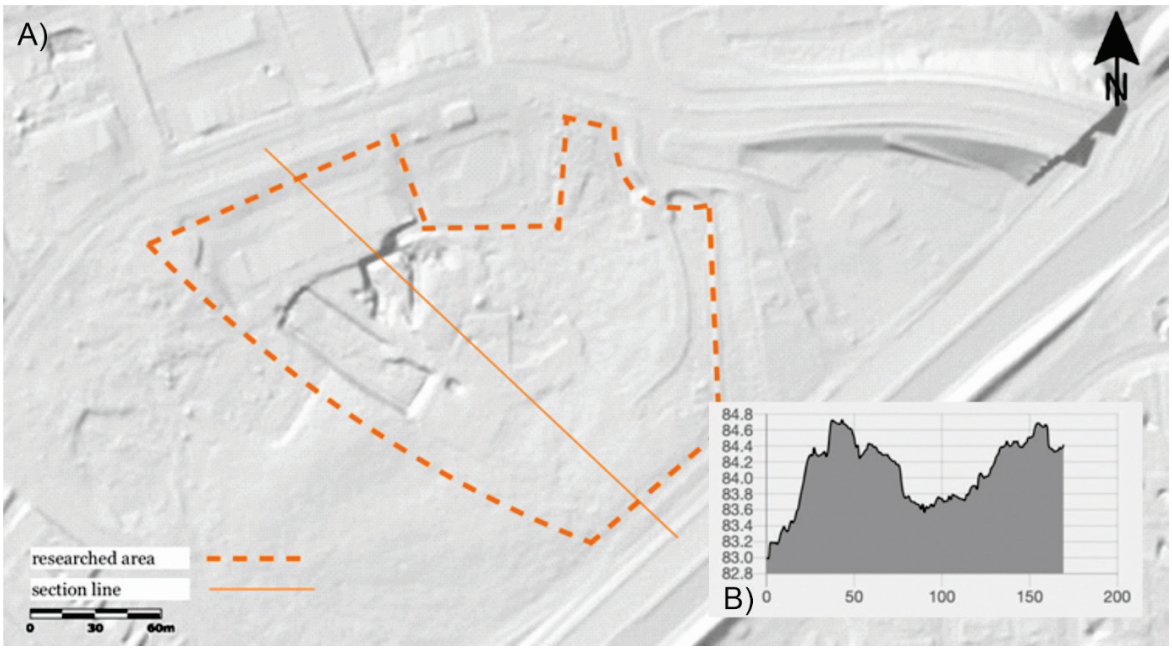


Fig. 6.11. Digital terrain model (A) with terrain profile (B), Mickiewicz housing estate
Rys. 6.11. Numeryczny model terenu (A) z przekrojem profilu (B), osiedle Mickiewicza
Source: geoportal.com.

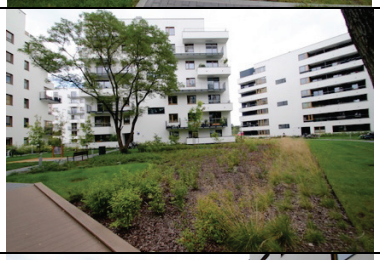
6.5.3. Rainwater system

The estate has a relatively high percentage of biologically active area. This is not only green, but also the use of partly permeable surfaces. The layout of the estate was combined with the existing greenery. Especially, mature trees with wide crowns were left. Nevertheless, some of the greenery is placed above underground parking which has

a negative impact of infiltration area. No rainwater is collected from the roofs and there is no additional artificial irrigation applied. The main element of RMS is partly permeable surfaces that increases the biological active area. Some slight depressions in terrain are observed. Component part of the RMS at this housing estate (Table 6.5) differs from the previous examples because it missing roof runoff catchment, the only source of the rainwater is the rain and some surface runoff. Besides that the housing estates has vrous types of greenery, impermeable and partly permeable surfaces.

Table 6.5

Component parts of elements of the rainwater system

Category	**Type**	**Picture, Foto PGM 2021**
Greenery	Low grass	
	Greenery over 1m hight	
	Trees: wide crawn	
Surfaces	Impermeable: concrete bricks without phase	
	Partly permeable: geo-grid	
Irrigation method	Surface runoff from the impermeable surfaces	

Author's photography's, 2021.

The following breakdown shows the typology of elements of RMS (Table 6.6). The nature based solution that can be recognized at the housing estate are flower beds and depression in the ground, but its highly questionable whether they were designed for retention reasons or purely esthetical.

Table 6.6

Elements of rainwater system

S	A	Picture	Name and main goal	Description
CD	1		Depression with green cascades – temporary retention	Deep depression with cascades of greenery capturing water pouring directly on the ground.
SD	3		Small (<2 m^2) depression – temporary retention	Element collecting water from surface runoff from the pavement. Accompanying greenery.
FB	18		Flower beds – increase in the absorptive capacity of the area	Flower beds captures water from the surface runoff and access of the water during heavy rains.

Author's photography's, 2021. S-symbol. A-amount.

The amount of greenery in the estate is impressive (70% of the total area), but it should be noted that it is mainly grass. Most of the terrain is flat. The lack of depressions in the terrain means that water from surface runoff cannot be temporarily retained and is directed to the sewage system. Moreover, big about of trimmed lawn causes luck of biodiversity. Apparently, the rainwater from the roofs is not collected but wasted in the sewage system. In Warsaw, the average annual rainfall equals 695 mm[22]. The area of roofs is around 5,500 m^2 what gives annually almost 4,000 m^3 of water that fills sewage systems from where is directed to the rives and end up in the sea.

[22] https://pl.climate-data.org/europa/polska/masovian-voivodeship/warszawa-4560/ [access: April 2022].

6.6. Conclusions

One of the strategies of Water Smart City is to restore the natural drainage capacity of cities by introducing nature based solutions. The successful strategy and therefore the system of rainwater management requires a composition of various elements that help to retain, infiltrate, store, treat, adapt to climate changes, and drain the rainwater. The main focus of the research were greenery types, surface types, irrigation method, and NBS that fulfill the aspects of the Water Smart City strategy.

For rainwater to be useful, it should feed the urban ecosystems. Big amount of biologically active area doesn't have an impact on increasing retention capacity if the water from roofs is directed to the sewage system. RMS was identified in first two research residential estates. In case of Green Meridian and Beaufort's housing estates, area of parking, some roads and pavements and greenery excluding private gardens and some main roads is the area of the RMS. Some roads have connection with overflow to the sewage. In both of the estates, there is a great number and variety of elements temporary retaining and infiltrating the water. Gravity is the force moving water between elements. Apart from that, the fact worth mentioning is a proportion between types of greenery. In both of the cases the highest percentage stands for greenery over 1 m height. In Green Meridian low grass and private gardens are around half of greenery itself what is more, comparing to Beaufort's estate, where low grass and private gardens is about 1/3 of the greenery. Apparently, at Mickiewicz housing estate, no water connection between possible RMS elements was found. What is more, no water from the roofs is collected, but directed to the sewage system. Therefore, despite big amount of biologically active area (70%), there is no increasing in retention capacity. Identified elements that could shape the RMS are few and placed in rather coincidental way, lucking plan in whole. Even though greenery is strictly connected to the water, RMS cannot be based just on big amount of trimmed lawn.

Fig. 6.12. Typical element of rainwater system at the Mickiewicz housing estate – flower bed
Rys. 6.12. Typowy element system gospodarowania wodą deszczową na osiedlu Mickiewicza – rabata kwiatowa
Source: author's photo, 2021.

Without planning the water direction and connection to the elements, they are just individual parts catching water falling directly on them. The trend of managing the rainwater is present in two out of three investigated housing estates. Despite that it is really positive that all of presented solutions meet NBS criteria. Those are elements that are cost-effective, imitate natural ecosystem and natural circulation of the water, provide biodiversity benefits and have positive impact on the reception of the space.

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Sandra PRZEPIÓRKOWSKA[1], Aleksandra ŚLIWA[2], Jakub ŚWIDZIŃSKI[3]

7. MYCELIUM-BASED INSULATION MATERIALS AS AN ECOLOGICAL ALTERNATIVE TO MINERAL WOOL

7.1. Introduction

The main contributor to global energy consumption n and CO2 emissions are building industry and transport[4]. One of the measures taken to decarbonize the sector is the tightening of the legislation oriented toward reducing the energy inputs for heating and cooling the buildings[5]. To comply with these standards both during the design process for the new buildings and as a factor in improving energy efficiency within the existing ones, larger amounts of insulation materials or insulation materials with lower thermal conductivity parameters are used. The manufacturing of building insulation materials has a damaging effect on the environment, and they are expected to take hundreds of years to decompose. The pursuit of sustainable materials that can be easily disposed at the end of their life cycle may contribute to the improvement of the unfavorable ecological balance. Bio-based architectural materials and low-tech components, characterized by simple processing methods and possibilities of reuse or natural decomposition fit into the principles of sustainable development[6]. One of the encouraging ecological alternatives are mycelium-based materials. Considering the

[1] Silesian University of Technology, Faculty of Architecture, Department of Urban and Spatial Planning, Gliwice, e-mail: sandra.przepiorkowska@polsl.pl.
[2] Silesian University of Technology, Faculty of Architecture, Department of Residential and Public Architectural Design, Gliwice, e-mail: aleksandra.sliwa@polsl.pl.
[3] Silesian University of Technology, Faculty of Architecture, Department of Urban and Spatial Planning, Gliwice, e-mail: jakub.swidzinski@polsl.pl.
[4] United Nations Environment Programme: 2020 Global status report for buildings and construction: towards a zero-emission, efficient and resilient buildings and construction sector, Nairobi, 2020.
[5] DZ.U. 2020, poz. 2351: Rozporządzenie Ministra Rozwoju, Pracy i Technologii z dnia 21 grudnia 2020 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie, 2020.
[6] Wasilewska A., Pietruszka B.: Materiały naturalne w ekobudownictwie, Przegląd Budowlany, 2017, Vol. 88, No. 10, pp. 50–53.

promising results of research on their properties[7] and the output of this paper, their implementation in construction would represent a shift toward the natural and sustainable materials that contribute to the reduction of the CO_2 emissions and lower the amount of construction sector waste production[8]. The integration of mycelium-based construction materials, exemplifies a futuristic approach to building infrastructure in smart cities, aligning with the principles of sustainable urban development.

7.2. Methodology and context of the study

The presented research is a continuation of the work on the application of mycelium-based sustainable materials in construction. The first phase culminated in a paper presented at the International Scientific Conference ACPS 2021: Architecture, City, People, Structure in 2021 on "Mycelium-based materials in architecture. A critical review". Previous analyses have shown that the conventional building material that most closely approximates the properties of mycelium-based materials are mineral and glass wools. This paper focuses on the possibility of implementing mycelium-based products in selected types of building partitions that involve various wools.

The aim of the research is to verify whether commercially available mycelium-based insulations may be applied as substitutes for conventional building materials. Due to the theoretical nature of the research, the next step is to implement the analysed solutions in practice in order to make appropriate measurements. At this stage, the intention of the authors is to provide a wider range of information on the potential applications of mycelium-derived organic materials.

In 2020, in Poland, 89.289 single-family houses were put into use, which is 97% of all newly constructed residential buildings, and for another 105.566 (out of 107.590 residential buildings overall) building permits were obtained[9]. Hence, for the purpose of this study, the partitions of a typical example of residential construction of a single--family building were analysed.

Past implementations using mycelium are primarily experimental exhibition displays, temporary buildings, and structures that do not directly alter building practices in Poland. Among the best known are the 2014 "Hi Fy" tower at the Museum of Modern Art in

[7] Mitchell J., Mautner A., Luenco S., Bismarck A., John S.: Engineered mycelium composite construction materials from fungal biorefineries: A critical review, Materials & Design, 2020, Vol. 187.
[8] Xing Y., Brewer M., El-Gharabawy H., Griffith G., Jones P.: Growing and testing mycelium bricks as building insulation materials. [In:] IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2018, Vol. 121: 022032.
[9] GUS, Budownictwo w 2020 roku, Źródło danych GUS, 2020.

New York, the 2016 Shell Mycelium Pavillion as part of the Kochi-Muziris Biennale, the Growing Pavilion developed for Dutch Design Week in Eindhoven in 2019, and Circular Garden, an art installation that grew for Milan Design Week in 2019[10].

Comparative analyses are based on data obtained from manufacturers: BIOHM (further referred to as "mycelium-based material (1)"), Mycellium.CO (further referred to as "mycelium-based material (2)"), Mushroom® Packaging (further referred to as "mycelium-based material (3)"), Grown.bio (further referred to as "mycelium-based material (4)") and MOGU (further referred to as "mycelium-based material (5)"). The products range from indoor acoustic panels to fire and water-resistant panels suitable for outdoor applications. The aim of the research is to verify whether the available products can replace wool and to what extent.

7.3. Characteristics of mycelium-based materials

The physical properties of mycelium are dependent on a number of factors: species, substrate and substrate type, supplementary materials used, processing technology, growth conditions, and drying method[11]. After drying, mycelium acquires its final technical properties, its resistance to external influences such as water and fire, as well as a measurable and controllable hardness. Dried form also prevents from uncontrolled growth and allergic reactions that are caused by spores, which are inactivated. Due to a large number of variables, the final material properties must be determined on the basis of specific product data (Table 7.1). Previous research proves the possibility of using mycelium products in the construction industry, and the parameters meet or exceed widely used conventional materials, including synthetic[12].

[10] Przepiórkowska S., Śliwa A., Świdziński J.: Biomateriały przyszłości – grzybnia, Architektura murator, 2022, Vol. 03, pp. 84–89.
[11] Xing Y., Brewer M., El-Gharabawy H., Griffith G., Jones P.: Growing and testing mycelium bricks as building insulation materials. [In:] IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2018, Vol. 121: 022032.
[12] Radziszewska-Zielina E.: Analiza porównawcza parametrów materiałów termoizolacyjnych, mających zastosowanie jako izolacja ścian zewnętrznych, Przegląd Budowlany, 2009, pp. 32–37.

Table 7.1

Technical parameters of mycelium-based materials and mineral wools *[13],**[14],***[15]

	material	**1**	**2**	**3**	**4**	**5**	**stone wool**	**glass wool**
	standard	UK	USA	USA	USA	EU	EU	EU
physical performance	density [kg/m³]	128	180 (ASTM C303)	120 (ASTM C303)	115,5 (AVANS)	180	40–200*	15–75*
	thermal conductivity [W/mK]	0,024 (LBU Labs)	0,059 (ASTM C518)	0,039 (ASTM C518)	0,058 (ASTM C155)	0,05 (UNI EN12664-2)	0.031–0.037 *	0.033–0.040 *
	compressive strength [MPa]	0,12 – 0,14	0,172 (ASTM C165)	0,124 (ASTM C165)	0,0021–0,046 (10% compress.) 0,49-1,79 (50% compress.) (ASTM D695)	0,01072 (UNI EN 826)	0,015 *	0,015–0,030*
	acoustic characteristics [NRC] (ISO 354)	data not avail.	0,53 at 2000Hz	data not avail.	data not avail.	0,4–0,6 at 2000 Hz (depending on shape)	0,9–1,15 at 1000 i 2000Hz (NRC) **	0,9–1,15 at 1000 i 2000Hz (NRC) **
fire performance	fire reaction (UNI EN 13501-1)	data not avail.	data not avail.	data not avail.	data not avail.	B-s1-d0	A1–A2 *	A1–A2*
	heat of combustion [MJ/kg] (EN ISO 1716)	16.36	data not avail.	data not avail.	data not avail.	data not avail.	18	11,54 MJ/kg ***
	flame spread [m²/m²] (ASTM E84)	data not avail.	18 class A	20 class A	20 class A	data not avail.	0 class A	≥0 class A
	smoke emission [m²/m²] (ASTM E84)	data not avail.	data not avail.	50	50	data not avail.	---------	max 25

[13] Radziszewska-Zielina E.: Analiza porównawcza parametrów materiałów termoizolacyjnych, mających zastosowanie jako izolacja ścian zewnętrznych, Przegląd Budowlany, 2009, pp. 32–37.

[14] Srivastava R.K., Dhabal R.L., Suman B. M., Saini A., Panchal P.: An estimation of correlation on thermo-acoustic properties of mineral wool, 2006.

[15] Półka M., Sulik P.: Analiza wybranych parametrów pożarowych wełny mineralnej i układów wełna mineralna-tynki cienkowarstwowe, Zeszyty Naukowe SGSP/Szkoła Główna Służby Pożarniczej, 2010, Vol. 40, pp. 99–111.

continue table 7.1

water reaction	water vapor permeation [dry cup] (ASTM E96)	data not avail.	30 permab.	30 permab.	data not avail.	data not avail.	---------	50
	moisture storage [m^3/m^3*100%] (ASTM C1498)	data not avail.	8 at 60% RH 12 at 80% RH	8 at 60% RH 12 at 80% RH	data not avail.	data not avail.	---------	water absorption by volume after long-term partial immersion ≤3%
other	compostability [days] (ASTM D6400)	data not avail.	35	30	data not avail.	data not avail.	>100 years	>100 years

Source: Data based on own research and interviews with designers and manufacturers of mycelium-based insulation conducted from March through May 2021 (submitted to publication via the ACPS conference).

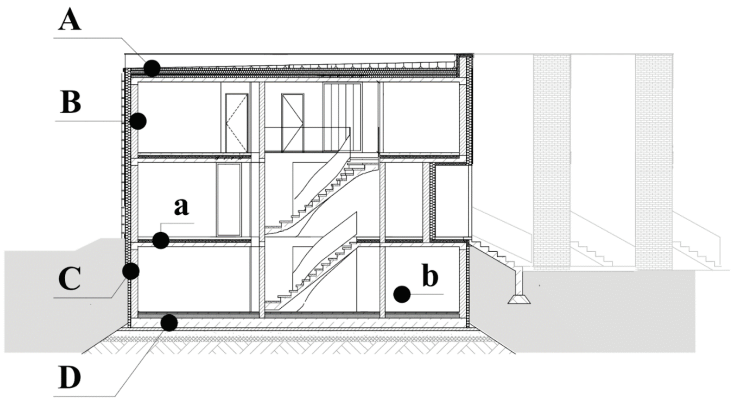
7.4. Potential for implementation

7.4.1. The scope of analysis

For the research, we have selected basic partitions in a single-family terraced building. The building is a part of an estate of 24 terraced houses completed in Gliwice in the year 2022. Completed buildings with an area of 150 m^2 on 3 floors meet the requirements for annual consumption of primary energy through the use of properly insulated partitions and application of the modern, energy-optimal installation solutions such as floor heating, heat pump system, mechanical ventilation with recuperation and recirculation. The appropriate scale and technology of the buildings and their typology allow an analysis of the building envelope in terms of the replacement of the insulation materials used with mycelium-based in order to cut down carbon footprint and decrease construction waste at the end of the building lifecycle. The investigated partitions are marked in Figure 7.1, and data on their thermal and fireproof requirements are presented in Table 7.2. The analysis assumes that the official guidelines contained in the regulations[16] for each building envelope are fulfilled. A detailed thermal diffusivity

[16] DZ. U. 2020, poz. 2351: Rozporządzenie Ministra Rozwoju, Pracy i Technologii z dnia 21 grudnia 2020 r.

analysis of the discussed partitions is also necessary, considering the significant consequences that may arise from moisture infiltration under unfavorable thermal--humidity conditions in the environment.



Exterior partitions: A – flat roof, B – exterior wall, C – basement wall, D – foundation slab

Interior partitions: a – inter – apartment party wall, b – inter – story floor

Fig. 7.1. Scheme of investigated partitions
Rys. 7.1. Schemat badanych przegród
Source: Author's scheme, 2022.

Table 7.2

Thermal and fireproof requirements of partitions

	heat transfer coefficient U [W/(m^{2}K)]	fire resistance rating R – load bearing capacity [min] E – integrity [min] I – insulation [min]
exterior partitions		
flat roof	0,15	no requirements
exterior wall	0,20	no requirements
basement wall	no requirements	no requirements
foundation slab	0,30	no requirements
interior partitions		
inter-apartment party wall	1,00	REI60
inter-story floor	no requirements	no requirements

Source: Data based on Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie[17].

zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie, 2020.

[17] DZ. U. 2020, poz. 2351: Rozporządzenie Ministra Rozwoju, Pracy i Technologii z dnia 21 grudnia 2020 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie, 2020.

7.4.2. External partitions

7.4.2.1. Flat roof

A typical solution was applied in the analysed building – a full flat roof based on a reinforced concrete slab, insulated with 20 cm mineral wool and with a sloping layer made of hard wool, the roof covering is an EPDM membrane (technical parameters presented in Table 7.3). In this partition, it is particularly important to maintain the highest level of airtightness and legally required thermal conductivity levels. In addition, the roof area should be suitable for servicing the roof of the building, which houses the air conditioning units, the air source heat pump and the solar panels.

Table 7.3

Technical parameters of the flat roof with primary insulation material

partition	**material**	**thickness [m]**	**thermal conductivity [W/(mK)]**	**thermal resistance [(m^{2}K/W]**
flat roof	EPDM membrane (roofing)	-	0.130	0.012
	hard mineral stone wool (sloping layer)	0.05	0.040	5.000
	mineral stone wool with ventilation	0.20	0.037	5.405
	vapor proof membrane	-	0.170	0.001
	reinforced concrete	0.15	1.700	0.206
	cement-lime plaster	0.01	1.000	0.020
		0.41	U = 0.145 [W/(m^{2}K)]	

Source: Data calculated based on producer data from Table 3.1.

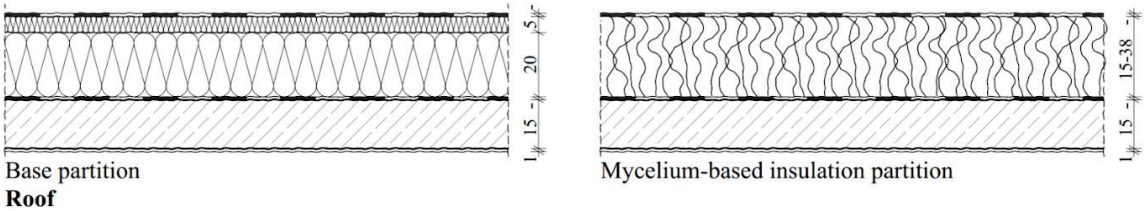


Fig. 7.2. Scheme of investigated partition
Rys. 7.2. Schemat badanej przegrody
Source: Author's scheme, 2022.

Table 7.4

Technical performance of primary and alternative mycelium-based insulation materials

material		thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K/W]	partition U [W/(m²K)]	total partition thickness [m]
hard mineral stone wool		0.05	0.040	5.000	0.145	0.41
stone wool		0.20	0.037	5.405		
mycelium-based materials	(1)	0.15	0.024	0.833	0.15	0.31
	(2)	0.38	0.059	0.847	0.15	0.54
	(3)	0.25	0.039	1.026	0.15	0.41
	(4)	0.38	0.058	0.862	0.15	0.54
	(5)	0.32	0.05	1.000	0.15	0.48

Source: Data calculated based on producer data from Table 3.1.

With the tested mycelium-based materials, the thickness of the applied partitions vary from 31 cm to 54 cm (Figure 7.2, Table 7.4). The disadvantage of the solution is a significant increase in the weight of insulation, which must be taken into account when designing the building structure. There are also doubts concerning the connection of the insulation with the roof water insulation, which require additional verification.

Mycelium is thus suitable for roofs not prone to flooding, i.e. inverted flat roofs (green, terrace). It is not suitable for inverted flat roofs due to the danger of biological corrosion as the waterproofing layer is embedded below the thermal insulation layer. Mycelium can be also used in a solid roof covered with roofing membrane. A combination of different types of roofing materials that are normally used with wools (i.e., e.g., surface felt and underlayment or single-ply roofing felt or PVC, FPO, TPO, or EPDM membrane) is to be further investigated. There are anticipated pest issues in partitions containing mycelium; as it is a natural insulating material, an additional separation layer may be required to protect against pests. Another of the concerns related to the roof envelope is biological corrosion in the case of application of insulation in terrace roof, slotted ventilated roof, and ducted ventilated roof.

7.4.2.2. Exterior wall

Exterior wall in the building is a three-layer masonry wall. The main bearing structure consists of 25 cm wide ceramic blocks and is insulated by hard stone wool. The final layer is clinker tile, glued to the insulation. Thermal transmittance of the partition is U = 0,17 [W/m²K)] which is more than enough to comply with requirements

implemented by polish law in 2021 (Table 7.5). The official minimal requirement of thermal transmittance of the external wall is $U \leq 0{,}2$ [W/m^{2}K)] and this value is the basis for analysing the feasibility of using an alternative insulation bio-material.

When using mycelium-based insulation, the width of the partition will increase in 3 cases, while it will decrease significantly if isolation 1 is used (Figure 7.3, Table 7.6). It is also important to pay attention to the mass of insulation, which for 1m^2 of partition insulated with wool is 15.6 kg while using alternative materials will increase even more than 3 times. For this reason, the technology of fixing should include additional mechanical elements securing the connection of thermal insulation with construction material.

Table 7.5

Technical parameters of the exterior wall with primary insulation material

partition	**material**	**thickness [m]**	**thermal conductivity [W/(mK)]**	**thermal resistance [(m^{2}K/W]**
exterior wall	clinker tile	0.02	1.000	0.020
	stone wool	0.20	0.040	5.000
	ceramic block	0.25	0.313	0.799
	cement-sand plaster	0.02	1.000	0.020
		0.49	U = 0.170 W/(m^{2}K)	

Source: Data based on the construction project.

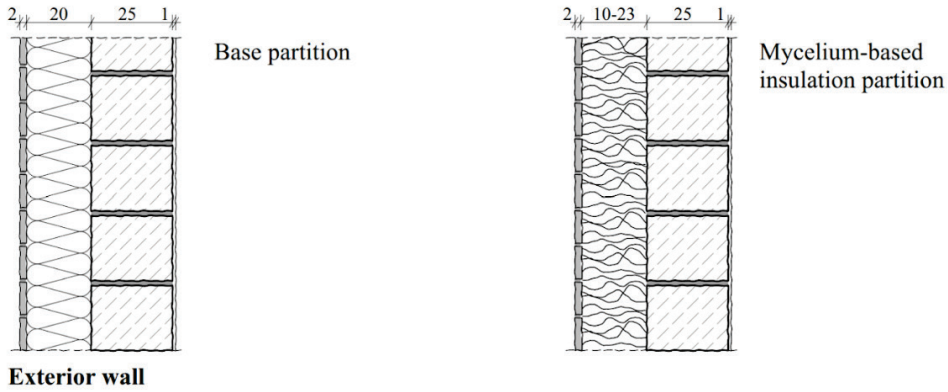


Fig. 7.3. Scheme of investigated partition
Rys. 7.3. Schemat badanej przegrody
Source: Author's scheme, 2022.

Table 7.6

Technical performance of primary and alternative mycelium-based insulation materials

material		thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K/W]	partition U [W/(m²K)]	total partition thickness [m]
stone wool		0.20	0.040	5.000	0.170	0.49
mycelium-based insulation	(1)	0.10	0.024	4.167	0.200	0.41
	(2)	0.23	0.059	3.898	0.200	0.57
	(3)	0.16	0.039	4.103	0.200	0.48
	(4)	0.23	0.058	3.966	0.200	0.57
	(5)	0.20	0.05	4.000	0.200	0.53

Source: Data calculated based on producer data from Table 3.1.

7.4.2.3. Basement wall

The basement wall is based on a reinforced concrete foundation slab, poured on site. Due to its location below ground level, the basement wall is additionally protected with vertical waterproofing. The main structure is insulated with a 10 cm layer of hard wool. A finishing layer of bucket foil was laid in order to additionally protect the wall against the pressure of the ground and to enable efficient draining of the rainwater. The required thermal transmittance coefficient of an underground wall is not specified in national regulations. Nevertheless, according to the construction standards, thermal insulation is necessary to prevent ground frost, so the coefficient for existing wall is at a level of U = 0.21 [W/m2*K], the performance of the investigated partition is specified in Table 7.7.

The use of alternative insulation materials, depending on the adopted solution, assuming the thermal parameters of the partition are maintained, will change the dimensions of the wall (Figure 7.4, Table 7.8). Due to the location, the width of underground wall layers is of secondary importance. Much more important issue is to ensure the tightness of walls exposed to rainwater and groundwater. It should be noted that, due to the substantial risk of moisture infiltration, discussed insulation applied in basement wall, may pose a greater risk compared to its application in other types of partitions. In case of a high level of underground water it is necessary to use additional waterproofing, which is the same way as in using mineral wool. The increased mass of mycelium-based insulation in comparison to stone wool in case of basement wall also does not play an important role as the ground protects the insulation against mechanical damage and possible tearing off of the layer.

Table 7.7

Technical parameters of the basement wall with primary insulation material

partition	material	thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K/W]
basement wall	dimpled foil	0.02	0.018	0.001
	stone wool	0.10	0.036	**2.778**
	waterproof membrane	0.00	0.018	0.001
	concrete block (500 kg/m3)	0.25	0.135	1.852
	cement-sand plaster	0.02	1.000	0.020
		0.38	U = 0.210 W/(m²K)	

Source: Data based on the construction project.

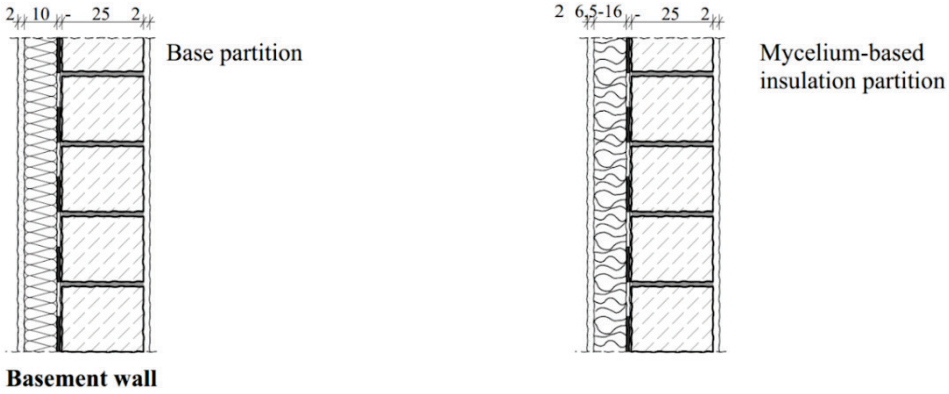


Fig. 7.4. Scheme of investigated partition
Rys. 7.4. Schemat badanej przegrody
Source: Author's scheme, 2022.

Table 7.8

Technical performance of primary and alternative mycelium-based insulation materials

material		thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K/W)]	partition U [W/(m²K)]	total partition thickness [m]
stone wool		0.10	0.036	2.778	0.210	0.38
mycelium-based insulation	(1)	0.065	0.024	2.708	0.210	0.345
	(2)	0.16	0.059	2.712	0.210	0.44
	(3)	0.11	0.039	2.821	0.210	0.39
	(4)	0.16	0.058	2.759	0.210	0.44
	(5)	0.14	0.05	2.800	0.210	0.42

Source: Data calculated based on producer data from Table 3.1

7.4.2.4. Flooring on the foundation slab

Foundation thermal insulation is required to be waterproof and resistant to compression, so wools are not a common choice. There are, however, suitable stone wool based products for these applications which are suitable for use as thermal insulation under foundation slabs. In the considered example, the layered structure of the foundation slab includes insulation made of stone wool, meeting the criterion of thermal insulating capacity with layer thickness equal to 4 cm (Table 7.9). The primary thermal insulating material meets the following technical parameters which are important for this partition wall: density = 140 kg/m^3 and compressive strength at 10% relative strain ≥ 0.03 mPa. The tested substitute materials based on mycelium have comparable densities ranging from 115.5 (4) to 180 kg/m^3 (2 and 5).

Table 7.9

Technical parameters of the flooring on the foundation slab with primary insulation

partition	**material**	**thickness [m]**	**thermal conductivity [W/(mK)]**	**thermal resistance [(m^{2}K)/W]**
flooring on the foundation slab	floor ceramics	0.02	1.050	0.019
	concrete base	0.05	1.650	0.030
	vapour proof membrane	0.00	0.170	0.001
	stone wool	**0.04**	**0.039**	**1.026**
	reinforced concrete	0.35	1.700	0.206
	concrete	0.10	1.050	0.095
	sand	0.30	0.40	0.75
		0.86	**U=0.283** W/(m^{2}K)	

Source: Data based on the construction project.

As far as compressive strength is concerned, the materials (1,2,3 and 5) have properties with higher thermal parameters than those of stone wool; only mycelium--based insulation (4) is less resistant and may require reinforcement in this regard (in the case of humidity parameters, the opposite may be true). Due to their insulating properties, bio-materials correspond to the thermal resistance of stone wool while maintaining the same material thickness (3), slightly thicker – 5 cm (2, 4 and 5), and even a lower layer thickness of 2 cm for the material (1) - complete data is shown in Figure 7.5 and Table 7.10.

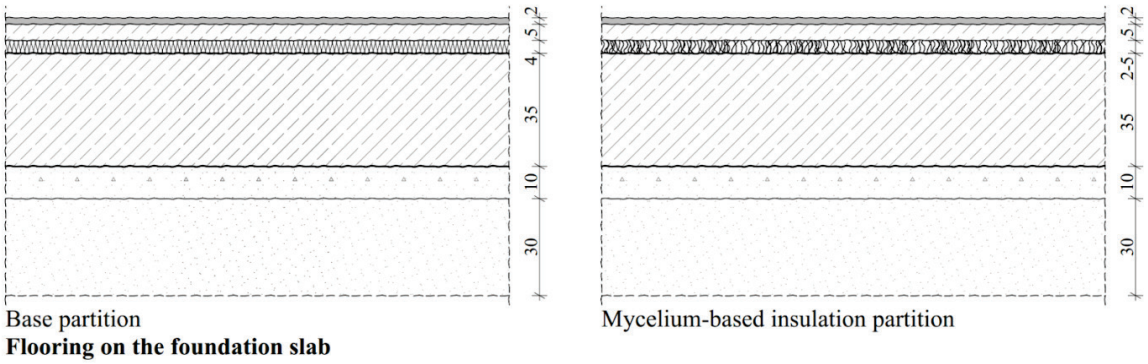


Fig. 7.5. Scheme of investigated partition
Rys. 7.5. Schemat badanej przegrody
Source: Author's scheme, 2022.

Table 7.10

Technical performance of primary and alternative mycelium-based insulation materials

material		thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K)/W]	partition U [W/(m²K)]	total partition thickness [m]
stone wool		0.04	0.039	1.026	0.283	0.86
mycelium-based insulation	(1)	0.02	0.024	0.833	0.302	0.84
	(2)	0.05	0.059	0.847	0.300	0.87
	(3)	0.04	0.039	1.026	0.283	0.86
	(4)	0.05	0.058	0.862	0.299	0.87
	(5)	0.05	0.05	1.000	0,286	0.87

Source: Data calculated based on producer data from Table 3.1.

7.4.3. Interior partitions

7.4.3.1. Inter-apartment party wall with expansion joint

In the case of this estate of terraced houses, the partition wall between apartments also serves as a dilatation wall between the buildings. In this case, official guidelines specify that the heat transfer coefficient is U ≤ 1.0 [W/m2*K]. In addition, the key feature of such a partition is its fire load-bearing capacity, fire tightness and fire insulation, which must be at least 60 min. The partition is a wall built of 25 cm thick ceramic blocks on both sides, with a 5 cm wide dilatation on the full height of the wall, filled with mineral wool (Table 7.11).

The fireproofing requirement is fulfilled by a single layer of ceramic blocks. Similarly, as far as thermal parameters are concerned, the required permeability

coefficient U ≤ 1.0 [W/m^{2}K] is met by a single layer of 25 cm hollow brick blocks with plaster on one side. The key distinguishing attribute of this wall is the occurrence of expansion joints, the width of which should be 5 cm between independent systems for structural reasons. This leads to the conclusion that the filling of the expansion joint is of little significance in terms of the legal requirements. However, the use of alternative bio-insulation will change the thermal performance of the compartment and significantly reduce the carbon footprint of the materials - the results of the survey are indicated in the Figure 7.6 and Table 7.12.

Table 7.11

Technical parameters of the inter-apartment party wall with expansion joint from primary insulation material

partition	**material**	**thickness [m]**	**thermal conductivity [W/(mK)]**	**thermal resistance [(m^{2}K/W]**
basement wall	cement-sand plaster	0.02	1.000	0.020
	ceramic block	0.25	0.313	0.799
	stone wool	**0.05**	**0.04**	**1.250**
	ceramic block	0.25	0.313	0.799
	cement-sand plaster	0.02	1.000	0.020
		0.59	**U = 0.320 W/(m^{2}K)**	

Source: Data based on the construction project.

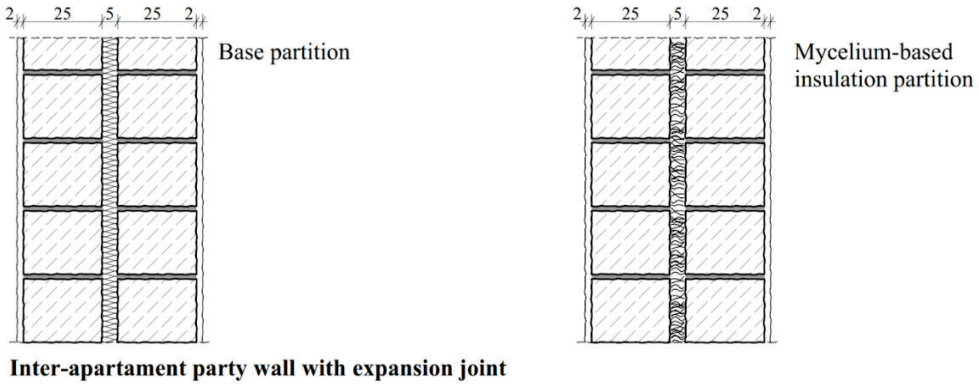


Fig. 7.6. Scheme of investigated partition
Rys. 7.6. Schemat badanej przegrody
Source: Author's scheme, 2022.

Table 7.12

Technical performance of primary and alternative mycelium-based insulation materials

material		thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K)/W]	partition U [W/m²K)]	total partition thickness [m]
stone wool		0.05	0.036	1.250	0.320	0.59
mycelium-based insulation	(1)	0.05	0.024	2.083	0.250	0.59
	(2)	0.05	0.059	0.847	0.370	0.59
	(3)	0.05	0.039	1.282	0.320	0.59
	(4)	0.05	0.058	0.862	0.360	0.59
	(5)	0.05	0.05	1.000	0.350	0.59

Source: Data calculated based on producer data from Table 3.1.

7.4.3.2. Inter-storey floor

In the case under consideration, the inter-storey ceiling is located between heated rooms of the same temperature, so it does not require thermal insulation. The ceiling structure is a reinforced concrete slab with a 10 cm layer of mineral wool on it, in which mechanical ventilation ducts are led, so the thickness of the layer results from reasons independent of the thermal insulation parameter (Table 7.13).

Table 7.13

Technical performance of primary and alternative mycelium-based insulation materials

partition	material	thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K)/W]
inter-story floor	wood flooring	0.02	0.180	0.111
	concrete base	0.08	1.650	0.048
	vapour proof membrane	0.00	1.000	0.002
	stone wool	0.10	0.039	2.564
	reinforced concrete	0.15	1.700	0.088
	concrete	0.10	1.050	0.095
	cement-sand plaster	0.01	1.000	0.010
		0.36	U=0.316 W/(m²K)	

Source: Data based on the construction project.

Due to the lack of requirements related to the thermal insulation parameter, the thickness of material alternatives based on mycelium was calculated with the assumption that the layer thickness equals 10 cm (Figure 7.7, Table 7.14).

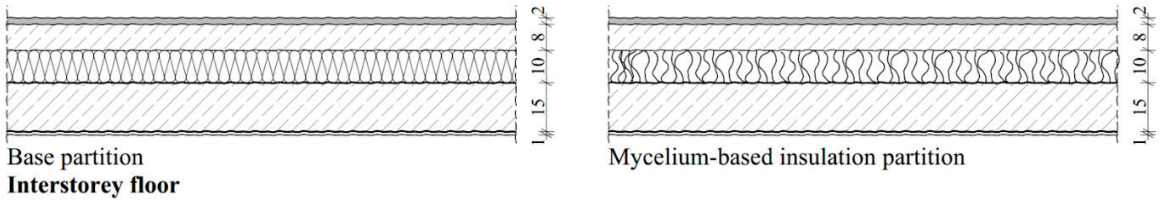


Fig. 7.7. Scheme of investigated partition
Rys. 7.7. Schemat badanej przegrody
Source: Author's scheme, 2022.

Table 7.14

Technical performance of primary and alternative mycelium-based insulation materials

Material		thickness [m]	thermal conductivity [W/(mK)]	thermal resistance [(m²K)/W]	partition U [W/(m²K)]	total partition thickness [m]
stone wool		0.10	0.039	2.564	0.316	0.36
mycelium-based insulation	(1)	0.10	0.024	4.167	0.210	0.36
	(2)	0.10	0.059	1.695	0.436	0.36
	(3)	0.10	0.039	2.564	0.316	0.36
	(4)	0.10	0.058	1.724	0.430	0.36
	(5)	0.10	0.05	2.000	0.385	0.36

Source: Data calculated based on producer data from Table 3.1.

7.5. Conclusions

The conducted analyses prove that in terms of thermal insulation parameter, ecological products based on mycelium can provide a substitute for conventional mineral wool insulation materials. Their performance often exceeds the relatively high insulating capacity of wools. The ability of mycelium panels to bond permanently with other materials, especially at high temperatures, is an issue that needs to be recognized and further investigated. In partitions not exposed to moisture, these materials can perform very well. As with mineral wools, the challenge is to maintain adequate compression resistance in horizontal partitions, but again, only one of the products may require further

testing or reinforcement in the form of a substructure. An important parameter from the point of view of facade insulation may be the significant weight of mycelium-based materials requiring the development of an appropriate substructure. When implementing mycelium-based insulations, it is also crucial to evaluate project-specific conditions, with a particular focus on fire safety measures.

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Grzegorz PERUŃ[1]

8. REVIEW AND DEVELOPMENT OF DATA SOURCES USED IN GEOGRAPHIC INFORMATION SYSTEMS

8.1. Introduction

Spatial information systems are well established and of great importance in today's world. Many institutions, using location information in the broad sense of the term, have implemented them long time ago into their activities, and it is difficult to imagine a return to using only classic maps, now called analog maps.

Spatial information systems are an effective tool for urban planning and development. It seems that the creation of smart city is not possible without the use of GIS, or at least this task is clearly facilitated by these systems. As will be presented later, among the components that make up a spatial information system is spatial data, to which this chapter of the monograph is devoted.

Generally, the term spatial information system should be understood as an information system which has several basic tasks, first of all, it allows the input of spatial data into databases, their collection in these databases, and then, during the actual exploitation, it enables the processing of these data and their visualization, as well as it allows to visualize the results of conducted analyses. If the scope of the system refers to the Earth's surface, then the name Geographical Information System (GIS) is often used, and if the scale of the study is large, the term Terrain Information System is also used. This division emerged in the second half of the 1980s, and the scale of 1:5000 was taken as the limit, up to which the term GIS is used, and above which the system is referred to as TIS. The versatility of GIS means that it is also used in other applications where position determination is important, and these include the use of the system to determine a position in space, concerning the surfaces of planets, or even during DNA gene sequence analysis[2].

[1] Silesian University of Technology, Faculty of Transport and Aviation Engineering, Department of Road Transport, e-mail: grzegorz.perun@polsl.pl.

[2] Davis D.: GIS dla każdego. ESRI Polska, Warszawa 2004; Gottlib D., Iwaniak A., Olszewski R.: GIS. Obszary zastosowań, PWN, Warszawa.

The scale of popularity of spatial information systems has been determined by the wide range of their applications, ranging from spatial planning of various types of facilities, such as public facilities such as health centers, hospitals, stores, and educational institutions, to determining the location of roads, the location of transmitters, to monitoring the spread of weather phenomena, social-economic, etc. This is due to the basic capabilities of these systems, which have developed over the years, and this process continues to allow for further expansion of GIS into new industries, allowing for more efficient decision-making based on analysis and simulation. The combination of spatial information with the characteristics of objects, taking into account the relationships between objects, and the possibility of efficient data updating are undoubtedly advantages of GIS.

According to numerous literature sources, the basic and necessary components of spatial information systems include algorithms, procedures, and methods for processing and sharing information, which together constitute software, databases in which spatial data are collected and stored, hardware, and people associated with data processing, software development and the target users of the system themselves[3].

The term GIS was introduced in the 1960s and was derived from the name of an information system that was developed for Canada. In the late 1980s, the acronym GIS also came to denote a scientific discipline, Geographic Information Science, which deals with geographic information and GIS methods and techniques. Later it was assigned the names geomatics and geoinformatics.

The Canada Geographic Information System (CGIS) is considered the first system of its kind, and it was developed for the Government of Canada in the early 1960s. It began a long but dynamic development of this type of system that continues today. In the early days, achievements primarily in the field of cartography were used, but the development itself was determined by hardware capabilities and therefore strongly depended on the achievements of computer science. The pace of development was also determined by other factors related to computer science, such as the development of software or database systems, but also by other achievements, including the development of data sources used in the systems.

Due to the interpenetration of the fields of application of GIS and cartography, people began to look for mutual relations between them[4]. Depending on the views, GIS began to be treated as a subset of the technical and analytical tools of cartography, which was

[3] Bielecka E.: Systemy informacji geograficznej. Teoria i zastosowania, Wydawnictwo Polsko-Japońskej Wyższej Szkoły Technik Komputerowych, 2006; Gaździcki J.: Systemy informacji przestrzennej, PPWK, Warszawa, 1990; Kwiecień J.: Systemy informacji geograficznej, Wydawnictwo Uczelniane Akademii Techniczno-Rolniczej w Bydgoszczy, Bydgoszcz 2004.

[4] Myrda G.: GIS czyli mapa w komputerze, Wydawnictwo Helion 1997; Richling A.: Systemy informacji geograficznej i ich znaczenie dla przyszłości geografii, P. Geograficzny, 1992, Vol. 64.

characteristic of cartographers, while proponents of GIS began to see spatial information systems as the successor of cartography, and cartography itself as a set of tools for the presentation of spatial data and the results of the analysis carried out on their basis. In fact, it is difficult to find a basis to fully justify any of the cited statements, GIS has not yet eliminated cartography but is a valuable tool that would not achieve the current level of applications and development if it did not also benefit from other fields, not only computer science but even remote sensing, photogrammetry and geodesy[5]. GIS systems undoubtedly grew out of the achievements of cartography and have their roots there, as it is the cartographic methodology that provides these systems with their concepts of modeling geographical space. They make it possible to organize information, they also lead to the creation of a model of geographical space, and many of them were created long before the advent of GIS or even computer science. Also, the idea of gathering and presenting information in layers has its roots in the times when GIS systems did not exist yet, namely this concept goes back to the 19th century when there was the development of overlay methods of developing classical maps. The early 20th century maps developed for New York City with economic and demographic themes is one such example[6].

Within the framework of this study, special attention was paid to the review of data sources used in geographic information systems and their development at the turn of the last decades. The main emphasis was placed on satellite techniques, which have clearly accelerated the acquisition of spatial data and thus triggered the development of GIS. However, a discussion of the characteristics of data sources and their development in the case of spatial data not related to the Earth's surface is completely omitted.

8.2. Geographic data characteristics

Spatial data relating to the Earth's surface is called geographic data as well as geodata. Their task is to describe objects by identifying their location, often supplemented by additional descriptive data. Thus, geographic data primarily include information about the location of objects in the adopted reference system, their geometric properties, spatial relationships with other objects, and several other descriptive features that define the desired properties[7].

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[5] Saliszczew K.: Kartografia ogólna, WNPW, Warszawa 1998; Sandecki J. (ed.): Teledetekcja, pozyskiwanie danych, Wydawnictwo Naukowo-Techniczne, Warszawa 2006.

[6] Baranowski M.: Rozwój kartografii komputerowej i systemów informacji geograficznej w Polsce na tle tendencji światowych, Polski Przegląd Kartograficzny, 1991, Vol. 23, No. 1–2; Kraak M., Ormeling F.: Kartografia – wizualizacja danych przestrzennych, PWN, Warszawa 1998.

[7] Werner P.: Wprowadzenie do systemów geoinformacyjnych, Warszawa 2004; Widacki W.: Wprowadzenie do systemów informacji geograficznej, IGUJ, Kraków 1997.

Due to the different purposes of spatial information systems, databases store information about objects, which can be both natural and artificial creations, but also social, economic, natural, and many other phenomena. Objects are described by specifying their attributes, which are divided into spatial and non-spatial. Spatial attributes in turn are divided into geometric and topological, while non-spatial attributes are divided into qualitative and quantitative[8]. This is depicted in Figure 8.1.

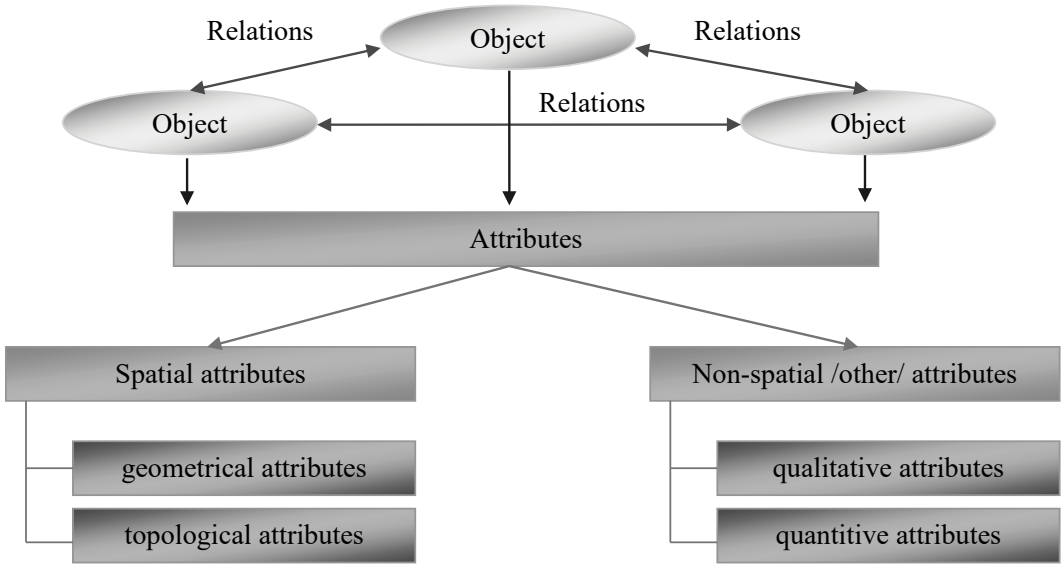

Fig. 8.1. Objects and their mutual relationships and classification of attributes describing objects
Rys. 8.1. Obiekty i ich wzajemne relacje oraz klasyfikacja atrybutów opisujących obiekty
Source: own elaboration based on literature data.

Geographic information systems distinguish the following relationships that occur between objects:

- bordering, e.g. two objects - land parcels with each other,
- affiliation, e.g. a freeway section between two exits belongs to the whole freeway,
- belonging, e.g. to any poviat, town, village, to a voivodeship.

In order to use geographic data, the transformation to a computer representation of the real world requires the development of a simplified version of it that can be understood by software, called a model[9]. As with any modeling, simplifications are necessary with this transformation, and it is necessary to create a data structure that allows for subsequent software processing. In the case of geographic data, each object must be given its location and, depending on the scale of the development, often also a specific shape. Topological relationships may also be specified. The way of visualization of

[8] Bielecka E.: Systemy informacji geograficznej. Teoria i zastosowania, Wydawnictwo Polsko-Japońskej Wyższej Szkoły Technik Komputerowych, 2006.
[9] Urbański J.: Zrozumieć GIS, Analiza informacji przestrzennej, Wyd. Naukowe PWN, Warszawa 1997.

objects on the screen or printout coming from the applied software is dictated by the standard adopted or developed, especially for these purposes. In this way, two models are distinguished:

- landscape models of geographic data, which are used to determine the location and topology, as well as other characteristics of objects,
- cartographic models of geographic data, which are used to determine how particular types of objects are represented on screen and/or print.

Based on the types of data used in spatial information systems, there are three main geographic data landscape models:

- vector models,
- raster models
- Triangulated Irregular Network (TIN) models.

The vector model is perfect for representing discrete data, the raster model – is for continuous data, while the TIN model - is for data containing information about the third dimension, i.e. height and it is used to represent terrain relief.

Depending on the type of geographic data - whether it is vector or raster, which results, among other things, from the way it is acquired, the way it is recorded and the subsequent possibilities of its processing differ. Data can be combined by presenting them in different layers, it is also possible to create complex objects, which are represented by more than one simple object. Complex objects are often created using vector data, in which each object is represented by a point, line, or surface[10].

Points allow objects to be represented by a coordinate pair, which are usually longitude and latitude. They have a simple visualization, consistent with the cartographic model used. They are perfect for presenting objects whose size is not important in further analyses.

The second way of representing objects is a line, used for determining the location of objects characterized by one dimension – length. It is commonly used to determine the location of rivers, roads, railroads, power lines, district, provincial, national, and other borders. Lines are recorded by a sequence of coordinates of consecutive points, marking the entire course.

Objects that require two-dimensional representation are represented by polygons, whose area is determined by a series of coordinates of points. Examples of objects requiring such representation are seas, lakes, parcels, administrative units, etc.

The decision to use a particular style of representation is influenced not only by the type and characteristics of the object but also to a very large extent by the scale of the

[10] Czyżkowski B.: Praktyczny przewodnik po ArcView 3.3., PWN, Warszawa 2006.

study. Small scale studies will be characterized by lower accuracy, which may result, for example, in the recording of surface objects in simplification by linear or even point objects.

The use of a vector model among all landscape data models allows to obtain high accuracy of objects location determination. Moreover, it also allows for recreating in computer representation the relations between objects, i.e. their topological relationships. Hence the division into simple vector model and topological vector model.

For geographic data recorded in raster form, different analysis and processing methods are used. The raster model is created by dividing the space into equal areas of square or rectangular shape. This operation is called tessellation and it results in a set (matrix) of elements, which are individual pixels. The position of individual pixels is given by their row and column numbers in the matrix. This is a very simple data record and therefore has found use often first in many GIS programs. Further operations based on the raster model take place differently from the vector model, but some similarities can be seen. Although the raster model is perfect for the representation of continuous data, it is possible to record the point, line, and polygon objects with its use, but this record will be more approximate, the bigger dimensions of a single element are, i.e. the bigger dimensions of the pixel are. Each pixel is accompanied by a single value, which can be any attribute. To increase the amount of data, it is necessary to use multiple layers, and data acquired from sensors mounted, for example, on artificial satellites of the Earth, recording electromagnetic radiation in different ranges is an example of such an approach. More information on this will be given later in the chapter.

Typical examples of data represented in raster models are terrain elevation, air temperature, air pressure, and even social phenomena. The concepts of spatial, spectral, and temporal resolution are directly applicable to raster data.

Related to spatial resolution is the size of a single pixel. As will be shown in the following sections, this is directly related to the way the data is acquired and the type of equipment used. The ability to distinguish objects in aerial photographs or satellite images depends mainly on this parameter.

The spectral resolution is a term related to the ability of the equipment used to acquire images in different ranges of electromagnetic radiation. Images are often captured in different ranges of radiation, not only in the visible light range.

Time resolution, on the other hand, allows determining the time after which a photo/image of the same area of terrain can be obtained. This is quite a characteristic parameter for any artificial satellite that is used to acquire geographic data. As it will be presented in section 3, this time varies considerably and can range from even tens of hours to tens of days and is due, among other things, to the altitude of the orbit.

Despite the ease of implementing the raster model and acquiring data for it, it has many drawbacks, including the large size of the databases. At the turn of the years and with the progress taking place in information technology, thus also in GIS systems, various forms of data storage optimization were applied, developing and using different methods of their compression. Looking from today's point of view, one can see numerous formats for saving images, although many of them are not used nowadays or have even been forgotten. All compression algorithms can be divided into lossy and lossless. Lossy compression typically allows for smaller data file sizes, but at the cost of content distortion due to the algorithms. The use of lossless compression prevents data degradation, but the effectiveness of such algorithms is usually lower from the standpoint of comparing data size before and after compression.

The last of the landscape models of geographic data presented was the TIN model, perfectly applicable to the presentation of three-dimensional data. It is the model of choice for creating numerical terrain models, allowing the height of the terrain position at any point to be determined. Unlike the raster model, the TIN model is usually irregular in structure, tessellation leads to triangles with varying side lengths. Each vertex of this triangle has known coordinates, allowing the computation to be performed anywhere in space. Simplifying considerations considerably, we can say that the TIN model is based on the topological vector model, additionally enriched with the height dimension. Analyses conducted with its use depend to a large extent on the density of vertices of the created grid, taking into account the discontinuities of the terrain by an appropriate selection of the location of grid points and on the interpolation algorithm used.

8.3. Geographic data sources

Geographic data can be extracted from a variety of sources including:

- satellite imagery,
- aerial photographs,
- geodetic measurements,
- measurements using satellite navigation systems[11].

Choosing a source from the above also involves choosing between raster data and vector data. The listed sources can be thought of as primary data sources, usually found in digital form, allowing for almost direct use in GIS programs. An airborne laser scanner

[11] Januszewski J.: Systemy satelitarne GPS, Galileo i inne, PWN, Warszawa 2006; Narkiewicz J.: GPS i inne satelitarne systemy nawigacyjne, Wyd. WKŁ, Warszawa 2007; Narkiewicz J.: Podstawy układów nawigacyjnych, Wyd. WKŁ, Warszawa 1999.

can also be used to feed systems that also need elevation data, such as TIN systems. It allows measuring the height of points located on the surface of the Earth with specified longitude and latitude coordinates. The measurement points are located close to each other and form a dense network, which makes the accuracy of height determination vary from 0.15 to 0.25 m[12].

Geographic data can also be secondary. These include traditional, classical maps and various databases. Scanning maps or photographs or creating terrain models based on topographic maps and levels visible on them, is not one of the most accurate ways of data acquisition, however, it is used. Secondary data are usually in analog form, which involves additional steps[13].

The division between primary and secondary data becomes blurred in some situations, as often data extracted from primary sources also need to undergo some preparation before being used in GIS systems. This processing, however, is more straightforward in nature, and the data extracted in this way is specifically intended for use in GIS. Secondary data, on the other hand, are obtained from other systems or have already been used in other studies. In this paper, attention will be focused on satellite imagery, undoubtedly a source of primary data.

Each of the sources is characterized by advantages and disadvantages, which in particular situations may determine the usefulness of the data thus obtained for the assumed purpose of the system work. Similarly, any data processing aimed at introducing them into spatial information systems is a source of potential errors. Both satellite images and aerial photographs are sources of raster data, while field measurements, whether geodetic or using satellite navigation systems, as well as airborne laser scanning, are sources of vector data. However, GIS software nowadays allows combining different types of data with each other as well as converting them[14].

Considering the type of landscape geographic data model, the data sources in the vector model can be both satellite images and aerial photographs, but in this case, the data obtained from measurements should be mentioned first. For the raster model the use of aerial photos and satellite images is the most natural way of data acquisition and in contrast to the vector model, does not require processing into vector form, so-called

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[12] Bielecka E.: Systemy informacji geograficznej. Teoria i zastosowania, Wydawnictwo Polsko-Japońskej Wyższej Szkoły Technik Komputerowych, 2006; Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W: GIS. Teoria i praktyka, Wydawnictwo Naukowe PWN, Warszawa 2008.

[13] Pietrzak M., Siwek J.: Wykorzystanie map historycznych, przetworzonych przy użyciu GIS do oceny zmian użytkowania ziemi na Pogórzu Wiśnickim. Przemiany środowiska na Pogórzu Karpackim, T. 1, IGiGP UJ, Kraków 2001, pp. 21–29.

[14] Litwin L., Myrda G.: Systemy informacji geograficznej - zarządzanie danymi przestrzennymi w GIS, Wydawnictwo Helion, 2005; Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W: GIS. Teoria i praktyka, Wydawnictwo Naukowe PWN, Warszawa 2008; Szczepanek R.: Systemy informacji przestrzennej z quantum GIS. Część I, Politechnika Krakowska, Kraków 2013.

vectorization. In the last of the presented models – the TIN model, the source can be again vectorized images and photos, but again the main role is played by measurement data, which can be complemented by height or topographic maps.

Satellite images, as well as aerial photos, are models of a part of Earth's surface, which are obtained in a specific range of the electromagnetic spectrum, not necessarily in the visible range. These models can be recorded in analog or digital form, but currently, digital technology is dominating.

Depending on the scale of satellite images and aerial photographs, objects located on the surface of the Earth may be recorded in varying detail. As the scale of an image or photograph decreases, the number of registered elements decreases, i.e. its detail decreases, however, it is usually accompanied by an increase in the spatial scope of the study. The number of registered details is influenced mainly by the type of sensor placed on the satellite or mounted on the plane, which will also depend on the quality of the obtained image in different weather conditions. In the case of aerial imagery, the quality of the acquired data is also affected by the flight altitude, the stability of the flight path, and many other factors that are not present in satellite imagery[15].

Despite various limitations, satellite images and aerial photographs have for years been considered the two richest sources of information used in spatial information systems. Remote sensing and photogrammetry, among others, are used to process and interpret the data, allowing to recognize objects recorded in these images and enrich spatial data with descriptive data (remote sensing, i.e. measurement of properties of objects without physical contact with them) and correct determination of sizes, reconstruction of shapes and mutual position (photogrammetry). This is the way to obtain a distortion-free orthophoto map[16].

To recognize objects on aerial photographs or satellite images, that is, acquired through various sensors, recording electromagnetic radiation both reflected or emitted by objects located on the Earth's surface, in different ranges of electromagnetic radiation, remote sensing methods, and so-called recognition features are used. These are characteristic features of objects, enabling their recognition and even determining additional parameters. Depending on the conditions, it is possible not only to determine the size, and color, but even the height of some objects. For example, this is possible for tall objects photographed at a particular time of day based on the length of their shadow. Due to such possibilities of object recognition, the so-called object recognition features are divided into direct and indirect ones:

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[15] Ciołkosz A., Misztalski J., Olędzki J.: Interpretacja zdjęć lotniczych, Wyd. Naukowe PWN, Warszawa, 1999.
[16] Makowski A. (red.): Systemy informacji topograficznej kraju, Wyd. PW, Warszawa 2005; Mularz S.: Podstawy teledetekcji, Wydawnictwo PK, Kraków 2004.

- direct features include the most basic properties of objects, i.e., size, shape, tone or color of the photographic image, texture, etc;
- indirect features of objects include features that indirectly indicate the presence of an object and its characteristic properties. In addition to the shadow size already given, topographic distribution is also included in this group.

The cost of data acquisition is a very important aspect of data source selection . At the turn of the years of GIS development, the costs of computer equipment, software, data acquisition, and user training varied significantly. The data themselves were difficult to access, often requiring huge resources necessary to acquire them, which was also associated with large time outlays e.g. for taking measurements. In the case of using secondary data, both time and financial outlays are transferred to activities such as digitization or vectorization, but also data correction.

Satellite images and aerial photographs, as the sources of raster data, have a common feature, which is obtaining information based on registered electromagnetic radiation employing passive or active devices. The first of them allows recording solar radiation or radiation emitted by objects on the Earth, whereas active devices have sources of radiation, which is reflected by objects on the Earth's surface.

8.4. Satellite images

Since the first artificial satellites were launched, they started to be seen as a very good source of geographical data. They provided data, especially for military needs, however, they also opened the way for obtaining data for civilian needs. Nowadays, information for practically the entire Earth's surface can be drawn from this source. Numerous literature sources tell us that the first satellite used for mapping was the Landsat satellite, and this was back in the early 1970s.

The ability to acquire useful images from satellites is primarily due to the altitude of the orbit. Because there are two main types of satellites, which include heliosynchronous and geostationary satellites, their imaging capabilities differ. A large proportion of satellites that move in heliosynchronous orbits, or orbits that are synchronous to the Sun, are circumpolar satellites, which in effect cause them to move relative to the Earth's surface at the same speed as the Earth rotates around its axis. Heliosynchronous satellites allow to obtain information about different fragments of the Earth, moreover, they enable imaging of the same fragment of the surface at the same regular time, which facilitates analysis of occurring changes in the observed area. Acquisition of data from this source

is characterized by the possibility of regular updating, but each time it requires the processing of data to the proper form, which is not always possible in an automatic or semi-automatic way.

Satellite images have a very different spatial resolution, according to different sources ranging from about 0.5 [m] to even 1 [km]. The size of acquired images expressed in pixels varies from a few hundred to a few thousand pixels in both directions, which, taking into account the spatial resolution, allows to determine the size of the imaged area in each image from about 9 x 9 [km] to 200 x 200 [km].

Besides spatial resolution, spectral and temporal resolutions are very important. Depending on the sensor installed on the satellite, the radiation can be recorded in one range of radiation (single-band systems) or many ranges simultaneously (multi-band). The simplest detector will be a sensor registering a range of visible radiation, but usually, devices registering more ranges are used.

Some of the best-known artificial satellites for acquiring this type of image are Landsat satellites, which in 2022 will record 50 years of operation.

Landsat is the name of a program to remotely acquire images of the Earth based on successive generations of satellites launched into space beginning in 1972. Some of these satellites are still operational (Landsat 7, Landsat 8, and Landsat 9), as shown in Table 8.1. One of the satellites, Landsat 6, was not put into service because it did not reach its planned orbit.

Table 8.1

Landsat satellites of the Earth remote image acquisition program

Satellite name	**Launch date**	**End date**	**Operat-ing time**	**Ranges and resolutions**	**Notes**
Landsat 1	July 1972	January 1978	66 months	Three-band RBV: 80 [m] Four-band digital MSS: 60 [m] /MS/	Original name: Earth Resources Technology Satellite 1. Altitude 900 [km], time resolution – 18 days
Landsat 2	January 1975	February 1982	85 month	RBV: 80 [m] Four-band digital MSS: 60 [m] /MS/	Altitude 900 [km], time resolution – 18 days

Satellite name	Launch date	End date	Operat-ing time	Ranges and resolutions	Notes
Landsat 3	March 1978	March 1983 / September 1983	60 months	RBV: 38 [m] /PAN/ Four-band digital MSS: 80 [m] /MS/	Altitude 900 [km], time resolution - 18 days. The 5th channel of the MSS failed shortly after launch
Landsat 4	July 1982	December 1993 (end of science data collection) / June 2001 (withdrawn from service)	136 months	Four-band digital MSS: 80 [m] /MS/ TM: 30 [m] /MS/ TM: 100 [m] /IR/	Seven-band TM, altitude 705 [km], time resolution – 16 days. Last remaining science data downlink capability failed in 1993
Landsat 5	March 1984	June 2013	351 months	Four-band digital MSS: 80 [m] /MS/ TM: 30 [m] /MS/ TM: 100 [m] /IR/	Seven-band TM, altitude 705 [km], time resolution – 16 days. MSS turned off in August 1995, TM in November 2011. In January 2013 satellite moved in to a lower orbit
Landsat 6	October 1993	October 1993	-	MSS: 80 [m] /MS/ ETM: 15 [m] /PAN/ ETM: 30 [m] /MS/ ETM: 120 [m] /IR/	Failed to reach orbit
Landsat 7	April 1999	-		ETM+: 15 [m] /PAN/ ETM+: 30 [m] /MS-RED, GREEN, BLUE/ ETM+: 30 [m] /NIR, SWIR-1, SWIR-2/ ETM+: 60 [m] /TIR/	Eight-bands ETM+ 8-bit data, altitude 705 [km], time resolution – 16 days. Single scene width about 165 [km]

Satellite name	Launch date	End date	Operating time	Ranges and resolutions	Notes
Landsat 8	February 2013	-		OLI: 15 [m] /PAN/ OLI: 30 [m] /MS/ OLI: 30 [m] /NIR, SWIR-1, SWIR-2/ TIRS: 100 [m] /TIR-1, TIR-2/	Original name: Landsat Data Continuity Mission, eleven spectral bands,12-bits data, altitude 705 [km], time resolution – 16 days
Landsat 9	September 2021	-		OLI-2 / TIRS-2 Four-bands visible spectral one band near-infrared spectral three-bands shortwave-infrared spectral 30 [m] one band panchromatic 15 [m] two-bands thermal infrared 100 [m]	Data is publicly available from USGS, Landsat 9 replaces Landsat 7 taking its place in orbit – joins Landsat 8 in orbit – 8 days out of phase with Landsat 8, eleven spectral bands, 14-bit data

Source: own elaboration based on literature and internet sources, e.g. [18, 19, 28, 29, wikipedia].

The lifetime of each satellite varies, with the first three generations ranging between 5 and 7 years. The 4th and 5th generations achieved longer operating times and were just over 11 years and 29 years respectively. The lifetime of the active satellites of the Landsat series is over 23 and 9 years respectively. The newest one is working since September 2021. The achieved lifetimes are very long, which is positive from the economic point of view of the project and allows to launch the next generations less frequently.

Successive generations of satellites differ in the parameters of their sensors. So far, Landsat satellites use the following multispectral cameras and scanners: RBV – Return Beam Vidicon; MSS - Multispectral Scanner; TM – Thematic Mapper; ETM – Enhanced Thematic Mapper; ETM+ – Enhanced Thematic Mapper Plus. The equipment specifications of the first three generations of satellites were very similar to each other. The Landsat 4 generation, of which Landsat 5 was almost a copy, had an upgraded MSS scanner design and was additionally equipped with a Thematic Mapper TM. Landsat 6 was to use for the first time an Enhanced Thematic Mapper in addition to the MSS scanner, capable of capturing 15 [m] resolution images in panchromatic mode. Due to the

failure of its launch, the next generation, which started work 5 and a half years later, used the Enhanced Thematic Mapper Plus solution, which also allowed to record images with a resolution of 15 [m] in panchromatic mode, but differed in additional capabilities of calibration (full aperture calibration). The next big changes are in Generation 8, which features the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS).

Based on data presented by NASA, Landsat 8 and 9 satellites are capable of recording data in 11 bands ranging from visible light, near-infrared, shortwave infrared, and thermal infrared wavelengths. Three bands are visible light – natural color in the ranges of red, green, and blue, which allows observations of shallow water and coral, tracking smoke/dust. Each of the following bands has its purpose, with bands 10 and 11 allowing the recording of surface temperature. The next generation of Landsat satellites is currently under development and is expected to offer more than twice the number of bands as Landsat 8 and 9, with up to 25 bands planned. The estimated launch date for the next satellite is 2029/2030 according to official information released by NASA.

A good overview of the development of the Landsat satellites, their timing, and launch dates is given in Figure 8.2.

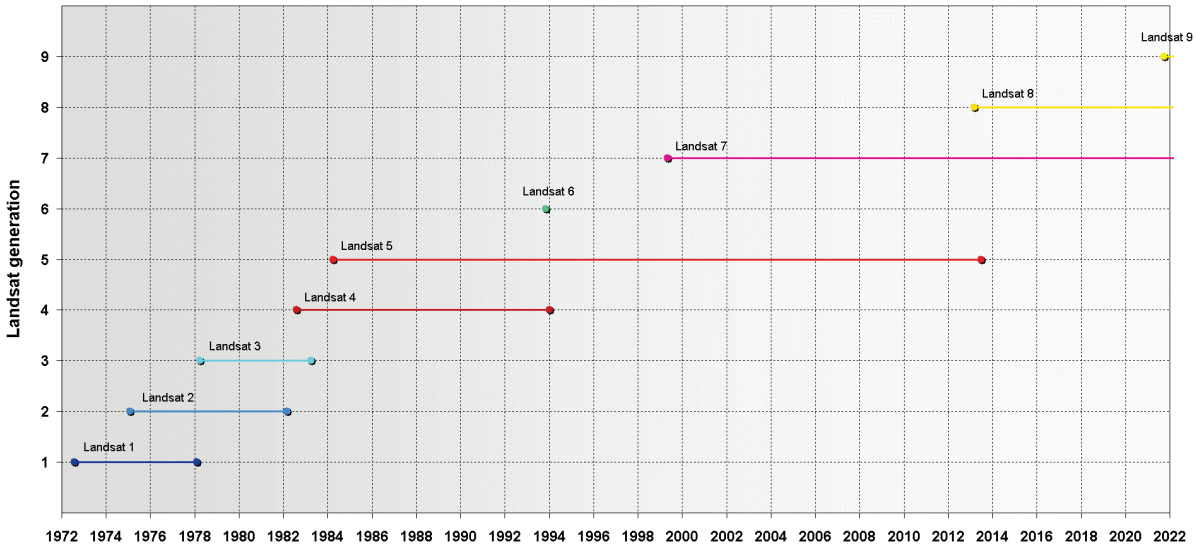

Fig. 8.2. Timeline of successive generations of Landsat satellites
Rys. 8.2. Linia czasu pracy kolejnych generacji satelitów Landsat
Source: own elaboration based on literature data

Among all the satellites of the Landsat series, the Landsat 5th generation features the most data expressed in terms of the number of images taken. This number is estimated to be over 3.7 million. Landsat 8 and Landsat 9, on the other hand, are characterized by the highest number of images taken per year (>700 scenes per day), but in terms of their

operating time, they currently rank second and third, respectively. Landsat 7 has taken about 3 million images, and Landsat 8 has about 2 million images.

For full imaging of the country's surface by Landsat satellites about 32 images are needed, but several of these images will cover a very small area of Poland. It should be also remembered that areas presented on neighboring satellite images partly overlap.

Geographic information systems also use data obtained from other satellites. Among more known satellites there are SPOT, Quickbird, IKONOS, Radarsat, IRS, Meteosat, and ORBImage. Some of the mentioned satellites have several variations – generations, differing similarly to the next generations of Landsat satellites in the instrumentation used, which in turn influences the spatial and spectral resolutions. Examples of these satellites are shown in Table 8.2.

Table 8.2

Satellites used to acquire images of Earth

Satellite name	**Start operation – end operation**	**Ranges and resolutions**	**Notes**
ERS-1	July 1991 – marzec 2002	25 [m]	Altitude 785 [km]. The first satellite of the European Space Agency (ESA). Imaged belt with a width of 100 [km]
ERS-2	April 1995	25 [m]	Compared to ERS-1 it had the ability to measure ozone in the atmosphere
Radarsat-1	November 1995	25x28; 30x28; 25x28; 50x50; 100x100 [m]	Ability to work at different resolutions and view terrain from different angles
Radarsat-2	December 2007	From 3 to 100 [m]	Imaged areas from 20 to 500 [km] wide
IRS-1 CD	December 1995 (IRS-1 C), September 1997 (IRS-1 D)	PAN 5,8x5,8 [m] LISS-3 23,2x23,5 [m] MIR 70x70 [m] WIFS 188x188 [m]	Two satellites differing in orbit (circular or elliptical). Time resolution of 24 days (IRS-1 C) / 25 days (IRS-1 D)
IKONOS	September 1999	PAN 0,82x0,82 [m]; MSS 4x4 [m]	Orbit 822 km above the pole, image covering an area 11x11 [km], time resolution 3 to 5 days
SPOT-4	March 1998	10 [m] /PAN/ 20 [m] /MSS/	Altitude 832 [km], image covering an area of 60x60 [km]
SPOT-5	May 2002	PAN 2.5x2.5 [m] MSS 10x10 [m] Short-wave Near Infrared 20x20 [m]	Orbit 832 km above the pole, image covering an area 60x60 [km]. Time resolution of 26 days

Satellite name	Start operation – end operation	Ranges and resolutions	Notes
SPOT-6	September 2013	1,5 [m] /PAN/ 6 [m] /MSS/	Orbit 695 km above the pole, image covering an area 60x60 [km]. Time resolution of 1–3 days
ORBImage OrbView 3	1999	PAN 1x1 [m]; MSS 4x4 [m]	
ORBImage OrbView 4	2000	PAN 1x1 [m]; MSS 4x4 [m] Hyperspectral 8x8 [m]	
Quickbird	November 2000	0.82x0.82 [m]; 3.28x3.28 [m];	Has not reached orbit, the first of three planned for launch by 2008
Quickbird-2	October 2001- December 2014	0,61x0,61 [m] /PAN/ 2,44x2,44 [m] /MSS – BLUE, RED, GREEN, NIR/	Altitude 450 [km]. Two sensors: panchromatic and four-channel multispectral. Imaged area 16.8x16.8 [km], time resolution 1–3.5 days, orbit 450 (original) / 482 (post orbit modification) [km], 11-bit data
Envisat	March 2002	25 [m]	Successor of ERS-1 and ERS-2. Altitude 790 [km]. Belt width 56-100 [km]
Alos	January 2006 – May 2011	Up to 10 [m] (Fine mode) Approx. 100 [m] (ScanSAR mode) 30 [m] (Fine Polarimetric mode)	Altitude 697 [km], imaged area 70x70 [km] (Fine mode), 250x250 [km] (ScanSAR mode), 30x70 [km] (Fine Polarimetric mode)
Worldview-1	September 2007	0,5 [m]	Altitude 496 [km], 11-bit data, image covering an area of 17.6x17.6 [km]
Worldview-2	October 2009	0,46/0,50 [m] /PAN/ 1,84 [m] /MSS/	Altitude 770 [km], image covering area 16.4x16.4 [km], time resolution 1.1 to 3.7 days
GeoEye	September 2008	PAN 0,41x0,41 [m]; MSS 1,65x1,65 [m]	Considered a complement to the IKONOS satellites. Imaged area 15.2x15.2 [km], time resolution 3 days
Meteosat-1 Meteosat-2 Meteosat-3 Meteosat-4 Meteosat-5 Meteosat-6 Meteosat-7	November 1977 June 1981 June 1988 March 1989 March 1991 November 1993 September 1997	VISIR 2,5x2,5 [km] TIR 5x5 [km]	First generation of the Meteosat satellites, operations completed

Satellite name	Start operation – end operation	Ranges and resolutions	Notes
Meteosat-8 Meteosat-9 Meteosat-10 Meteosat-11	August 2002 December 2005 July 2012 July 2015	11 of the channels at a spatial resolution of 3x3 [km] HRV 1x1 [km]	Second generation of the Meteosat satellites, currently in use: Meteosat-9 – Meteosat-11

Source: own elaboration based on [17].

As can be seen, the spatial resolution for satellite images varies significantly. The temporal resolution also varies over a wide range, ranging from a few minutes (for Meteosat), to tens of days, such as for some IRS, Landsat, SPIN, etc. satellites.

8.5. Summary

The overview of geographic data sources used in GIS presented in this chapter of the monograph was intended to show the variety of ways of data acquisition. It was preceded by the characteristics of geographic data and all basic information allowing us to understand the whole issue. The characteristics of the data discussed are very much determined by the way they are acquired and the form in which they feed the databases. A different set of data can be obtained using data acquired during field measurements, another using aerial photographs and satellite images. The main selection factor here is the form of the data – whether it is a vector or raster data and how much additional information, so-called metadata, accompanies it.

The analysis of the development of data sources focuses mainly on satellite images, presenting the characteristics of the most famous satellites used for data acquisition, both public and privately launched. Much space is devoted to presenting the achievements of the Landsat program, which for the last 50 years has set some standards.

Aerial imagery shares many of its characteristics with satellite imagery. For many years the analog technique was used and in some cases still is, requiring post-processing of images to digital form, thus requiring digitalization. The use of digital cameras makes it possible to eliminate this step and is a natural step in the evolution of this data source. In the case of aerial imaging, it is faster and cheaper to put into use the latest developments, use newer sensors, etc., which in the case of satellite imaging requires launching another satellite of a newer generation.

[17] Peruń G.: Systemy informacji przestrzennej. Materiały dydaktyczne do wykładu, Politechnika Śląska, Katowice 2011; Peruń G.: Systemy informacji przestrzennej. Materiały dydaktyczne do zajęć, Politechnika Śląska, Katowice 2011; QuickBird Data Sheet, DigitalGlobe 2014.

Another difference between taking aerial photographs and creating satellite images is the altitude at which such images are acquired. Unlike satellite images, the height at which aerial images are acquired is usually between 3 and 9 [km], which results in a much smaller area presented in the image. Aerial images can also be taken in different radiation ranges, depending on the needs of their later use.

Although both satellite images and aerial photographs are raster data sources, it is possible to process them into vector form. It is also possible to create three-dimensional models, which results from the possibility of creating stereoscopic images from pairs of overlapping images. Geographic data acquired from artificial satellites are characterized by the possibility of studying areas of large areas, but still on small scale. It is also possible to image areas that are inaccessible for various reasons, which is not always possible to do using aerial imagery. These, however, are characterized by higher resolution, so they can provide data for GIS systems operating on a larger scale.

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Aleksandra ŚLIWA[1]

9. VIRTUAL REALITY TECHNOLOGY IN THE CONTEXT OF SMART LIVING

9.1. Introduction

The issue of inhabitation is relatively rarely discussed in the concept of Smart Cities, considering the importance of its role in the processes of shaping cities[2]. The original concentration on aspects of maximizing the efficiency of urban infrastructures has undergone a significant transformation on two fronts, first through the implementation of digital communication technologies, then by taking into account human capital, social relationships and the potential of inclusive civic participation[3]. It should be emphasized that the pursuit of intelligent and sustainable urban development is a measure to achieve the goal of improving the quality of life of its present and future inhabitants. The quality of habitation understood as the realization of life processes is therefore the culmination of the efforts of all parties involved in the task of modeling and developing urban structures. Consideration of the transformations of inhabitation processes accompanying the emergence of a new medium in the form of virtual reality technology can bring new findings in terms of knowledge about shaping the Smart Cities of the future. Awareness of the existence and influence of virtual space on the physical world will contribute to a more conscious shaping of residential spaces, following the

[1] Silesian University of Technology, Faculty of Architecture, Department of Residential and Public Architectural Design, e-mail: aleksandra.sliwa@polsl.pl.

[2] Jonek-Kowalska I.: Rozwój inteligentnych miast w polsce w kontekście niezrównoważonych budżetów jednostek samorządu terytorialnego. [In:] Jonek-Kowalska I. (ed.) Wyzwania i uwarunkowania zarządzania inteligentnymi miastami. Wydawnictwo Politechniki Śląskiej, Gliwice 2019, pp. 91-106; Chrisidu-Budnik A.: Współczesne kierunki rozwoju inteligentnych miast w kontekście potencjału relacyjnego. [In:] Kusiak-Winter R., Korczak J. (red.): Ewolucja elektronicznej administracji publicznej, E-Wydawnictwo, Prawnicza i Ekonomiczna Biblioteka Cyfrowa, Wydział Prawa, Administracji i Ekonomii Uniwersytetu Wrocławskiego, Wrocław 2021, pp. 151–169.

[3] Kowalska-Styczeń A.: Badanie złożonych zjawisk społecznych w kontekście inteligentnego miasta. Inteligentny rozwój inteligentnych miast, CeDeWu Sp. z o.o., Warszawa 2020, pp. 137–146; Sim D.: Miasto życzliwe. Jak kształtować miasto z troską o wszystkich, Wysoki Zamek, Kraków 2020.

example of the late 19th and early 20th centuries, when architectural theory and practice were redefined through the awareness of the existence of physical space[4].

The research includes analyses of the influence of virtual reality technologies on the processes of habitation in the context of the formation of the phenomenon of intelligent habitation as a component of the Smart City of the future. The aim of the research is to assess the impact of modern information technologies on the processes of habitation and to formulate prospects for their future development. The starting point for the analysis is the concept of *compilation dwelling* by Grzegorz Nawrot[5] referring to the multidimensionality of inhabitation processes taking place simultaneously in the material structures of cities and in the information clouds. The complex structure of dwelling processes understood in this perspective also includes the aspect of functioning in cyberspace and the virtual world, where the city residents perform subsequent activities associated with habitation[6]. The process of relocation of activities to the virtual sphere was highlighted during the restrictions associated with the COVID-19 pandemic, which forced remote working and learning, realized through modern communication technologies. Thus, specific external conditions established a peculiar anomaly affecting the natural processes of transformation of the processes of habitation. The phenomenon of functioning in virtual space is progressing and influencing residential processes, which will be reflected in the shapes of housing spatial structures in Smart Cities of the future.

9.2. Research methods

In order to evaluate the impact of the phenomenon of virtual reality technology on inhabitation processes, I have applied the methods of historical-interpretive research and logical argumentation[7]. I considered the common factor of the analyzed phenomenon of virtual reality and processes of inhabitation to be the spatial context proper to the issue of architecture. Hence, the first stage of analysis focuses on the sensory perception of space, which in virtual conditions becomes an object of implementation of subsequent

[4] Leśniakowska M.: Przestrzeń w architekturze, [Online] 2012, https://teoriaarchitektury.blogspot.com/2012/07/marta-lesniakowska-przestrzen-w.html.
[5] Nawrot G.: O współczesnych formach zamieszkiwania w mieście, Wydawnictwo Politechniki Śląskiej, Gliwice 2015; Nawrot G.: Symultaniczność i kompilacja a obraz miejsca, Budownictwo i Architektura, 2018, Vol. 18, No. 2, pp. 29–38.
[6] Nawrot G.: O współczesnych formach zamieszkiwania w mieście, Wydawnictwo Politechniki Śląskiej, Gliwice 2015.
[7] Niezabitowska E.: Metody i techniki badawcze w architekturze, Wydawnictwo Politechniki Śląskiej, Gliwice 2014.

inventions aiming at simulation of the fullest possible sensual experience. The work is summarized with an overview of existing tools for virtual space exploration. Thereafter, I proceed with an interpretation of past applications of virtual reality technology in other industries and disciplines concluding with a prediction for further collaborative development of inhabitation processes and virtual reality technology in the Smart City of the future.

9.3. Virtual reality (vr) technology

9.3.1. From simulation to alternative reality

The phenomenon of virtual reality does not have a homogenous origin, but it is the effect of collective and simultaneous actions of creators of various industries, therefore the beginnings of the technology can be found in many sources. There are three essential elements for its existence: Immersion, Interaction, and Imagination (3xI)[8].

To achieve 3xI, it is necessary to recreate the sensory experience that drove inventions related to the film industry in the 20th century. Understanding the complexity of the sensory experience of space, Morton Heilig constructed devices in the 1950s and 1960s that form the basis of today's equipment in the category of creating immersive experiences. These were, represented in Figure 9.1, the 1960 *Stereoscopic-television apparatus for individual use* - the prototype of VR goggles and created two years later *Sensorama simulator*[9].

The stereoscopic-television apparatus was equipped with kinescopes, lenses, headphones, and blowers that emitted wind and smells, while the Sensorama was already using a three-dimensional image in a wide field of view, stereo sound, generated wind, smells, and vibrations.

[8] Burdea G. C., Coiffet P.: Virtual reality technology, John Wiley&Sons, Hoboken, New Jersey 2003.
[9] Burdea G. C., Coiffet P.: Virtual reality technology, John Wiley&Sons, Hoboken, New Jersey 2003.

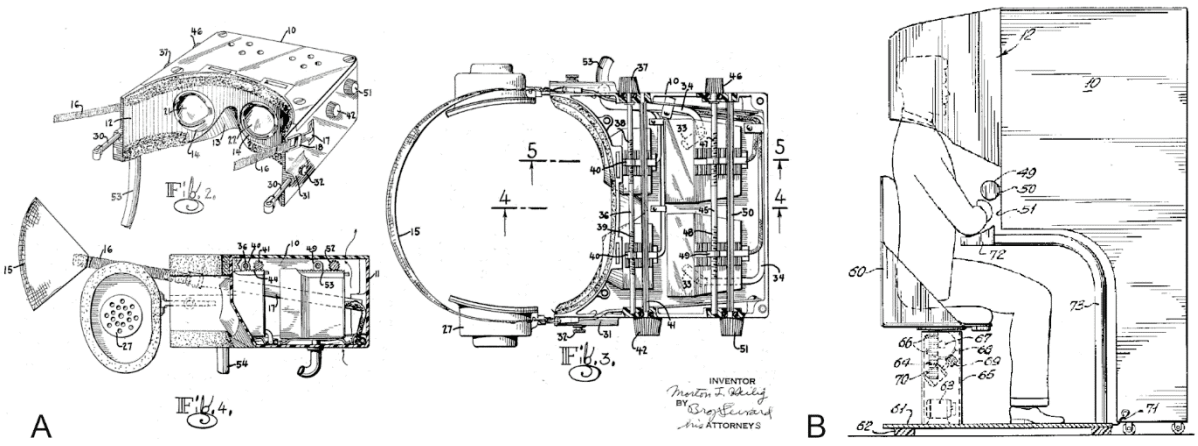

Fig. 9.1. A: Morton Heilig patent – Stereoscopic-television apparatus for individual use, B: Morton Heilig patent – Sensorama simulator device.

Rys. 9.1. A: Patent Mortona Heiliga – Stereoskopowo-telewizyjny aparat dla indywidualnego użytkownika, B: Patent Mortona Heiliga – symulator Sensorama.

Source: Ad. A.: Figures 3,4 and 5 of U.S. Patent 2,955,156, Morton Heilig, Public domain, via Wikimedia Commons; Ad. B.: Figure 5 of U.S. Patent 3,050,870, Morton Heilig, Public domain, via Wikimedia Commons[10].

Another source of VR technology can be considered the artistic and technological activities of Myron W. Krueger, who developed a series of installations aimed at creating a simulation of a parallel environment that allows participants to interact mutually. Subsequent installations: 1969's *Glowflow*, 1970's *Metaplay*, 1971's *Psychic Space*, and 1975's *Maze* and *Videoplace* were ventures aimed at creating a responsive environment[11]. These explorations continued with the later 1992 realization of CAVE (Cave Automatic Virtual Environment) by Thomas DeFanti and Daniel Sandin[12]. The concept of a *virtual cave*, which is a separate, real space serving the purpose of exploitation of the virtual environment, to this day provides an ideological and technical basis for the implementation of new technological solutions, which indicates that both worlds, real and virtual, have common elements and remain dependent on each other.

Figure 9.2 shows the fundamental change between virtual cave technology and VR goggle technology - in the first case, the physical space, in which the observer is located, is at the same time the limit for his or her mobility, and in the second case, by using goggles and omnidirectional treadmills, the physical space no longer limits the observer, who can explore the unlimited virtual space in an atavistic way.

[10] U.S., New York Patent nr 2,955,156, 1960; U.S., New York Patent nr 3,050,870, 1962.

[11] Krueger M.: Responsive environments. New York, NY, USA: Association for Computing Machinery, 1977, [In:] AFIPS '77: Proceedings of the June 13-16, national computer conference, 1977, pp. 423–433.

[12] Asanowicz A.: Systemy rzeczywistości wirtualnej w architekturze, Architecturae et Artibus, 2012, pp. 5–12.

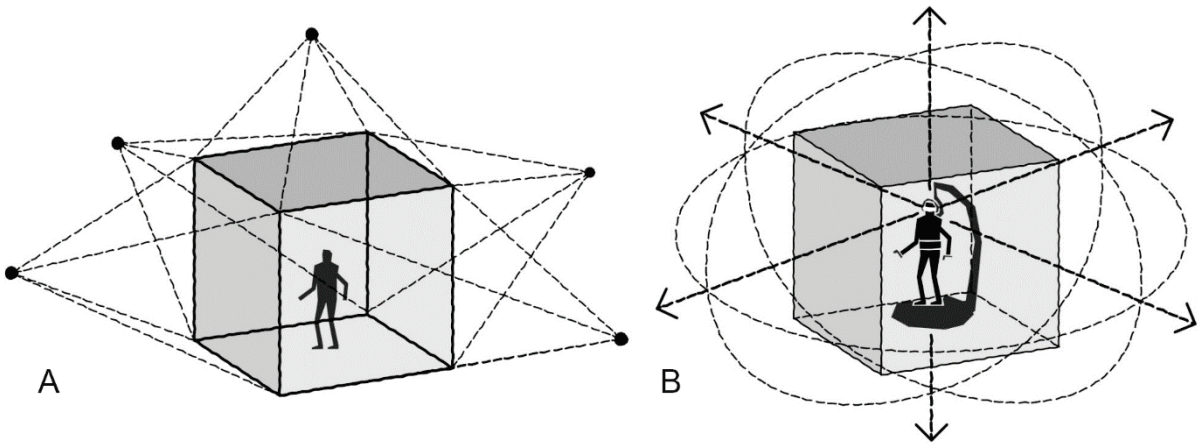

Fig. 9.2. Evolution of virtual reality technology – types of projection: A – model "CAVE" (Cave Automatic Virtual Environment); B – model model using VR goggles and an omnidirectional treadmill

Rys. 9.2. Ewolucja technologii wirtualnej rzeczywistości – typy projekcji: A – model „CAVE" (Cave Automatic Virtual Environment); B – model wykorzystujący gogle VR oraz bieżnię wielokierunkową

Source: Author's scheme, 2022.

Simultaneously, the creation of an alternative three-dimensional space was addressed by the IT industry, which soon after the transfer of two-dimensional drawing mechanisms to computer screens has created a virtual three-dimensional environment supporting design processes, which gave rise to 3D modeling[13]. Since then, virtual reality technologies have been continuously developed and applied in further fields: medicine, entertainment, design, training, scientific and artistic industries (Figure 9.3). For the purposes of architecture and construction, design software is a particularly important application of three-dimensional digital technologies, including BIM[14], parametric design software[15] as well as three-dimensional digital surveys that truly shape the image of contemporary architecture. The following step involves the creation of virtual representations of existing objects in the form of digital twins[16] enabling not only the presentation of concepts, investment planning and conducting multi-discipline and social consultations, but also simulations, collection of data from intelligent devices in buildings and cities, allowing

[13] Śliwa A.: IT technologies in architecture and space representation. Bruno Zevi methods revisted, Architecture Civil Engineering Environment, 2019, Vol. 12, No. 3, pp. 35–40.

[14] Building Information Modeling.

[15] Januszkiewicz K.: Projektowanie parametryczne oraz parametryczne narzędzia cyfrowe w projektowaniu architektonicznym (Parametric design and parametric digital tools in architectural design), Architecturae et Artibus, 2016, Vol. 3, pp. 43–60.

[16] Bujari A., Calvio A., Foschini L., Sabbioni A., Corradi A.: IPPODAMO: a digital twin support for smart cities facility management, Rome: 2021. [In:] GoodIT '21: Conference on Information Technology for Social Good, pp. 49–54.

for simulations, prediction of problems, identification of design flaws, and verification of potential solutions. A significant change comes with new instruments in the long-standing design paradigm in all design disciplines, including architecture[17]. The next step in the development of digital technologies is to create not a simulation, but an independent, alternative environment with its own development prospects, whose unlimited possibilities we are not yet fully aware of[18]. The embodiment of the idea of alternative, virtual reality is becoming a rising popular term metaverse – the internet considered as an imaginary area without limits where you can meet people in virtual reality[19].

Fig. 9.3. Applications of virtual reality technology
Rys. 9.3. Zastosowania technologii wirtualnej rzeczywistości
Source: Author's scheme, 2022.

9.3.2. Sensory experience simulators

Virtual reality technology represents the next step in the work of improving the representation of space[20]. Conventional methods of representing three-dimensional reality were attempts to translate multisensory experience into the symbolic language of signs (technical projections and cross-sections), flattened it to a two-dimensional form (elevation views, perspectives) or were unable to satisfy the parameter of scale (mock-ups)[21]. The three-dimensional real world, together with the mechanisms regulating its cognition remained out of reach. Digital technologies have

[17] Słyk J.: Space and form of information architecture, Przestrzeń i Forma, 2019, Vol. 40, pp. 9–24; Helenowska-Peschke M.: Architektura w kontekście fenomenu wirtualnej rzeczywistości, Czasopismo Techniczne, 2011, Vol. 14, pp. 141–146.
[18] Grosz E.: Architecture from the outside: Essays on Virtual and Real Space, The MIT Press Cambridge, Massachusetts, London 2001.
[19] Metaverse [Online], https://dictionary.cambridge.org/dictionary/english/metaverse.
[20] Zevi B.: Architecture as Space. How to Look at Architecture, Horizon Press, New York 1957; Śliwa A.: IT technologies in architecture and space representation. Bruno Zevi methods revisted, Architecture Civil Engineering Environment, 2019, Vol. 12, No. 3, pp. 35–40.
[21] Zevi B.: Architecture as Space. How to Look at Architecture, Horizon Press, New York 1957; Śliwa A.: IT technologies in architecture and space representation. Bruno Zevi methods revisited, Architecture Civil Engineering Environment, 2019, Vol. 12, No. 3, pp. 35–40.

made it possible to omit the difficulties associated with the actual creation of space, reducing it to the necessary minimum in the form of CAVE, three-dimensional reality has been created in a digital environment, thus reducing the former problem to the challenge of satisfying the needs of the human senses, through which we experience space and the objects in it. The digital aspect of this method has one fundamental property that has not been available before – it enables remote sharing of the created spatial reality in any place and at any time.

Table 9.1

Tools for sensory exploration of a virtual space

No.	Tools for sensory exploration of a virtual space	
	Sense	**Device**
1	sight	screens, monitors, projectors, virtual glasses (VR goggles)[22]
2	hearing	speakers, headphones
3	touch	vibrating vests and belts, software simulated force resistance, blowers, the virtual hand metaphor, controllers with vibrotactile motors, mechanical actuators enabling users to feel the shape of virtual objects, 'plasters' using SMA technology, a full-body haptic suit deploying electrical muscle stimulation[23]
4	smell	masks and air blowers imitating scents, scent printers, scent diffusers, scent screens[24]
5	taste	taste simulators based on electric charge and heat emission[25]
6	balance	VR multi-directional treadmills[26], balance platforms[27]
7	temperature	temperature-emitting clothing[28], trigeminal based temperature illusions[29]

Based on the author's research.

The experience is multidimensional, and its individual elements generate information about the perceived structures – the integration of all sensations leads to the creation of a complete image of the created reality[30].

[22] There are a number of models available in the commercial video game market: Oculus Rift, Oculus Go, HTC Vive, Samsung Gear, Play Station VR.

[23] Price S., Jewitt C., Yiannoutsou N.: Conceptualising touch in VR. Virtual Reality, 05 January 2021, pp. 863–877.

[24] Gosain D., Sajwan M.: Aroma tells a thousand pictures: digital scent technology a new chapter in it industry, International Journal of Current Engineering and Technology, 25 August 2014, pp. 2804–2812.

[25] Kerruish E.: Arranging sensations: smell and taste in augmented and virtual reality, The Senses and Society, January 2019, pp. 31–45.

[26] Similar to VR goggles, for video game purposes, there are available omnidirectional treadmills: Virtuix Omni, KatVR, KatWalk MINI.

[27] For a variety of entertainment and health applications, there are balance-based devices such as platforms: Icarus or The Prokin 212 MF system.

[28] Markiewicz J., Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.

[29] Brooks J., Nagels S., Lopes P.: Trigeminal-based temperature illusions. [In:] CHI '20: CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA 2020, pp. 1–12.

As presented in Table 9.1, we can observe a significant progress in the development of devices and technologies that enable digital transmission of information addressed to the senses: sight, hearing, touch, smell, taste, balance or temperature[31]. VR technology is finding more and more applications in the gaming, education and training industries[32]. Simulators are constructed to imitate specific circumstances, focusing on the feelings of those participating in the simulations[33]. It seems to be only a matter of time before the full experience of three-dimensional reality offering the full spectrum of stimuli will be fully reflected. A completely immersive exploration of virtual reality created in a digital environment may contribute to opening a new chapter in the history of civilization.

9.4. Smart dwelling as a component of the smart city

The adjective *smart* is most often used to describe technology, cities and homes, but less often in the context of living as a process[34]. The IT-based equipment of apartments introduces a number of improvements, but the real transformations in this field concern changes in daily functioning. Relocation of activities connected with habitation to the sphere of virtual reality may influence the shape of houses in a practical way, just as the evolution of the house – *edifice* – corresponds to cultural and civilization transformations[35]. The transfer of habitation processes to immersive and responsive virtual spaces may redefine the concept of *smart habitation* in the future.

9.4.1. Applications of virtual reality technology in habitation processes

The processes of habitation are constantly transforming, shaping the image of residential architecture as their physical emanation. The processes of habitation, on the other hand, depend on the daily activities that take place inside or outside the home – in

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[30] Pallasmaa J.: Oczy skóry, Instytut Architektury, Kraków 2012.
[31] Cognitive science specialists distinguish other senses besides the basic five (Pallasmaa, 2012).
[32] Markiewicz J. i Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.
[33] Markiewicz J. i Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.
[34] Chrisidu-Budnik A.: Współczesne kierunki rozwoju inteligentnych miast w kontekście potencjału relacyjnego. [In:] Kusiak-Winter R., Korczak, J. (red.): Ewolucja elektronicznej administracji publicznej, E-Wydawnictwo, Prawnicza i Ekonomiczna Biblioteka Cyfrowa, Wydział Prawa, Administracji i Ekonomii Uniwersytetu Wrocławskiego, Wrocław 2021, pp. 151–169.
[35] Nawrot G.: Symultaniczność i kompilacja a obraz miejsca, Budownictwo i Architektura, 2018, Vol. 18, No. 2, pp. 29–38.

workplaces, schools or restaurants. The range of activities that take place in dwelling places depends on many factors, among others: economic status, cultural aspects, or technological advancement. The development of IT technologies has made it possible to carry out some of these activities in cyberspace, as it was observed during the restrictions in functioning related to the COVID-19 pandemic. Activities involving interpersonal contact and information transfer can be carried out remotely. Among the activities that define the state of living, we can distinguish two groups: the first group includes activities that focus on body needs – shelter, sleep, preparing and eating meals, taking care of personal hygiene, and the second group that includes activities that often focus on social interactions such as work, study, recreation, and social meetings. By now the second group of activities can be performed to a significant extent in the cyberspace[36] (Figure 9.4). As Piotr Cichocki claims: "The context of digital virtual architectures is a new phenomenon, dynamically entering the world of human relations (...)"[37], thus, remote communication redefines the ways of fulfilling the needs of human relationships, changing the requirements for the physical spaces that serve them, which also applies to residential spaces.

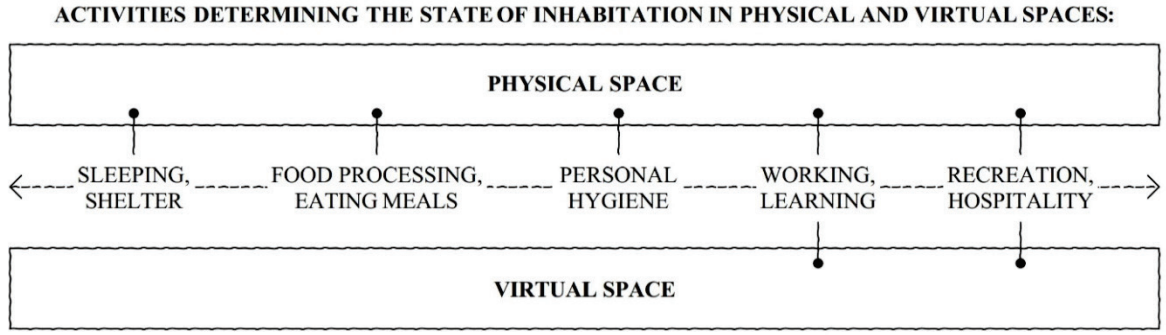

Fig. 9.4. Activities determining the state of inhabitation in real and virtual spaces,
Rys. 9.4. Czynności określające stan zamieszkiwania w przestrzeniach fizycznej oraz wirtualnej
Source: Author's scheme, 2022. Based on: (Nawrot, O współczesnych formach zamieszkiwania w mieście, 2015, str. 141)

So far, the implementation of virtual reality technology for training purposes shows the advantages of these solutions in the areas that, in many aspects, can also relate to residential housing. On the basis of the research results38, it can be assumed that extending the non-transformable physical space of dwellings with virtual space for

[36] Not every type of work is possible to carry out remotely.
[37] Cichocki P.: Projektowanie relacji. Czyli o tym jak architektura internetu i jej twórcy wytwarzają społeczne praktyki, [In:] Świątkowska B. (ed.) My i oni. Przestrzenie wspólne / Projektowanie dla wspólnoty. Fundacja Bęc Zmiana, Warszawa 2014, pp. 192–203, str. 193.
[38] Markiewicz J., Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.

entertainment, sports, socializing, work, and study can contribute to reducing the consumption of physical spatial resources and environmental impacts associated with the construction industry and transportation.

9.4.2. Spatial consequences of the presence of virtual reality technology in residential structures

Changes in the patterns of everyday activities are reflected in the structure of dwellings (Table 9.2). Modern dwellings consist of adequately equipped rooms dedicated to specific activities: from sleeping, through resting, preparing and eating meals, personal hygiene, work, study and various entertainment, to entertaining guests. Some of these spaces are merged or multifunctional due to the limited space of the apartments. Activities that require most privacy or are intended for activities that require isolation and concentration remain separate. The emergence of a new type of activity in the form of virtual space exploration will create the need to separate and equip another room or rooms depending on the number of residents and their needs in terms of virtual reality use. Just as the appearance of computers has revolutionized the design methods of office workstations, the hardware requirements associated with the exploration of virtual space will likely change the physical space structures of housing, work and study spaces. The existing solutions and devices for virtual space exploration indicate that the spatial needs of the new activity can be met by providing a separate room – a virtual cave – allowing for free movements, or large enough to accommodate the largest piece of equipment, that is a multi-directional treadmill, a specialized chair, or a balance platform. Due to the need to ensure immersion, the room may be additionally soundproofed, but it does not require a window or natural sunlight. The multifunctionality of VR equipment provides the ability to perform a variety of activities, so a dedicated room can function as a place for work, study, recreation without the need to expand the space dedicated to it. If in the future there will be a general change in the forms of activity due to the further development of virtual reality technology, perhaps the VR function will replace the current functions of the existing supplementary rooms, such as playrooms, game rooms, studios, or study rooms.

Table 9.2

Premises for activities determining the state of inhabitation

No.	Premises for activities determining the state of inhabitation		
	Activity group	**Facility**	
1	sleeping, shelter	bedrooms, living rooms	
2	food processing, eating meals	kitchens, dining rooms	
3	personal hygiene	toilets, bathrooms	
4	working, learning	workshops, offices, children's rooms, study rooms	virtual caves
5	recreation, hospitality	playrooms, game rooms, gyms, guest rooms, lounges	

Based on the author's research.

9.5. Conclusions and summary

Dwelling understood as a process is relatively rarely a subject of discussions related to the idea of Smart Cities. Nevertheless, significant transformations related to the development of modern digital technologies are taking place in this area. The changes do not only concern the use of more and more advanced equipment and the central and remote control of apartments, but above all they concern changes in the everyday functioning of residents, thus affecting the essence of habitation, which is reflected in residential architecture.

The development of virtual reality technology corresponds to the successive attempts to satisfy the needs of the human senses as comprehensively as possible. The aim of subsequent devices is to create real or simulated stimuli to reproduce an immersive and responsive experience of created space and the objects in it. Virtual reality technology is finding an increasingly wide field of implementation. Research indicates that the field of habitation may provide a promising ground for the implementation of virtual reality technology, which is already applied in the realization of various daily activities, touching the spheres of entertainment, socializing, study, and work. Changes in the ways in which everyday activities are carried out will force changes in the shape of dwellings through the need for separate rooms dedicated to VR needs.

Assuming that the current progression of the development of digital technologies and simulation devices will be maintained, we can suppose that in the near future functioning in a multidimensional virtual reality will be highly immersive and even difficult to

distinguish from physical reality. Under such conditions, inhabitation will probably be fully compilational and multidimensional, but it is difficult to judge today how this will affect the quality of inhabitation due to the excessive number of unknowns.

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Adam DUSTOR[1]

10. VOICE BIOMETRIC SYSTEMS IN SMART CITIES

10.1. Introduction

Security and related issues are extremely important in modern information systems. Therefore, there is a huge demand for effective and reliable methods of identification and identity verification. The existing methods of verification based on specific knowledge (password, PIN number) or possessed equipment (bank card, key) are highly unreliable. The first requires memorizing and is susceptible to eavesdropping or guessing while the second must be properly stored and is vulnerable to loss, destruction, copying or theft. The third and most modern method is verification based on biometric features of the human body. Among the biometric features used today we can distinguish physical and behavioral ones. The most important physical characteristics are fingerprints, iris pattern, facial image, retina pattern, hand shape. Behavioral features are mainly voice and handwritten signature. There is no biometric feature that can provide flawless identity verification, therefore biometric methods are usually complementary to traditional methods.

Security systems based on physical features are usually more reliable and stable in time. Iris pattern or fingerprint does not change over time while behavioral biometric like human voice is severely affected by the speaker's emotional state or illness. As a result, the accuracy of voice based biometric systems is significantly lower than iris-based systems.

In near future, biometric systems will be very common in all information and security systems that are an inherent part of each smart city. In some countries, especially in PRC, such systems are almost everywhere. Face recognition implemented in majority of street cameras is used to recognize criminals that are sought by the police.

[1] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: adam.dustor@polsl.pl.

Human voice as a security key

Automatic speaker recognition is a process that implements a series of decision rules on measurable features of speech signal to determine whether a given utterance belongs to a specific speaker or set of speakers. The need for voice-based person recognition occurs where no other way of checking or verifying the identity of people is possible, e.g., when communicating with a computer using speech, telephone, or radio communications. Other examples of automatic speaker recognition include data protection systems against unauthorized access, control of devices by voice by authorized persons, telephone shopping, access to computers, information services or databases. Automatic speaker recognition is also widely used in forensics and judiciary.

Automatic speaker recognition is usually divided into two tasks, namely automatic speaker identification and automatic speaker verification. Speaker identification is the process of assigning an unknown speaker utterance to a given speaker class from a specified set of M speakers. Voice verification is the process of confirming or rejecting the claimed identity based on a sample utterance of the speaker being verified. The basis for the acceptance or rejection decision is the comparison of the similarity function between the voice pattern and the recognized sample with a fixed threshold value. The issue of speaker verification can be treated as a recognition process with two classes: YES – belonging to the set, and NO – not belonging to the set of speakers. Speaker verification can also be considered as a special case of speaker identification in an open set of speakers for M = 1.

Speaker recognition systems can be divided also into two important classes, namely text-dependent and text-independent systems. In text-dependent systems, it is required that the linguistic content of the test utterance is the same as that previously recorded during system training. The consequence of this is the necessity to utter specific passwords during the recognition procedure and their frequent repetition in case of difficulties with user recognition. Due to the type of password, they can be divided into systems with personal password and common password. Despite being more reliable and simpler than text-independent systems, these systems have very serious disadvantage of not being immune to an impostor's reconstruction of a speaker's previously recorded password. Since people recognize speakers independently of their utterances, text--independent systems, in which the test utterance may differ from the training utterance and may be prompted by the system, are of greater interest to researchers.

Text-independent systems are divided into:

- fixed vocabulary – during training, users must utter a fixed set of words, the order of which randomly changes during each user testing;

- event-dependent – the test utterance contains a linguistic event that is extracted from the speaker utterance;
- unrestricted – there are no restrictions on the test utterance.
- Regarding the method of communication with the user, we can divide them into:
- systems with text prompting – the system displays a text on the screen that the user has to read;
- systems with voice prompting – the user has to repeat the statement heard;
- systems without prompting – using spontaneous speech.

Because prompted systems require the user to repeat a different utterance each time, they are very effective in preventing the possibility of replaying a previously recorded user voice. However, in the case of these systems, it is required to check whether the user said what was asked, so they must also implement speech recognition.

10.2.1. Speaker recognition – a general idea

The block diagram of the automatic voice identification system is shown in Figure 10.1, while the verification system is shown in Figure 10.2. In both cases, the decision-making process uses rules based on the calculation of similarity function values to patterns taken from the pattern bank. In the case of identification, the recognition result is the class for which the calculated similarity value to a given pattern is the highest. In the case of verification, the similarity is calculated only for one pattern (the one whose identity is declared) and an additional decision is required to accept or reject the speaker.

In speaker identification, the only error that can occur is the misidentification of the speaker voice. The parameter characterizing the accuracy of recognition is the identification rate in %. As the number of speakers registered in the system increases, the probability of wrong identification also increases. This phenomenon is a serious obstacle on the way of building systems with many registered users.

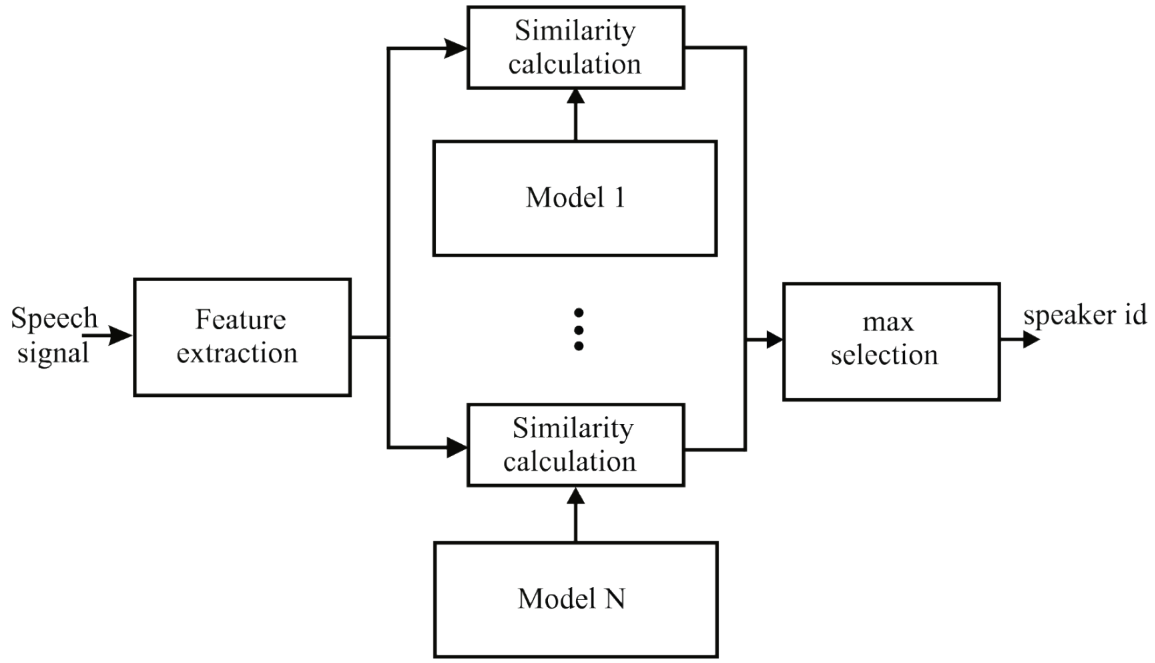

Fig. 10.1. Block diagram of speaker identification system
Rys. 10.1. Schemat blokowy systemu identyfikacji mówcy
Source: Own research.

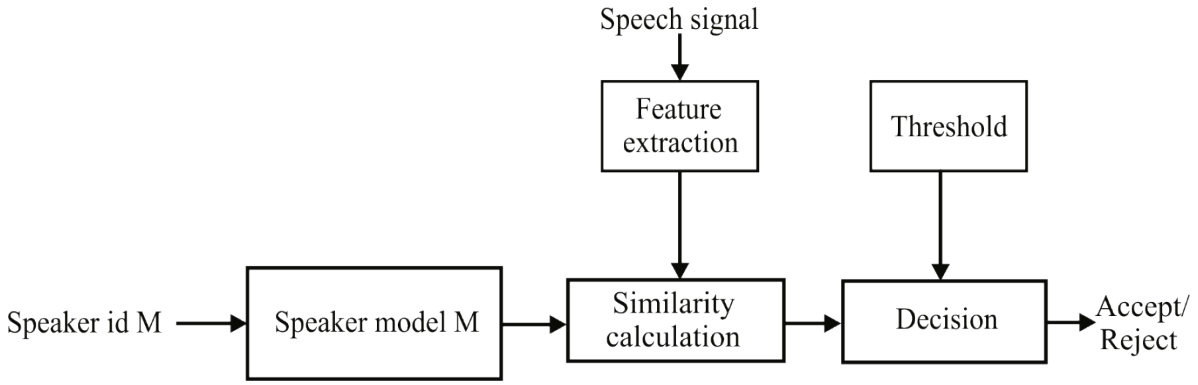

Fig. 10.2. Block diagram of speaker verification system
Rys. 10.2. Schemat blokowy systemu weryfikacji mówcy
Source: Own research.

In the process of verification, a test utterance is compared with only one model, the one whose identity is declared. As a result of such comparison, the utterance may be falsely rejected by the system – False Rejection error, or falsely accepted – False Acceptance error. The quality of the system is characterized by the probabilities of False Acceptance Rate (FAR) and False Rejection Rate (FRR). These errors depend on the value of the decision threshold[2]. Depending on the application of the speaker recognition system, it is advantageous to vary these probabilities and thus regulate the

[2] Dustor A.: Problematyka błędów w biometrycznych systemach rozpoznawania głosu, [in:] IC-SPETO 2011, Ustroń 2011, pp. 133–134.

security of the system. For example, in applications related to remote banking services, it is necessary to ensure a very low probability of accepting a fraudster even at the cost of a longer verification procedure and a higher probability of false rejection.

A full evaluation of the verification system is possible with the help of Detection Error Tradeoff (DET) curves[3,4] which provide a full description of all possible system operating conditions. With their help it is possible to determine the value of FAR if FRR is known, the value of FRR if FAR is known and the EER value (Equal Error Rate) corresponding to the threshold for which the false acceptance rate is equal to the false rejection rate[5].

10.2.2. Feature extraction

A fundamental issue that affects the effectiveness of a voice recognition system is the choice of the best measurable physical parameters of the speech signal associated with the recognized classes. The effectiveness of the recognition system will depend largely on to what extent the physical parameters of the speech signal capture the speaker's personal characteristics. The most used physical parameters of the speech signal in speaker recognition include:

- parameters determined directly from the time course such as relative utterance lengths of individual phonetic elements, time envelope of the amplitude or intensity of the sound, zero crossing rate of the speech signal, distribution of time intervals;
- parameters determined from the spectrum of the speech signal such as averaged amplitude spectrum, power spectrum, fundamental frequency, frequencies and amplitude ratios of formants, short-term spectrum, spectral moments;
- linear predictive coding parameters and their derivatives such as Linear Prediction Cepstrum Coefficien (LPCC) cepstral parameters and reflection coefficients.

The ideal parameters used for voice recognition should have high inter-speaker and low intra-speaker variability. Over the years, it has been shown that the lowest recognition error rates are provided by the means of Mel Frequency Cepstral Coefficients (MFCC) parameters[6] which take into account the nonlinear characteristics of human hearing.

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[3] Dustor A.: Problematyka błędów w biometrycznych systemach rozpoznawania głosu, [in:] IC-SPETO 2011, Ustroń 2011, pp. 133–134.
[4] Martin A., Doddington G., Kamm T., Ordowski M., Przybocki M.: The DET curve in assesment of detection task performance, [in:] Proceedings of the EUROSPEECH 1997, Rhodes 1997, pp. 1895–1898.
[5] Dustor A.: Problematyka błędów w biometrycznych systemach rozpoznawania głosu, [in:] IC-SPETO 2011, Ustroń 2011, pp. 133–134.
[6] Rabiner L.R., Juang B.H.: Fundamentals of speech recognition, Prentice Hall, 1993.

Studies on the influence of parameters and their dimensionality on error rates include works[7,8]. The parameters LPC, LPCC as well as reflection coefficients k and MFCC were investigated. The ROBOT and TIMIT speech resources were used for the study. By far the lowest error rates were obtained for cepstral MFCC parameters, not much worse for LPCC parameters and by far the worst for LPC prediction coefficients.

Using GMM (Gaussian Mixture Models), 100% correct identifications is possible for a small set of speakers, it is only necessary to provide sufficiently long training and test utterances and to use MFCC parameters with sufficient dimensionality.

The paper[9] also investigated the effect of the speech corpora used on error rates. It turned out that this parameter is crucial when testing systems with low error rates. The results for the TIMIT[10] database (630 speakers) were almost four times worse than for the ROBOT[11] database (30 speakers). Reliable voice biometrics research requires large datasets to get results statistically significant.

10.2.3. Speaker models

The problem of voice modelling, similarly, to feature extraction, is a key stage on the way to building a low-error voice recognition system. As a result of many years of research on this issue, we have a very rich set of algorithms based both on generative approach (estimation of probability distribution) and discriminative approach (minimization of classification error on training set). Among the generative algorithms, the simplest approach is to use only the nearest neighbor algorithm. The speaker model then consists of all learning vectors. The similarity of a test sequence to such a model is calculated sequentially by finding for each test vector the nearest neighbor from the set of all learning vectors of a given speaker and calculating the distance between these vectors.

As the number of learning vectors can be large, for long learning sequences a more common approach is to use data clustering based on the k-means or LBG (Linde – Buzo – Gray) algorithm. This allows all learning vectors to be replaced by some small set of centroids. The vector quantization approach produces satisfactory results provided that

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[7] Dustor A.: Speaker verification with TIMIT corpus – some remarks on classical methods, [in:] Proceedings of the 24th International Conference on Signal Processing Algorithms, Architectures, Arrangements and Applications (SPA), Poznań, Poland 2020.

[8] Dustor A., Kłosowski P., Izydorczyk J.: Influence of Feature Dimensionality and Model Complexity on Speaker Verification Performance, [in:] Communications in Computer and Information Science, Springer-Verlag, Berlin, Germany 2014, Vol. 431, p. 177–186.

[9] Dustor A., Kłosowski P., Izydorczyk J., Kopański R.: Influence of corpus size on speaker verification, [in:] Communications In Computer and Information Science, Springer-Verlag, Berlin Heidelberg, Germany 2015, Vol. 522, p. 242-249.

[10] TIMIT LDC93S1: https://catalog.ldc.upenn.edu/LDC93S1.

[11] Adamczyk B., Adamczyk K., Trawiński K.: Zasób mowy ROBOT, [in:] Biuletyn Instytutu Automatyki i Robotyki, WAT, 2000, Vol. 12, p. 179–192.

the speech quality is relatively high (no noise) and the number of speakers is small. Studies on the application of data clustering in voice biometrics include works[12] in which the effect of the number of centroids on the verification error rate was investigated.

A more complicated but also more effective approach (assuming there is enough learning material) is the use of statistical modelling where the voice model is a certain set of parameters. In the simplest version, these are parameters characterizing a single multivariate normal distribution. In a more complex case, the speaker is represented by a linear combination of M normal distributions, each of which is described by a vector of mean values μi, a covariance matrix Ci and a certain weighting factor pi. Such a model, called Gaussian mixture GMM, and its modifications have been for many years the so-called gold standard in speaker modelling. The disadvantages of GMM models include the necessity of estimation many parameters, especially in the case of models with full covariance matrices, and thus the frequent phenomenon of overfitting. Of the most important modifications, the GMM-UBM (Gaussian Mixture Model – Universal Background Model) algorithm, in which individual models are created from one reference model, should be mentioned first [13]. Another, even more advanced approach is to combine GMM models with a Support Vector Machine (SVM)[14].

Studies on voice recognition using GMM models include publications[15]. The research was performed for the TIMIT resource. It turned out that using MFCC cepstral parameters and GMM models with diagonal covariance matrices, it is possible to obtain EER error values for verification of the order of one percent or even below.

Another approach to voice modelling is the use of discriminative approaches. Examples of classifiers that have been applied in voice recognition are the SVM[16] and

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[12] Dustor A., Kłosowski P.: Biometric voice identification based on fuzzy kernel classifier, [in:] Communications in Computer and Information Science, Vol. 370, pp. 456–465, Springer-Verlag, Berlin Heidelberg, Germany 2013; Dustor A., Kukiełka A.: Detekcja sygnału mowy w systemach rozpoznawania głosu, [in:] IC-SPETO 2012, Ustroń 2012, pp. 79–80.

[13] Reynolds D.A., Quatieri T.F., Dunn R. B.: Speaker verification using adapted gaussian mixture models, [in:] Digital Signal Processing, 2000, Vol. 10, pp. 19–41.

[14] Vapnik V.: The nature of statistical learning theory, Springer, New York 1999.

[15] Dustor A.: Speaker verification with TIMIT corpus – some remarks on classical methods, [in:] Proceedings of the 24th International Conference on Signal Processing Algorithms, Architectures, Arrangements and Applications (SPA), Poznań, Poland 2020; Kłosowski P., Dustor A., Izydorczyk J.: Speaker verification performance evaluation based on open-source speech processing software and timit speech corpus, [in:] Communications in Computer and Information Science, Springer-Verlag, Berlin Heidelberg, Germany 2015, Vol. 522, pp. 400–409.

[16] Dustor A., Bąk M.: Wykorzystanie maszyny wektorów podpierających w weryfikacji mówcy, [in:] Współczesne Aspekty Sieci Komputerowych, Tom 1, Wydawnictwa Komunikacji i Łączności, Warszawa 2008, pp. 299–308.

also KHK which is a kernel version of the classical Ho-Kashyap (HK) classifier[17]. The nonlinearity introduced with a Gaussian kernel function has allowed for very promising results when there is little learning data.

Fuzzy set theory can also be used for voice modelling. Fuzzy Ho-Kashyap (FHK) classifier[18] which is a kind of combination of linear HK classifiers based on fuzzy inference system allowed with the use of Kleene-Dienes implication to obtain lower EER error value than for GMM approach[19]. It is also possible to combine fuzzy approach with the kernel approach (kernel function). Example results for the Fuzzy Kernel Ho-Kashyap (FKHK) classifier with linguistic interpretation of the kernel matrix are given in[20].

Recent modelling approaches are based on the use of Joint Factor Analysis (JFA) and the so-called i-vector[21]. Deep neural networks[22] and the so-called x-vectors[23] based on them are also used in modelling. However, these methods require very large learning data sets to correctly estimate the parameters of these models.

10.2.4. Speaker verification system – implementation

In this chapter, an example of real speaker verification system is presented. Implementation of all signal processing procedures, speaker training and recognition was done with the help of an open-source software such as Sidekit Python package[24] and Anaconda[25] with separate environment with all required by Sidekit packages.

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[17] Dustor A., Kłosowski P., Izydorczyk J.: Speaker recognition system with good generalization properties, [in:] 2014 International Conference on Multimedia Computing and Systems (ICMCS), Marrakech 2014, pp. 206–210; Dustor A.: Voice verification based on nonlinear ho-kashyap classifier, [in:] 2008 IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering, Novosibirsk 2008, pp. 296–300.

[18] Dustor A.: Speaker verification based on fuzzy classifier, [in:] Man-Machine Interactions, AISC 59, Springer--Verlag, Berlin Heidelberg 2009, pp. 389–397.

[19] Dustor A.: Speaker verification based on fuzzy classifier, [in:] Man-Machine Interactions, AISC 59, Springer--Verlag, Berlin Heidelberg 2009, pp. 389–397.

[20] Dustor A., Kłosowski P.: Biometric voice identification based on fuzzy kernel classifier, [in:] Communications in Computer and Information Science, Vol. 370, pp. 456–465, Springer-Verlag, Berlin Heidelberg, Germany 2013; Dustor A.: Application of fuzzy kernel ho-kashyap classifier to speaker verification, [in:] Proceedings of the 18th International Conference Mixed Design of Integrated Circuits and Systems – MIXDES 2011, Gliwice 2011, pp. 581–586.

[21] Dehak N., Kenny P.J., Dehak R., Dumouchel P., Ouellet P.: Frontend factor analysis for speaker verification, [in:] IEEE Transactions on Audio, Speech, and Language Processing, Vol. 19, No. 4, 2011.

[22] Sztahó D., Szaszák G., Beke A.: Deep learning methods in speaker recognition: a review, [in:] ArXiv, https://arxiv.org/ftp/arxiv/papers/1911/1911.06615.pdf, 2019.

[23] Snyder D., Garcia-Romero D., Sell G., Povey D., Khudanpur S.: Xvectors: Robust dnn embeddings for speaker recognition, [in:] 2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2018, pp. 5329–5333.

[24] Larcher A., Lee K.A., Meignier S.: An extensible speaker identification SIDEKIT in Python, [in:] International Conference on Audio Speech and Signal Processing ICASSP 2016.

[25] Anaconda software – www page: https://www.anaconda.com.

For the research on speaker verification, TIMIT[26] corpus was applied. The DARPA TIMIT Acoustic-Phonetic Continuous Speech Corpus has been designed to provide speech data for the acquisition of acoustic-phonetic knowledge and for the development and evaluation of automatic speech recognition systems. TIMIT has resulted from the joint efforts of several sites under sponsorship from the Defense Advanced Research Projects Agency – Information Science and Technology Office (DARPA-ISTO). Text corpus design was a joint effort among the Massachusetts Institute of Technology (MIT), Stanford Research Institute (SRI), and Texas Instruments (TI). The speech was recorded at TI, transcribed at MIT, and has been maintained, verified, and prepared for CD-ROM production by the National Institute of Standards and Technology (NIST). TIMIT contains a total of 6300 sentences, 10 sentences spoken by each of 630 speakers from 8 major dialect regions of the United States. It may be obtained from Linguistic Data Consortium.

For the research, whole data of TIMIT corpus were used. Universal background model was obtained from the speech of the 130 speakers. Speaker models for the rest 500 speakers were adapted from the UBM via MAP (Maximum A Posteriori) procedure[27]. During training speaker's GMM[28] only mean supervector was adapted. As there are 10 utterances for each of 630 speakers, 6 were used for training and the remaining 4 for testing. As a result, there were 2000 (500·4) target trials and 998000 (499·4·500) nontarget trials for each combination of feature dimensionality and number of mixtures. Number of mixtures in GMM-UBM models was changed from 16 to 512 (diagonal covariance matrix). As a feature vector MFCC[29] parameters with supplemental delta features were used. Performance was examined for vectors with 5, 10, 15 and 20 features. All tests were conducted without voice activity detection. During training and testing the same signal processing procedure was used. Speech files were pre-emphasized and segmented into 25ms pieces. Verification performance was characterized in terms of the two error measures, namely the false acceptance rate FAR and false rejection rate FRR. These measures correspond to the probability of acceptance an impostor as a valid user (acceptance of the non-target) and the probability of rejection of a valid user (rejection of target). Varying the decision level, Detection Error Tradeoff (DET) curves, which show dependence between FRR and FAR, may be plotted. Another performance measure is an EER which corresponds to

[26] TIMIT LDC93S1: https://catalog.ldc.upenn.edu/LDC93S1.
[27] Reynolds D.A., Quatieri T F., Dunn R.B.: Speaker verification using adapted gaussian mixture models, [in:] Digital Signal Processing, 2000, Vol. 10, pp. 19–41.
[28] Reynolds D.A., Quatieri T.F., Dunn R.B.: Speaker verification using adapted gaussian mixture models, [in:] Digital Signal Processing, 2000, Vol. 10, pp. 19–41.
[29] Rabiner L.R., Juang B.H.: Fundamentals of speech recognition, Prentice Hall, 1993.

error rate achieved for the decision threshold for which FRR = FAR. In other words, EER is just given by the intersection point of the main diagonal of DET plot with DET curves.

Performance of the speaker verification system as a function of complexity of the speaker model is shown in Figure 10.3, Figure 10.4, Figure 10.5, Figure 10.6, for the feature vector of dimensionality 5, 10, 15 and 20 respectively. Achieved EER values for each model are depicted.

It may be observed that error rates of the speaker verification system are strongly dependent on the number of features extracted from each segment of speaker utterance and on the complexity of the voice model. For 5 features per frame of speech, the lowest EER value was approximately 5.28% for the GMM-UBM with 512 mixtures (Fig. 10.3) while for 20 features per segment of speech and 512 mixtures achieved EER was 1.04% (Fig. 10.6). Although these error rates are relatively high for the standalone security system, such biometric system may be implemented as an additional security level accompanying traditional system based on knowledge (PIN number) or equipment (bank card). After careful selection of decision threshold in such biometric system, it is possible for example in Figure 10.5 to achieve false acceptance rate 0.2% when FRR = 10% is acceptable. In other words, 1 out of 10 valid users may require re-verification but only 1 out of 500 impostors would be falsely accepted by the system.

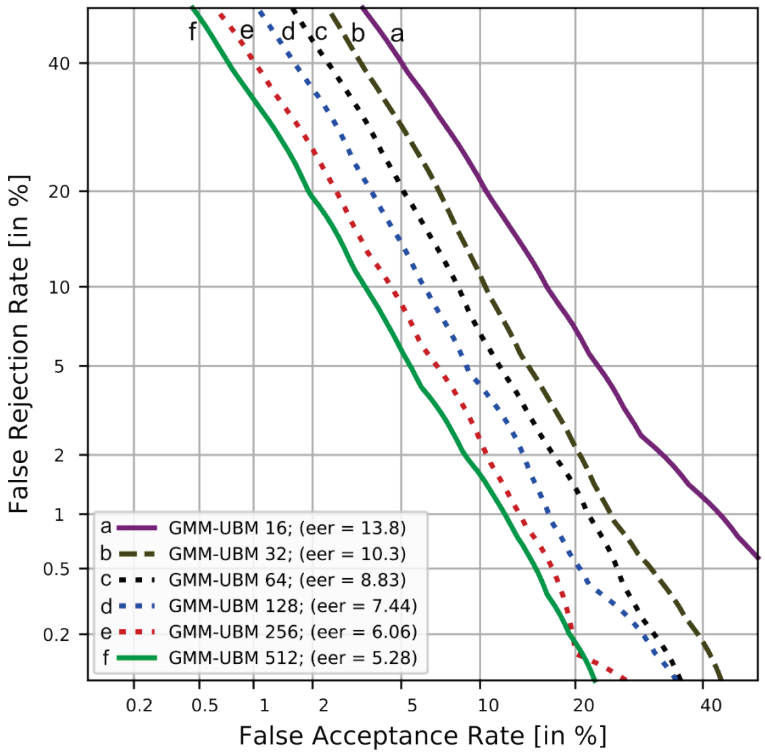

Fig. 10.3. Influence of model size on speaker verification (5 features)
Rys. 10.3. Wpływ rozmiaru modelu (5 parametrów na segment) na proces weryfikacji
Source: Own research.

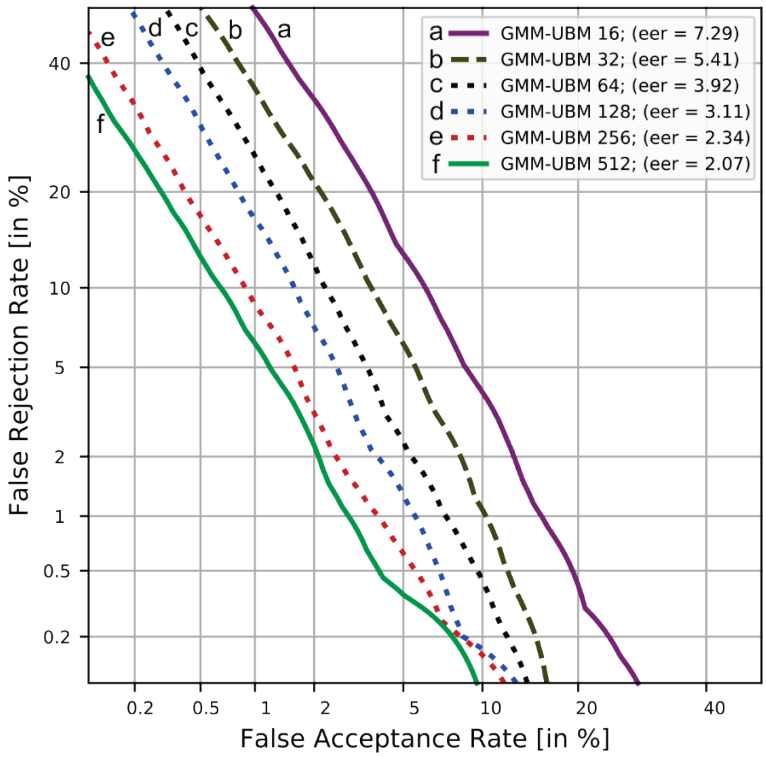

Fig. 10.4. Influence of model size on speaker verification (10 features)
Rys. 10.4. Wpływ rozmiaru modelu (10 parametrów na segment) na proces weryfikacji
Source: Own research.

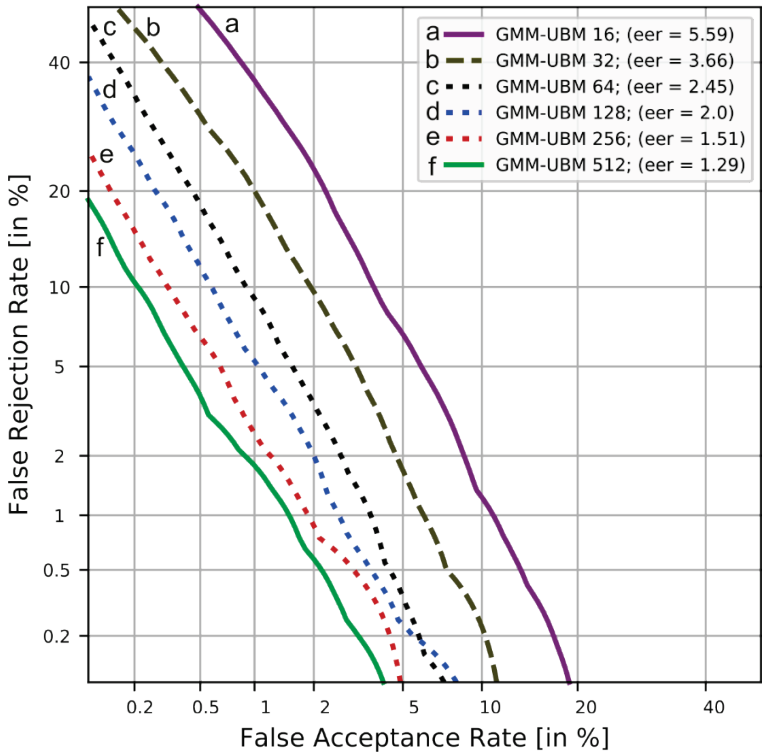

Fig. 10.5. Influence of model size on speaker verification (15 features)
Rys. 10.5. Wpływ rozmiaru modelu (15 parametrów na segment) na proces weryfikacji
Source: Own research.

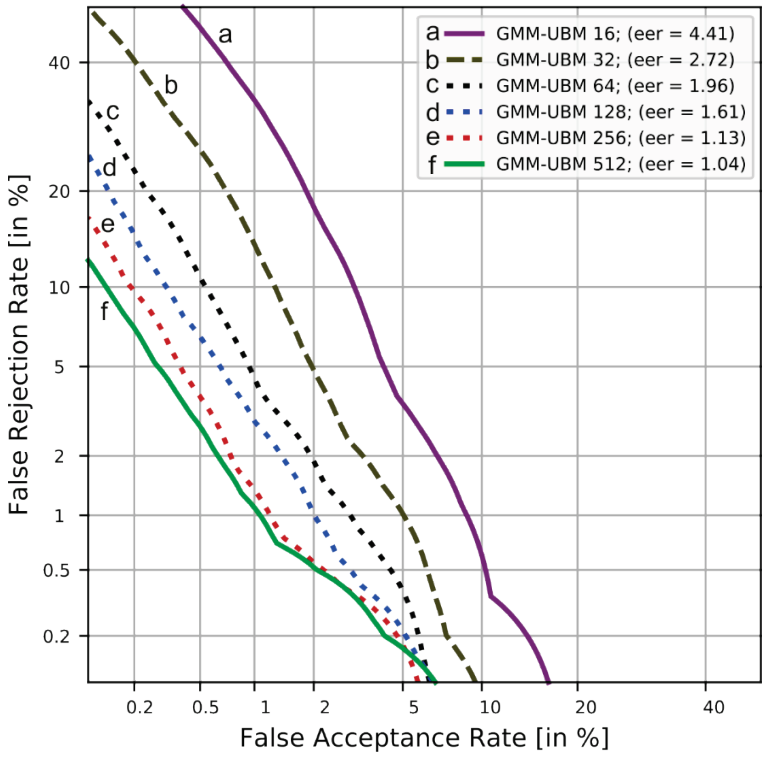

Fig. 10.6. Influence of model size on speaker verification (20 features)
Rys. 10.6. Wpływ rozmiaru modelu (20 parametrów na segment) na proces weryfikacji
Source: Own research.

10.3. Summary

In this study fundamentals of voice biometric systems were presented. The most important functional blocks of the recognition system, namely feature extraction and voice model construction were discussed. An example of real speaker verification system implemented in Python and its performance was also covered. It was demonstrated that careful selection of feature dimensionality and number of mixtures in speaker model may lead to significant reduction of verification errors, leading in the best scenario to EER value of 1.04%.

Additional security level provided by such biometric system may be implemented in many smart applications which would require user personalization or identity recognition. In many information systems, very common in future smart cities, such additional level of security will be of great importance.

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Grzegorz DZIWOKI[1], Marcin KUCHARCZYK[2], Wojciech SUŁEK[3]

11. IMT 2020 MOBILE NETWORKS AS UNIVERSAL WIRELESS TRANSMISSION PLATFORM

11.1. Introduction

Digitalization, identified with the way in which information is represented, processed and transmitted, is currently one of the basic elements that define how the modern world works. Its usefulness, or even indispensability, was clearly revealed during the pandemic, when whole societies were forced to transfer a significant part of their activity to the virtual world. Thus, it turned out that social media made it possible to maintain social relations, digitalization of production processes - to manage them remotely, and access to the global Internet – to maintain the continuity of the education. Many more similar examples could be mentioned in this regard.

The work on the further development directions of the digital world has already intensified at the beginning of the second decade of the 21st century. Modern industries that are a part of the broadly defined e-economy have gained in importance. The concept of the fourth industrial revolution (Industry 4.0) was outlined, which is based on the use of robotics, machine processing, artificial intelligence, cloud services, and the Internet of Things[4]. Smart factories are talked about, depicted as complex cyber-physical systems capable of efficiently managing available resources and providing products tailored to individual consumer needs[5]. The combination of modern industry with the service sector,

[1] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: grzegorz.dziwoki@polsl.pl.
[2] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: marcin.kucharczyk@polsl.pl.
[3] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: wojciech.sulek@polsl.pl.
[4] Kagermann H., Wahlster W., Helbig J.: Securing the future of German manufacturing industry. Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group, Frankfurt 2013.
[5] Chen B., Wan J., Shu L., Li P., Mukherjee M., Boxing Y.: Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges, IEEE Access, 2018, Vol. 6, pp. 6505–6519, DOI: 10.1109/ ACCESS.2017.2783682.

which successfully finds its place also in the virtual world, results in the development of modern vertical industries/markets that specialize in carrying out specific types of task from the planning phase to the deployment of the final product. Among them, it is worth to mention, being actively supported by modern information and communication technologies, such the verticals as: education, health, public services, transport, energy management, which when properly integrated can create efficiently working complex ecosystems.

An example of that ecosystem can be a smart city, which as a vital organism, knows the needs of its inhabitants and responds accordingly[6]. Fast and reliable access to information plays a key role in efficient management of this dynamic environment. The changes ongoing in urban agglomeration concern not only the values of parameters characterizing the selected area of its functionality, but also the current structure of the city, which is formed, among others, by buildings, vehicles and the inhabitants themselves. Therefore, appropriate forms of information exchange are necessary that will not impose unnecessary restrictions on the operation and development of the city. Among the various modes of communication, mobile wireless networks are considered the most suitable type of infrastructure. They provide flexible access to the end user, who is now increasingly not only a human but also a machine. They also enable the provision of "anytime, anywhere", "here and now" services.

11.2. Evolution of digital mobile networks

Mobile networks in their current form have undergone a rapid evolution from purely analog solutions (1G system) through digital 2G and 3G systems with the dominant role of circuit switching[7], to full implementation of packet switching [8] (in 4G systems and above) as a more efficient way of using available communication resources. At first, digital systems were dominated by voice transmission complemented by SMS services. The latter, despite their limitations and low reliability, have quickly found non-standard applications e.g. in measurement or monitoring data acquisition systems[9]. In subsequent

[6] Law K.H., Lynch J.P.: Smart City: Technologies and Challenges, IT Professional, 2019, Vol. 21, No. 6, pp. 46–51, DOI: 10.1109/MITP.2019.2935405.

[7] A dedicated channel is established between two communicating endpoints, even if they are not currently exchanging information.

[8] Particular communication resources are utilized only when some part of information (a packet) must be transmitted between endpoints.

[9] Wang H., Zeng R., He J., Sheng X., Zou J.: Data acquisition in distribution system with the GSM network, Proceedings. International Conference on Power System Technology, 2002, Vol. 3, pp. 1768–1771 , DOI: 10.1109/ICPST.2002.1067836.

years, packet transmission, particularly including mobile Internet access popularized in 4G systems, finally sealed the universal nature of these networks. It should be emphasized at this point that the idea of a universal wireless network was first incorporated into 3G mobile systems. It was the fruit of years of work by standardization committees on the requirements for the global IMT-2000 system[10], which in the European edition was deployed at the beginning of the 21st century under the abbreviation UMTS (Universal Mobile Telecommunications System).

The IMT-2000 requirements first identified the need to build a network capable of supporting communications for a variety of digital services. Four traffic quality classes were identified: conversational, streaming, interactive, and background[11]. In retrospect, the requirements for these classes may not seem excessive. The maximum data rates for UMTS did not exceed 2 Mbit/s, and the minimum latencies were on the order of tens of milliseconds. By the standards of the time, which were dominated by text and voice data services, these were acceptable values[12]. After all, the era of smartphones was to begin only in a few years (the first iPhone running iOS in 2007, followed a year later by the HTC Dream running Android), and widespread communication under the Internet of Things remained in the realm of plans.

The proliferation of internet services has led to continuous improvements in UMTS. The priority was to enhance the efficiency of packet transmission. The modifications introduced in the physical layer of the link between the user's terminal and base station (Node B) have included, fast scheduling for better resource sharing among users, adaptive modulation and coding and fast retransmissions[13]. The most advanced extensions for UMTS, called HSPA+, set the upper limit for downlink at a theoretical level of 336Mbit/s, although implementations in mobile operators' networks usually offered a much lower value – 42Mbit/s. Interestingly, further development of the networks now referred to as 3.5G took place in parallel with the construction of infrastructure for new Long Term Evolution (LTE)[14] mobile networks to meet still rapidly growing demand for broadband Internet access.

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[10] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000), Recommendation ITU-R M.1457, Geneva, May 2000.

[11] International Telecommunication Union: Performance and quality of service requirements for International Mobile Telecommunications-2000 (IMT-2000), Recommendation ITU-R M.1079, Geneva, May 2000.

[12] Rapeli J.: UMTS: targets, system concept, and standardization in a global framework, IEEE Personal Communications, Vol. 2, No. 1, pp. 20–28, Feb. 1995, DOI: 10.1109/98.350860.

[13] Das A. et al.: Evolution of UMTS toward high-speed downlink packet access, “Bell Labs Technical Journal”, 2003, Vol. 7, No. 3, pp. 47–68, DOI: 10.1002/bltj.10018.

[14] Astely D., Dahlman E., Furuskär A., Jading Y., Lindström M., Parkvall, S.: LTE: the evolution of mobile broadband, IEEE Communications Magazine, April 2009, Vol. 47, No. 4, pp. 44–51, DOI: 10.1109/MCOM.2009.4907406.

The general guidelines and analysis[15] were adopted to develop the next generation system. It was assumed that the maximum transmission speed should be about 100 Mbit/s for high mobility and about 1 Gbit/s for low mobility, and the maximum transmission delays should not exceed 10 ms. Concurrently, it was emphasized that the proposed solutions should take into account the current technological innovations and trends in development of new types of broadband services. The work undertaken resulted in a set of requirements for IMT-Advanced (4G) systems[16], first published in 2012, with reference to the specifications, considering the LTE-Advanced system as a natural evolution of the LTE system developed several years earlier.

Finally, peak data rates in the latest version of the LTE-Advanced specification (representing the next stage in the development of IMT-Advanced system) can reach values of 32 Gbps (downlink) and 13.6 Gbps (uplink). These values are many times higher than initially assumed and typical for next-generation systems. Among the transmission techniques of physical layer, OFDM (Orthogonal Frequency Division Multiplexing) modulation, which allows to organize simultaneous data transmission on many independent subcarriers, has established its position. Additionally, binary information can be encoded on a given subcarrier by means of complex signal constellations as large as 256 symbols. This means that a single symbol transmitted on a given subcarrier contains information represented by as many as 8 bits. An important role in the transmission of large amounts of data also plays the maximum bandwidth for a single transmission, which according to the specification is up to 640 MHz. The technique used here is carrier aggregation, which consists in simultaneous OFDM transmission on multiple carriers. But the developers of the system have even gone a step further. Recognising that bandwidth requirements may vary depending on the application, a support for Internet of Things (IoT) connectivity, including low bandwidth 200 kHz as part of the NB IoT service, is included in the set of specifications. Another addition is the extension of connectivity with a channel for direct communication of end devices without participation of base stations (sidelink), intended mainly for public safety services.

[15] International Telecommunication Union: Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000, Recommendation ITU-R M.1645, Geneva, June 2003; International Telecommunication Union: Requirements related to technical performance for IMT-Advanced radio interface(s), Report ITU-R M.2134, 2008.

[16] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced), Recommendation , Geneva, Jan. 2012.

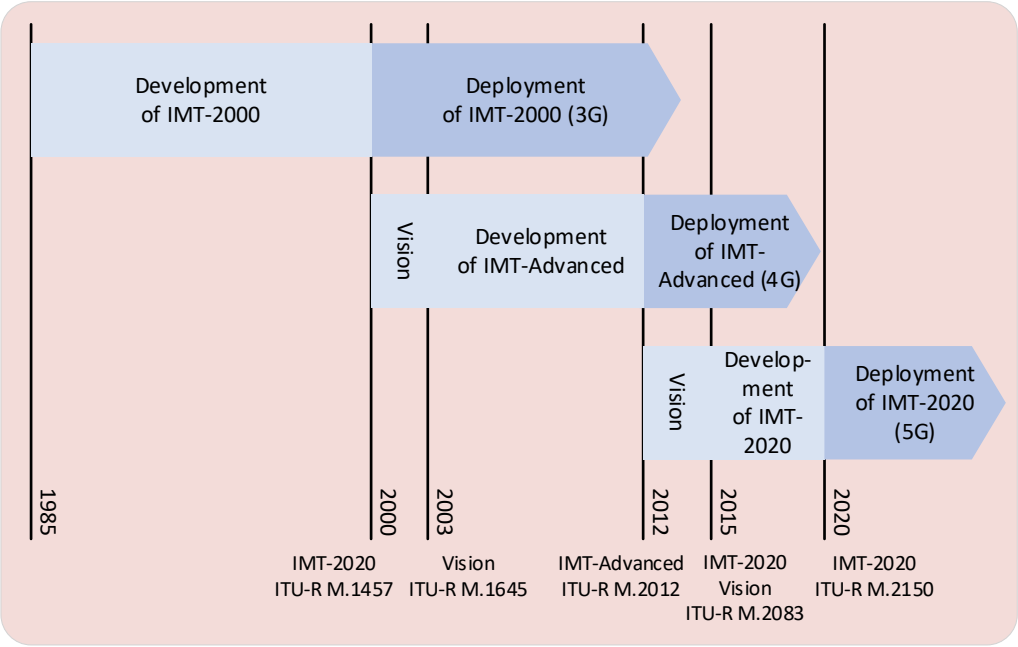

Fig. 11.1. Evolution of digital mobile systems – timeline
Rys. 11.1. Ewolucja cyfrowych systemów mobilnych – oś czasu

As in the case of previous generations (see Figure 11.1), the publication of the first release of the IMT-Advanced[17] system specification in 2012 initiated the start of conceptual work on its successor, called IMT-2020. The awareness of the growing importance of information and communication technologies in various areas of socio--economic life, including the rapidly growing market of electronic services, was reflected in the work of engineering teams on the conditions of the new system. A wide range of current and future applications with diversified demand for communication resources posed a serious challenge to the selection of transmission technology, frequency ranges, and network structure.

11.3. IMT-2020 – objectives and assumptions

The constant increase in the amount of information that is being exchanged is an undeniable fact. We need information to effectively shape and control the reality around us. Especially as this reality is becoming more and more complex due to growing automation and robotisation. Using today's technological advances in areas such as electronics, information and telecommunications technologies, we create new solutions or services that increase the comfort of life and, in addition, function more and more

[17] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced), Recommendation , Geneva, Jan. 2012.

autonomously. The systems developed within the vertical branches of Industry 4.0 are often spatially extensive solutions with a large variability of the number of users and their mutual location. Moreover, the user group also includes devices. And it is machine-to--machine (M2M) or machine-to-human (M2H) communication, alongside traditional human-to-human communication, that becomes one of the key challenges for the new mobile system.

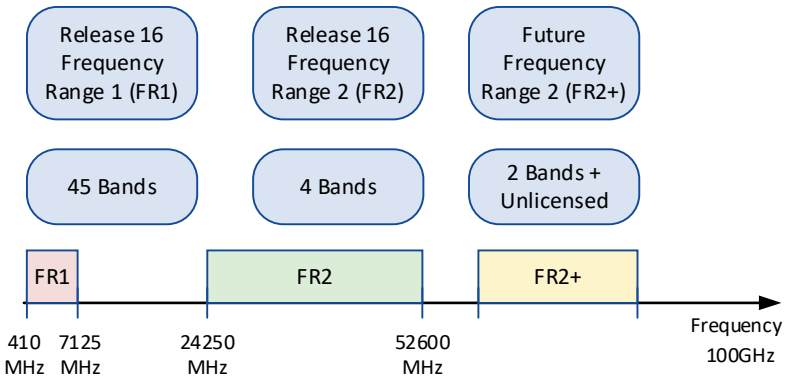

Fig. 11.2. Frequency bands for the IMT-2020 systems
Rys. 11.2. Pasma częstotliwościowe dla systemów IMT-2020

In response to the rapidly growing number of users and applications, bandwidth requirements are also increasing. Additional resources are requested in frequency bands above 6 GHz[18] because those below are already mostly occupied by the existing systems. Figure 11.2 shows the allocation of frequency bands for the IMT-2020 systems[19]. However, when high frequencies (including millimeter waves above 30GHz – mmWave transmission) are used, it is important to keep in mind the range limitations due to the nature of propagation of such signals. Besides growing attenuation along with the increase in the frequency of transmitted signals, additional factors that hinder transmission are e.g. atmospheric induced attenuation (including rain-induced attenuation), foliage-induced attenuation and higher material penetration loss[20]. On the other hand, the reduced transmission range, from perspective of the overall system throughput, may also be an advantage. Traffic in a given area can be handled by mutually non-interfering small picocells/femtocells, which increases area traffic capacity. However, it is impossible not to mention here the inconvenience associated with the large

[18] International Telecommunication Union: Technical feasibility of IMT in bands above 6 GHz, Report ITU-R M.2376-0, Geneva, July 2015.
[19] MT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond Report M.2083-0 (09/2015).
[20] International Telecommunication Union: Technical feasibility of IMT in bands above 6 GHz, Report ITU-R M.2376-0, Geneva, July 2015.

number of base stations, as well as the control data that must be transmitted if the supported user moves within several such picocells during the connection. A separate challenge is the technological aspects of building silicon chips that support transmission in the millimetre wave band[21].

An approach supporting effective management of available capacity should take into account, at the design stage of a new system, the varying requirements for link characteristics. Different demands are imposed on access to multimedia services, and others on systems for traffic control, remote health monitoring, emergency warnings, etc. Therefore, for the designed IMT-2020 systems (and beyond), commonly referred to as the fifth generation (5G) systems, three usage scenarios have been initially distinguished[22]:

- **Enhanced Mobile Broadband (eMBB)** – a continuation and improvement of the popular mobile access to the broadband network. The focus is on higher bandwidth and mobility requirements for multimedia and data services over a large coverage area. A range of future services including VR (Virtual Reality) and AR (Augmented Reality) are considered.
- **Ultra-Reliable and Low Latency Communications (uRLLC)** – a new area of so-called critical applications, designed in particular for autonomous systems. The key factors for these applications are: high safety level, fast response, high operational reliability.
- **Massive Machine Type Communications (mMTC)** – an evolution of M2M services towards solutions that support communication between large number of low-cost and energy-efficient devices. The amount of information exchanged, speed rate and latency are not critical here.

Figure 11.3 presents examples of specialized applications (verticals) and their assignment to the usage scenarios[23].

[21] Juneja S., Pratap R., Sharma R.: Semiconductor technologies for 5G implementation at millimeter wave frequencies – Design challenges and current state of work, ”Engineering Science and Technology, an International Journal”, 2021, Vol. 24, pp. 205–217.
[22] International Telecommunication Union: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, Recommendation ITU-R M.2083-0, Geneva, Sep. 2015.
[23] International Telecommunication Union: Minimum requirements related to technical performance for IMT-2020 radio interface(s), Report ITU-R M.2410-0, Geneva, Nov. 2017.

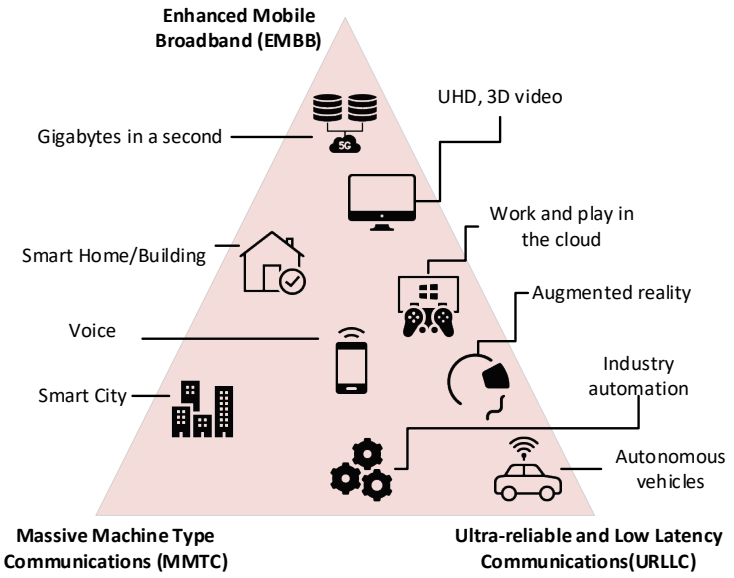

Fig. 11.3. Usage scenarios of IMT-2020 with system examples
Rys. 11.3. Scenariusze zastosowań IMT-2020 z przykładami systemów

To systematize the features of the future system, a set of Key Performance Indicators (KPIs)[24] has been defined and used as benchmarks in the evaluation of the IMT-2020 system proposals. The most characteristic KPIs are:

- Bandwidth (BW) – maximum aggregated range of frequency spectrum;
- Peak Data Rate (PDR) – maximum data rate per user in case of ideal error–free conditions when all radio resources designated for user data are utilized (i.e. excluding control and guard resources, reference signals etc.);
- User Experienced Data Rate (UDR) – achievable throughput, i.e. the number of bits per second delivered to higher layer of the system, measured as 5% of the CDF (Cumulative Distribution Function) user throughput;
- Peak Spectral Efficiency (PSE) – peak data rate normalized by the channel bandwidth;
- User Plane Latency (UPL) – the time necessary to deliver information between transmitter and receiver at the level of 2/3 Layer of the system;
- Control Plane Latency (CPL) – the time necessary for transition from idle state to active state of the device;
- Connection Density (CD) – total number of devices per unit area assuming that the predefined QoS (Quality of Service) conditions[25] are met;

[24] International Telecommunication Union: Minimum requirements related to technical performance for IMT-2020 radio interface(s), Report ITU-R M.2410-0, Geneva, Nov. 2017.
[25] International Telecommunication Union: Guidelines for evaluation of radio interface technologies for IMT-2020, Report ITU-R M.2412-0, Geneva, Oct. 2017.

- Mobility (M) – maximum speed of the mobile device assuming that the predefined QoS conditions are met;
- Area Traffic Capacity (ATC) – is the total traffic throughput served per geographic area.

Table 11.1

Relation between KPI and the usage scenarios

KPI	**USAGE SCENARIOUS**	**IMT-2020**	**IMT-Advanced**
BW	eMBB	100 MHz – 1GHz (in bands above 6 GHz)	Up to 100 MHz
PDR	eMBB	DL: 20 Gbps UL: 10 Gbps	DL: 1 Gbps UL: 50 Mbps
UDR	eMBB	100 Mbps	10 Mbps
PSE	eMBB	DL: 30 bps/Hz UL: 15 bps/Hz	DL: 15 bps/Hz UL: 6,75 bps/Hz
UPL	eMBB. uRLLC	4 ms, 1 ms (uRLLC)	10 ms
CPL	eMBB, uRLLC	10 ms	100 ms
CD	mMTC	$1x10^6$ devices/km^2	$0,1x10^6$ devices/km^2
M	eMBB	500 km/h	350 km/h
ATC	eMBB	10 Mbps/m^2	0,1 Mbps/m^2

However, not all of these parameters are critical for every usage scenario. Table 11.1 shows the reference values for selected KPIs along with an indication of the usage scenarios for which each parameter is particularly important and how it compares to the original requirements for previous IMT-Advanced systems. As can be seen, most KPIs relate to applications that require fast, mobile network access. It is the most widespread and, in retrospect, mature type of service. Many times, this is the only way to connect the user to the global Internet. Nevertheless, in the physical structure of the same system, there should be separate resources (network slices) intended for building independent logical networks that implement specialized services/applications with different requirements (see Figure 11.4). Many of these applications are still under development or testing.

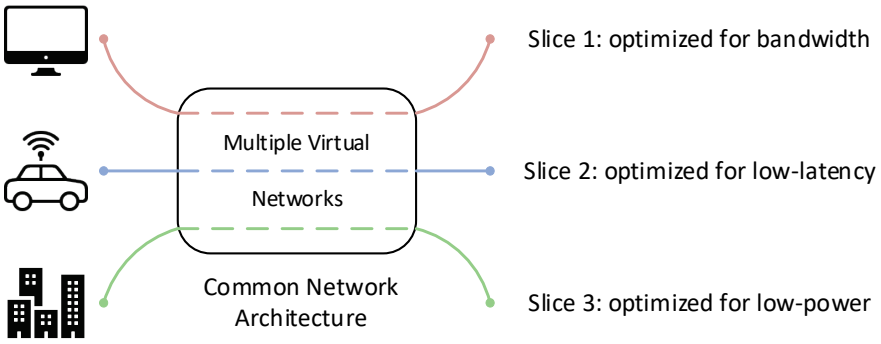

Fig. 11.4. Network Slicing
Rys. 11.4. Plasterkowanie sieci

The requirements for the 5G systems, due to the significant increase in the number of users, the traffic they generate, and the high demand for service diversification, were met by 4 specifications of mobile networks[26]. The New Radio (NR) proposal of the 3GGP consortium was among them in the standalone (SA) and non-standalone (NSA) versions. The second, NSA, assumes coexistence of the new solution with the LTE-Advanced network, whose EPC (Evolved Packet Core) network temporarily takes over the traffic generated in 5G terminals[27]. This incremental deployment of 5G is a very beneficial solution from the perspective of both mobile system operators and end device manufacturers. Coexistence of both radio interfaces can be used to increase throughput using dual connectivity, i.e. transmission on independent frequency bands and to different base stations, if such capabilities are supported by terminal equipment. In a situation where new frequency bands have not yet been made available, the Dynamic Spectrum Sharing mechanism comes to rescue, which is responsible for sharing frequency resources with LTE-Advanced during the migration phase from 4G to 5G[28].

The evolutionary and harmonious deployment of 5G as a new component of the multi-system mobile network (2G and 3G systems are still in operation, but their phase--out is ongoing) can be mostly attributed to its versatility and flexibility. The system architecture at the logical/virtual level is service-oriented as never before. These services, due to their specific nature and in order to maintain high standards of quality and efficiency of network operation as a whole, require access to diverse physical resources at the radio network plane. The allocation of these resources is handled by the physical layer of the system, which has appropriate mechanisms for this purpose.

[26] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2020 (IMT-2020), Recommendation ITU-R M.2150-1, Geneva, Feb. 2022.
[27] Liu G., Huang Y., Chen Z., Liu L., Wang Q., Li N.: 5G Deployment: Standalone vs. Non-Standalone from the Operator Perspective, IEEE Communications Magazine, November 2020, Vol. 58, No. 11, pp. 83–89, DOI: 10.1109/MCOM.001.2000230.
[28] Xin J., Xu S. and Zhang L.: Dynamic Spectrum Sharing for NR-LTE Networks, 2021 2nd Information Communication Technologies Conference (ICTC), 2021, pp. 161–164, DOI: 10.1109/ICTC51749.2021.9441612.

11.4. Key methods and technologies in physical layer of 5G systems

Radio transmission between end terminals is becoming more and more sophisticated nowadays. It is carried out at specific moments in time and frequency ranges. Data security can be adjusted to current transmission conditions and the communicating devices can even be "aware" of each other's position in space. All this is done in order to most effectively use and share limited communication resources with other users.

During the development of the specification for the 5G system, particular attention was paid to improving the reconfigurability of the system in the physical layer plane. The applied techniques and processing methods presented below, on the one hand, support the coexistence with the existing LTE system, and on the other hand, meet the new requirements for IMT-2020 systems.

11.5. Orthogonal Frequency Division Multiplexing (OFDM)

Successful transmission of digitally represented information requires its transformation into a physical signal with parameters corresponding to the current transmission conditions. This process is performed in a processing block called a digital modulator. In the 21st century, among many available solutions, Orthogonal Frequency Division Multiplexing (OFDM) modulation has gained wide popularity[29]. It is characterized by high flexibility in both time and frequency domain. The transmitted digital data are encoded in OFDM modulation symbols, with a duration that can be selected so that the transmission of a single symbol takes place during the unchanged properties of the transmission channel. Moreover, the information contained in a single OFDM symbol is transmitted over many frequency subchannels/subcarriers independent/orthogonal to each other. This is especially important in wireless systems. The principle of radio wave propagation causes that the properties in the frequency domain of the transmission channel are very diverse. Both, the attenuation characteristics and the phase delays vary greatly as a function of frequency. They introduce distortions into the transmitted information, which are removed at the receiver in a block called the equalizer. The independence of the individual subchannels in OFDM modulation greatly

[29] Weinstein S.B.: The history of orthogonal frequency-division multiplexing [History of Communications], IEEE Communications Magazine, November 2009, Vol. 47, No. 11, pp. 26–35, DOI: 10.1109/MCOM.2009.5307460.

simplifies the operation of the equalizer. Finally, it is also possible to exclude a subchannel of any frequency from transmission in case of very high distortions or when it results from the organization of the transmission.

OFDM modulation has been implemented in the physical layer of many wireless systems[30] including WiFi computer networks, DVB digital television, and LTE. Due to the compatibility of the radio interface with LTE-Advanced systems, it has also become the solution adopted in 5G NR networks. Its success, in addition to the above properties, is attributed to the simple implementation scheme that uses the Fast Fourier Transform (FFT) at its core. The size of the FFT determines the maximum number of frequency subchannels on which simultaneous data transmission can be carried out. In practice, some of them are intended to transmit training signals, and those at the band edges are switched off in order to adjust the bandwidth and minimize interference in adjacent transmission channels. In a single subchannel, the binary data is encoded using complex numbers belonging to a set called a signal constellation. The most common constellations are Quadrature Phase-Shift Keying (QPSK) and M-Quadrature Amplitude Modulation (M-QAM) where M denotes the number of symbols in the set. As the complexity of the constellation increases, the spectral efficiency of the modulation is enhanced, unfortunately with an increase in susceptibility to transmission errors due to distortion and noise.

The OFDM modulation specification for the 5G NR system is a development of the one in the LTE-Advanced system. The length of the physical frame (10 ms) has been preserved, in which there are 10 subframes of 1 ms with a variable number of slots. Each slot consists of 14 OFDM symbols, which, depending on the selected transmission format, can be downlink (DL), uplink (UL), or flexible (DL or UL). The main change in relation to LTE is the doubling of the size of the FFT (4096) and the introduction of numerology. This term is used to specify the range of variations in the subcarrier spacing, starting from the value of 15 kHz (as for LTE) through subsequent doubling, up to the value of 960 kHz for mmWave transmission (Release 17 of the New Radio specification[31]). An increase in the subcarrier spacing corresponds to a decrease in the symbol length (greater number of slots in the subframe), and consequently to an increase in available bit rate. In the case of OFDM modulation, it is possible to easily control the allocation of time-frequency resources, depending on the actual amount of transmitted data, services provided, or the number of users. In the 5G system, similarly to LTE, the

[30] Hwang T., Yang C., Wu G., Li S., Ye Li G.: OFDM and Its Wireless Applications: A Survey, IEEE Transactions on Vehicular Technology, May 2009, Vol. 58, No. 4, pp. 1673–1694, DOI: 10.1109/TVT.2008.2004555.

[31] European Telecommunications Standards Institute: 5G, NR, Physical channels and modulation, 3GPP TS 38.211 version 17.1.0 Release 17, Sophia Antipolis, France, Apr. 2022.

basic unit of data allocation has been defined - Physical Resource Block (PRB) – consisting of 12 consecutive subcarriers with a variable number of OFDM symbols[32]. The control mechanisms of the system are responsible for efficient adjustment of PRB to current transmission requirements.

11.6. Massive Multiple Input Multiple Output (mMIMO) and Beamforming

There are many adversities in wireless signal transmission. Unpredictable and variable conditions of multipath signal propagation and users mobility cause phenomena of deep fades that significantly reduce the power of received signal observed in the frequency and time domain. Poor transmission conditions result in loss of transmission quality despite methods minimizing distortions introduced by the channel. Error correction coding can improve the performance, but the price is lower transmission speed.

However, the multipath, which is an inherent feature of wireless propagation can also be successfully exploited to increase system throughput by modifying the radio part of the transmitter and receiver with multi-antenna systems. Each wireless link between any transmitting and receiving antenna is considered as a separate transmission subchannel in a multiple-input-multiple-output (MIMO) type channel structure[33]. Providing spatial sub--channel independence by mutually spacing the transmitter (receiver) antennas more than half a wavelength apart, the data rate (using spatial multiplexing) or the transmission reliability (using spatial diversity) of the entire transmission can be increased. In the former case, each transmitting antenna sends a unique data stream, while in the latter case, one and the same stream (with some modification) is sent by all antennas. On the transmitter side, it is also possible to shape the directional characteristics of the antenna array (beamforming) by introducing, for example, appropriate phase delays of the signal delivered to individual antennas or more advanced precoding algorithms in the baseband processor.

Advanced MIMO techniques are already successfully used in bands up to 6 GHz (sub-6 GHz) by legacy mobile systems (e.g., LTE). The relatively small wavelength allows to place up to several antennas on users' terminals (ongoing research assumes up

[32] European Telecommunications Standards Institute: 5G, NR, Physical layer procedures for data, 3GPP TS 38.214 version 17.1.0 Release 17, Sophia Antipolis, May 2022.
[33] Paulraj A.J., Gore D.A., Nabar R.U., Bolcskei H.: An overview of MIMO communications – a key to gigabit wireless, Proceedings of the IEEE, Feb. 2004, Vol. 92, No. 2, pp. 198–218, DOI: 10.1109/JPROC.2003.821915.

to 10 antennas[34]) and, in the case of base stations, matrices consisting of a dozen or even several dozen radiating elements (massive MIMO)[35]. The signal emitted by such a matrix can be freely directed in all dimensions of space[36] (3D/full dimension beamforming; vertical beam positioning is a novelty here in particular), including the creation of multiple independent beams for connections to different users (multiuser MIMO)[37]. Knowing the transmission direction allows for more efficient power management and increases system capacity.

MIMO techniques become particularly important at millimeter wave[38]. With a large number of devices communicating at distances not exceeding several hundred meters, when any object in the transmission path can effectively block the signal, the ability of the devices to actively control the beam becomes an essential component of the communication system.

11.7. Carrier Aggregation (CA)

Improvements in transmission performance through the use of multi-antenna techniques have their limitations due to the physical size of the devices (especially important in the case of user terminals) and the complexity of the antenna modules. Further throughput increase within a given communication link can be supported by additional frequency resources. Due to OFDM modulation and arrangement of the transmission in the PRB structure, 5G systems already have quite extensive possibilities of flexible control of the allocated frequency spectrum. In the millimeter band, the demand for high bit rates can be effectively satisfied by large values of OFDM modulation subcarrier spacing (new numerologies introduced in Release 17 of the New Radio specification[39]). However, this will be a short range transmission.

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[34] Khan J., Ullah S., Ali U., Tahir F.A., Peter I., Matekovits L.: Design of a Millimeter-Wave MIMO Antenna Array for 5G Communication Terminals, Sensors, 2022, 22, 2768. doi.org/10.3390/s22072768.

[35] Borges D., Montezuma P., Dinis R., Beko M.: Massive MIMO Techniques for 5G and Beyond--Opportunities and Challenges, "Electronics" 2021, 10, 1667. doi.org/10.3390/electronics10141667.

[36] Nadeem Q., Kammoun A. Alouini M.: Elevation Beamforming With Full Dimension MIMO Architectures in 5G Systems: A Tutorial, IEEE Communications Surveys & Tutorials, 2019, Vol. 21, No. 4, pp. 3238–3273, DOI: 10.1109/COMST.2019.2930621.

[37] Spencer Q.H., Peel C.B., Swindlehurst A.L., Haardt M.: An introduction to the multi-user MIMO downlink, IEEE Communications Magazine, Oct. 2004, Vol. 42, No. 10, pp. 60–67, DOI: 10.1109/MCOM.2004.1341262.

[38] Bjornson E., Van der Perre L., Buzzi S., Larsson E.G.: Massive MIMO in Sub-6 GHz and mmWave: Physical, Practical, and Use-Case Differences, IEEE Wireless Communications, April 2019, Vol. 26, No. 2, pp. 100–108, DOI: 10.1109/MWC.2018.1800140.

[39] European Telecommunications Standards Institute: 5G, NR, Physical channels and modulation, 3GPP TS 38.211 version 17.1.0 Release 17, Sophia Antipolis, France, Apr. 2022.

The current coexistence with LTE on sub-6GHz bands imposes its own constraints on the time-frequency distribution of shared resources. As a result, for a 5G system, the maximum transmission rates over a single 100 MHz wide frequency channel using MIMO do not exceed 5 Gbps[40]. This is the result that does not meet the requirements expected for IMT-2020 systems. The solution here is brought by a technique called Carrier Aggregation, also implemented in LTE-Advanced[41].

Data transmission is carried out simultaneously over several OFDM channels called Carrier Component. Various combinations of these channels are possible. They may be in close vicinity (intra-band contiguous) or distant (intra-band non-contiguous) or even located in separate bands (inter-band non-contiguous). The IMT-2020 specification assumes aggregation of up to 16 CCs. Analyses of such transmission for sub-6GHz bands report that the maximum throughput values are at the level of 80 Gbps (DL) and 40 Gbps (UL) at a total bandwidth occupancy of 1.6 GHz[42]. This applies only to the licensed band. In the longer term, the possibility of including unlicensed bands in the transmission is also being considered.

Although multiband transmission via CA seems conceptually simple, there are many challenges from a device design perspective. A solution with the least hardware complexity that consists of a single radio path can be proposed, especially for the intra--band cont. CA scenario. In this case, the channel aggregation procedure is performed all in the digital domain in the baseband processor. Since the result of CA is a wideband signal, special attention is paid to the linearity of analog circuits to minimize spurious in--band interferences. In a system of multiple independent analog paths (for non-cont. CA), additional efforts must be made to ensure proper isolation between them and to compensate for the attenuation contributed by the analog combiner[43].

11.8. Non-Orthogonal Multiple Access (NOMA)

In mobile systems, there is a clear increase not only in the amount of data transferred, but also in the number of simultaneously supported devices. This trend will continue in

[40] Fuentes M., et al.: 5G New Radio Evaluation Against IMT-2020 Key Performance Indicators, IEEE Access, 2020, Vol. 8, pp. 110880–110896, DOI: 10.1109/ACCESS.2020.3001641.
[41] Yuan G., Zhang X., Wang W., Yang Y.: Carrier aggregation for LTE-advanced mobile communication systems, IEEE Communications Magazine, February 2010, Vol. 48, No. 2, pp. 88–93, DOI: 10.1109/MCOM.2010.5402669.
[42] Fuentes M., et al.: 5G New Radio Evaluation Against IMT-2020 Key Performance Indicators, IEEE Access, 2020, Vol. 8, pp. 110880–110896, DOI: 10.1109/ACCESS.2020.3001641.
[43] Park C.S., Sundström L., Wallén A., Khayrallah A.: Carrier aggregation for LTE-advanced: design challenges of terminals, IEEE Communications Magazine, December 2013, Vol. 51, No. 12, pp. 76–84, DOI: 10.1109/MCOM.2013.6685761.

the future, given the range of highly specialized services proposed especially in the IoT area. Although most of them are only at the planning or concept stage, it is anticipated that the link resource allocation methods used so far may prove to be insufficient in the face of massive M2M communication.

The applied transmission technologies in natural way allow individual users to be allocated separate time and frequency resources (OFDM), and approximately – with precise beamforming – also spatial resources. This method of accessing the system is called Orthogonal Multiple Access (OMA) because, by principle, the transmissions of individual users are mutually separated and independent. In currently proposed IMT-2020 systems, this is the only form of sharing radio resources. However, research is underway to increase the capacity of the system by using a Non-Orthogonal Multiple Access technique in which the transmissions of several users interfere with each other.

Among the NOMAs, two variants can be distinguished: Power domain NOMA and Code domain NOMA[44]. Multi-access in the power domain implies the simultaneous transmission of multiple users' signals with different power levels at the same time, at the same frequency, and in the same direction in space (e.g., by a base station). The power value assigned to a given component depends primarily on the distance over which the signal is to be transmitted. In the receiver, all components are analyzed simultaneously as one combined signal. The component with the highest power is received first, the others represent unwanted interference to it. If the receiver was the recipient of the signal this stage of detection is completed. If not, using the Successive Interference Cancellation (SIC) method, the receiver removes the decoded component from the received signal and the detection process begins again. In the case of code multi-access, each pair of connection participants is assigned a different user-specific spreading sequence based on which a decision is made to whom the transmission is directed.

Besides increasing the system capacity, non-orthogonal multi-access reduces the transmission latency due to less restrictive rules in time resource allocation. The lack of strict resource management also affects the smaller amount of necessary signaling data transmitted in the system during scheduling process. However, the use of this approach increases the computational complexity of the detection algorithms, which in the case of user terminal must be taken into account, at least in terms of increased energy consumption. Some additional processing steps include the determination and transmission of channel state information or error correction features during SIC.

[44] Dai L., Wang B., Yuan Y., Han S., Chih-Lin I., Wang Z.: Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends, IEEE Communications Magazine, September 2015, Vol. 53, No. 9, pp. 74–81, DOI: 10.1109/MCOM.2015.7263349.

11.9. Low Density Parity Check (LDPC) and Polar codes

Compared to LTE and LTE-Advanced, an important new element of the physical Layer processing in 5G are new error correction (channel) coding schemes, namely LDPC and Polar codes in data channels and control channels respectively.

Due to the excellent correction performance and parallelized decoding algorithm, LDPC codes were previously incorporated in a number communication standards, like DVB-T2, Wi-Fi 802.11n and WiMAX. The main advantages in comparison with Turbo codes used in LTE are better area throughput efficiency, higher achievable peak throughput, improved decoding latency and improved performance, with error floors below the block error rate of 10^{-5} for all code sizes[45]. The high throughput of multiple Gbps, especially for eMBB 5G deployment scenarios, can be handled effectively by the encoding and decoding schemes of the designed LDPC codes.

LDPC codes are one of the best known block error correction coding schemes. The scheme designed for 5G NR uses a quasi-cyclic structure of LDPC parity check matrices (PCM), where the PCM is defined by a smaller base matrix and a set of cyclic shifts values (CSVs). The base matrix defines positions of square submatrices in PCM that are identity matrices shifted by a corresponding CSV. This developed scheme allows for a dynamic configuration of PCM size (by changing the submatrix size) as well as code-rate adaptation, by the rate-matching technique. Besides the LDPC coding, the processing chain includes cyclic-redundancy-check (CRC) attachment, rate matching and bit-interleaving. The CRC is attached for additional error detection, thanks to which a very low probability of undetected errors can be achieved. The CRC is used in retransmission protocol procedures.

For control channels, in 5G NR, Polar codes replaced tail-biting convolutional codes (TBCC) of LTE. Polar codes, are the class of channel codes, which can be perceived as a special class of block codes with a portion of code-vector that is frozen to specific values. Polar coding was proven to achieve the symmetric capacity of a binary input discrete channel, using a low-complexity successive cancelation (SC) decoding. The main advantage of over the TBCCs, but also turbo codes and typical LDPC codes, is that polar codes with SC-List decoding with outer CRC, typically outperform them at moderate codeword sizes of the order 50…500 bits, which is sufficient for typical control information payloads.

[45] Hui D., Sandberg S., Blankenship Y., Andersson M.: Channel Coding in 5G New Radio, IEEE Vehicular Technology Magazine, December 2018, Vol. 13, No. 4, pp. 60–69, DOI: 10.1109/MVT.2018.2867640.

11.10. Conclusions

The introduction of 4G networks a decade ago sealed the changes in the use of mobile networks at that time. Popular voice calls have been dominated by broadband access to Internet services. It gave mobile networks the hallmarks of universality. Even then, it was recognized that this universality should be supported by optimal use of radio resources. Improvements made in the following years became the basis for the development of new IMT-2020 systems, for example the 5G New Radio system proposed by the 3GPP consortium.

The 5G system is based on the idea: many services over one network. The network that already at the physical layer is able to flexibly allocate appropriate amounts of resources depending on the type of service provided. This is possible thanks to the applied transmission techniques, which discretise physical resources. With elementary units of throughput defined in the time, frequency and even spatial domain, it is possible to manage the efficient operation of the entire system on an ongoing basis.

However, the true potential of the 5G network will only be revealed when it is widely deployed in the mmWave bands. Then the structure of the network infrastructure will change. Short-range transmissions will force the construction of a large number of additional base stations, not necessarily stationary ones. Direct communication between terminals (so-called sidelink) will gain in importance. Many modern vertical services will have a chance to spread. In Europe, two public-private partnerships, "5G Infrastructure Public Private Partnership" (5G PPP) and "Smart Networks and Services Joint Undertaking (SNS JU)" have undertaken this task through numerous projects including those related to Smart City idea[46].

[46] Full 5G Consortium Parties: The European 5G annual Journal/2021, TO-EURO-5G Project, grant agreement number: 761338 under Horizon 2020 funding programme https://bscw.5g-ppp.eu/pub/bscw.cgi/d424095/5G%20European%20Annual%20Journal%202021.pdf.

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Marcin KUCHARCZYK[1], Grzegorz DZIWOKI[2], Wojciech SUŁEK[3]

12. WIRELESS CONNECTIVITY STANDARDS FOR INTERNET OF THINGS DEVICES IN SMART CITIES

12.1. Mobile communication systems

Publicly available wireless connectivity in cities is provided by cellular network systems, the history of which begins in 1979, when the analog mobile telephony system was launched in Japan (NTT network, Nippon Telegraph and Telephone). During this period, for example, the Scandinavian NTT system (Nordic Mobile Telephone, 1981) and the North American AMPS (Advanced Mobile Phone System, 1983) were established. Today all these systems are classified as 1G (1st Generation) systems which, despite general similarities, were created based on separate regional standards.

The next generation, 2G systems, are digital systems, but still based on independent standards. The North American D-AMPS standard was created in 1990 and it was implemented three years later. In Europe, in 1991, the GSM (Global System for Mobile Communications) system was established. In the later process of the mentioned systems development, the equipment manufacturers and standardization organizations around the world recognized the need of unification and in 1998 the 3GPP organization (the 3rd Generation Partnership Project) was established. Already under the banner of this organization, standards for packet data transmission called 2.5G were established, such as GPRS (General Packet Radio Service, 2000, made by ETSI, the European Telecommunications Standards Institute) and EDGE (Enhanced Data rates for GSM Evolution, 2003, compliant with the requirements of IMT-2000 issued by ITU, the International Telecommunication Union).

[1] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: marcin.kucharczyk@polsl.pl.
[2] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: grzegorz.dziwoki@polsl.pl.
[3] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: wojciech.sulek@polsl.pl.

The 3G systems are following the requirements in technical specification IMT-2000[4], which was released in 2000, but had been developed since 1992. The first commercial launch of the 3G cellular network was in 2001 in Japan. The specificity of 3G systems, compared to previous generations, is the separation of the data communication subsystem (packet switching) within the core network outside the area of the voice communication (circuit switching). The UMTS (Universal Mobile Telecommunications System) and CDMA2000 (Code-Division Multiple Access) standards included in the 3G network define the broadband Internet access services. The following generations of mobile standards maintain the trend of increasing available data rates.

Since the 4th generation (4G), mobile communication systems are changing from voice transmission systems, where an additional service is data transmission to packet data transmission systems, which offer voice communication as part of the available services. Transmission standard requirements under 4G have been described by ITU as part of the IMT-Advanced specification[5], and the 3GPP implementation is the LTE (Long Term Evolution) cellular system, first practically launched in Scandinavia in 2009. The available services, apart from the already mentioned packet-switched telephony, include mobile access to the World Wide Web, high-definition mobile TV, and video conferencing - broadband Internet access in general.

The direction of increasing the network performance is continued in the next generations of mobile wireless communication systems. Increasing access speed to network resources entails higher requirements for user equipment (UE) in terms of computational complexity, i.e. hardware resources and energy consumption. In the area of smart cities, however, the requirements leans toward the number of devices rather than the speed of communication. Internet of Things (IoT) devices in smart cities (e.g., weather stations, measurement sensors, home automation devices) typically send or receive small amounts of data at low speeds, but with constant access to the network. The specificity of requirements depending on the application (use cases) has been noticed by the standard developers (3GPP, ITU), which results in the creation of various options under a common umbrella, taking into account applications and mutual coexistence.

[4] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – 2000 (IMT-2000), Recommendation ITU-R M.1457, Geneva, May 2000; International Telecommunication Union: Performance and quality of service requirements for International Mobile Telecommunications – 2000 (IMT-2000), Recommendation ITU-R M.1079, Geneva, May 2000.

[5] International Telecommunication Union: Requirements related to technical performance for IMT-Advanced radio interface(s), Report ITU-R M.2134, 2008; International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – Advanced (IMT-Advanced), Recommendation ITU-R M.2012, Geneva, January 2012.

12.2. Internet of things devices

The IoT in the context of smart cities is used to define networking between devices like smart sensors, with software that enables to collect and process data, to connect with each other and exchange data via communication networks, in particular the worldwide Internet network. The word internet in the name suggests that these devices are connected to the public Internet network, although the actual requirement is only to be connected to any (local or wide) network and individually addressed allowing access to each device directly in order to send or receive the data.

On the consumer market, IoT technology is most often synonymous with products related to the concept of smart home, i.e. home automation devices that allow you to control lighting and heating, manage the home security system, control cameras and other devices in the household. Moving from the area of the smart home to the smart city, available sensors and controllers are used to manage the city by monitoring and controlling vehicle traffic, managing the availability of public transport, providing information related to the functioning of the city to both residents and tourists, or intelligent energy grid resource management. IoT device management is available from the level of mobile smartphones or via the web.

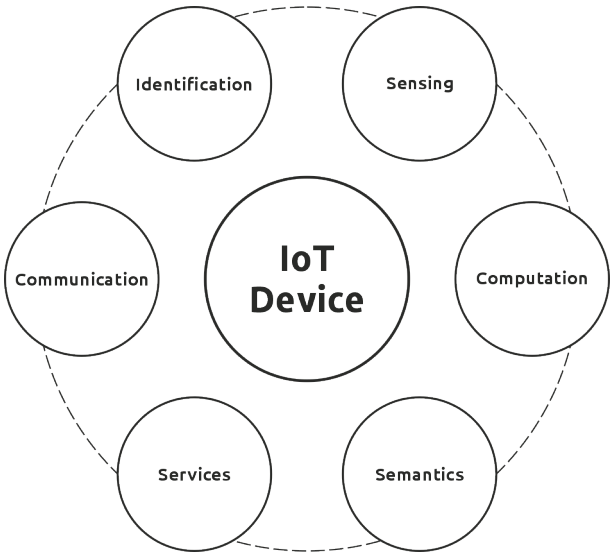

Fig. 12.1. Possible elements of the IoT device
Rys. 12.1. Możliwe komponenty urządzenia IoT

Figure 12.1 shows a general view on building blocks that an IoT device may contain[6]. IoT devices can be perceived as a computer systems that can identify each other based on

[6] Abu-Rgheff M. A.: 5G Physical Layer Technologies, University of Plymouth, United Kingdom, Wiley-IEEE Press, 2019.

their parameters. When sensors are connected, they can be used to retrieve data from the environment. This data is transmitted over an available connection, usually wireless. The CPU (Central Processing Unit) that is the central unit of the IoT device can perform calculations based on the collected data and share the results through the implemented web services. When there are more devices, they can form a structure of connected objects that communicate with each other within a defined semantics. All these functions are assumed to be performed by a computer system with low computational resources and low energy demand, so the communication interface should also meet such assumptions.

The specific requirements for connectivity with IoT devices have already been noticed when defining 4G standards, where the application definitions appeared from the mainstream of developing networking participants. Today, the division clearly diversifying the parameters of wireless connectivity depending on the application is an integral part of the next generation (5G) evolution process. This diversity is presented in the form of the 5G triangle, which appeared in the ITU-R M.2083 recommendation[7] and defines the usage scenarios for 5G wireless systems.

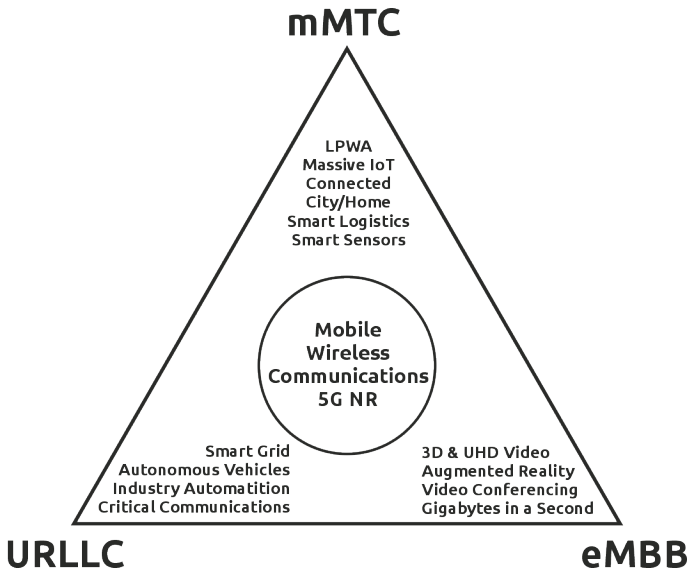

Fig. 12.2. Three main use cases of mobile wireless communications systems
Rys. 12.2. Trzy scenariusze zastosowań sieci mobilnych

The 5G triangle can be found in the literature in many versions, and Fig. 12.2 is one of the examples presenting the three main usage scenarios defined in the recommendations for wireless systems, for the 5G NR (5G New Radio) radio layer:

- eMBB (enhanced Mobile Broadband), focuses on providing higher bandwidths for use in mobile broadband communications, for example for UltraHD (Ultra High

[7] International Telecommunication Union: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, Recommendation ITU-R M.2083, Geneva, September 2015.

Definition) video streaming, augmented reality or video conferencing (this is a continuation of the evolution of mobile networks towards higher bandwidths);

- mMTC (massive Machine Type Communications), designed for large numbers of low-power devices that regularly transmit small amounts of data, i.e. for massive Internet of Things deployments in smart home or smart cities;
- URLLC (Ultra Reliable Low Latency Communications), ideal for mission critical applications where network reliability and low latency are the most important, examples include autonomous cars and remote control or automation industrial processes.

Internet of Things devices, in the context of smart cities, are positioned in the mMTC category. As part of the city infrastructure, the need to install a large number of such devices is apparent today (monitoring of traffic, weather and environmental conditions, control of energy consumption and supervision of lighting systems, etc.), but the amount of data transmitted to and received from these devices will not be large, and there is no need to meet strict timing requirements. Within a smart city there will also be a place for devices that need wide bandwidth (urban monitoring) or high network reliability (autonomous vehicle traffic) but such usage models are not the subject of this chapter.

12.3. Massive machine type communications standards

The 3GPP organization, which currently defines wireless communication standards for mobile systems, publishes successive versions of them using subsequent Releases. Each Release assumes co-existence with previous Releases and defining a stable platform for new features implementation at a given point in development. New functionalities added in subsequent Releases can therefore be implemented within existing systems or systems in the design or implementation stage. Formally approved (frozen) standards are published by standardization organizations that are members of the 3GPP[8], such as ETSI, which maintains numbering in issued standards consistent with 3GPP technical specifications.

The basis for the development of 3GPP standards are technical recommendations issued by ITU-R (ITU Radiocommunication Sector). The requirements for fourth generation of mobile services (4G) were defined in the IMT-Advanced recommendation,

[8] The 3rd Generation Partnership Project (3GPP): Official Publications, updated July 17, 2018, https://www.3gpp.org/specifications/63-official-publications.

the final version of which was published in 2012 (ITU-R M.2012[9]). As part of Release 8 of the 3GPP specification, the LTE standard was defined, which defines a new (compared to 3G) radio layer for mobile systems that is assumed to be compatible with the ITU-R recommendation. However, actual compliance with IMT-Advanced assumptions is not achieved by 3GPP specifications until Release 10, which is referred to as the LTE Advanced[10] standard. In 2021, ITU-R published the ITU-R M.2150 recommendation[11], which defines the next generation of mobile services (5G) created under the name IMT-2020. From the 3GPP side, the new generation of the radio interface (5G-NR) and other aspects of the new generation of mobile systems appear in the Release 15 of 2019, which is referred to as the first phase of 5G system implementation (The 5G System – Phase 1).

As of today, the last published version of the technical specifications 3GPP is Release 17 (5G). Previous Releases define the basis of 4G, then 5G systems as well as extensions, enhancements, or specific applications within the previously defined basis.

An example of such a specific application are the mMTC class devices, which require a radio interface in the technology generally referred to as Low Power Wide Area (LPWA). LPWA is designed to transmit small amounts of data at low rates and with low power requirements (providing long battery life), while having long range. The last of the conditions is not met by previously created systems of wireless devices using Bluetooth or ZigBee technologies for communication. The industry's needs related to range have been taken into account by such technologies as LoRaWAN or SigFox, which possess all the LPWA features. Unfortunately, these systems require their own network of transmitters (base stations) to operate, independent to mobile operators infrastructure. Therefore, it seems natural and economically viable to implement LPWA technology within publicity available mobile services. As part of the documents created by 3GPP, several LPWA-type standards were created, intended for IoT devices: LTE-M/LTE-MTC (Long-Term Evolution Machine Type Communication), NB-IoT (Narrowband-IoT) and EC-GSM-IoT (Extended Coverage-GSM-IoT). These technologies will be briefly described in the following subsections.

[9] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – Advanced (IMT-Advanced), Recommendation ITU-R M.2012, Geneva, January 2012.
[10] Dahlman E., Parkvall S., Skold J.: 4G: LTE/LTE-Advanced for Mobile Broadband, Academic Press, London, United Kingdom, 2011.
[11] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – 2020 (IMT-2020), Recommendation ITU-R M.2150, Geneva, February 2021.

12.4. LTE-M (EMTC)

The name LTE-M, or LTE-MTC, is a term used in industry and refers to machine-type devices communications over LTE networks (Long Term Evolution for Machine-Type Communications). Release 12 of the 3GPP specifications defines a low-cost (LC) enhancement to the requirements (Machine Type Communications enhancements): MTCe/LC-LTE[12]. The defined parameters function under the notion of the user equipment category Cat-0. Transmission in the full LTE bandwidth is assumed, i.e. 20 MHz, at rates up to 1 Mbps using a single-antenna system (SISO, Single-Input Single-Output). Optionally, the transmission can be carried out in Half-Duplex mode.

The focus on IoT devices has been enhanced in Release 13. Requirements for IoT devices regarding the transmitter power, battery life (10 years on a 5 Wh battery with a transmission of up to 200 bytes a day), transmission coverage and the number of devices in a given area (1 million per 1 square km) have been defined[13]. These requirements generally define ultra-low complexity and low-cost devices. The technical specification introduces devices of the M1 category and the appropriate LTE-M Cat-M1 operating mode. This mode is similar to defined for Cat-0 devices, the main difference is the operating bandwidth, which has been set to constant value 1.4 MHz. The bandwidth reduction enables significant energy consumption reduction. Theoretically achieved transmission speeds still reach 1Mbps in Full Duplex mode, but in Half Duplex mode it is about 300 kbps. Transmission standards for LTE-M class devices defined in a limited band are also referred to as eMTC (enhanced MTC).

The value of 1.4 MHz is formally the smallest value supported by the LTE system (more specifically Legacy LTE) and refers to 6 adjacent Physical Resource Blocks (PRBs) of 12 subcarriers with 15 kHz spacing in each, which sums to 1.08 MHz, giving with guard bands the total of 1.4 MHz. In contrast, usually the base station uses a wider channel (20 MHz) because, as mentioned earlier, the primary purpose of building LTE networks is to increase the speed performance, which is proportional to the bandwidth. Regardless of the channel bandwidth, around the center frequency using only 6 PRBs, a synchronization sequence (Primary Synchronization Signal – PSS and Secondary Synchronization Signal – SSS) is periodically transmitted, as well as a block of broadcast data (PBCH, Physical Broadcast Channel, containing MIB, Master Information Block) informing about the base station parameters. A device wishing to connect to the network based on this data, also in the 1.08 MHz core, sends a Random-Access Preamble as part

[12] European Telecommunications Standards Institute: ETSI TS 122 368, Service requirements for Machine-Type Communications (MTC) – Stage 1 (3GPP TS 22.368 version 12.4.0 Release 12), Sophia-Antipolis, France, 2014.
[13] Ratasuk R., Mangalvedhe N., Bhatoolaul D. and Ghosh A.: LTE-M Evolution Towards 5G Massive MTC, 2017 IEEE Globecom Workshops (GC Wkshps), 2017, pp. 1–6.

of a random-access channel (PRACH Physical Random Access Channel), whose parameters can be deciphered from the base station identification data. The problem that needed to be solved is that further transmission in LTE is performed according to the information contained in the PDCCH (Physical Downlink Control Channel) control channel, which occupies the full bandwidth of the system, which would require increasing the complexity of the device to support a wider bandwidth.

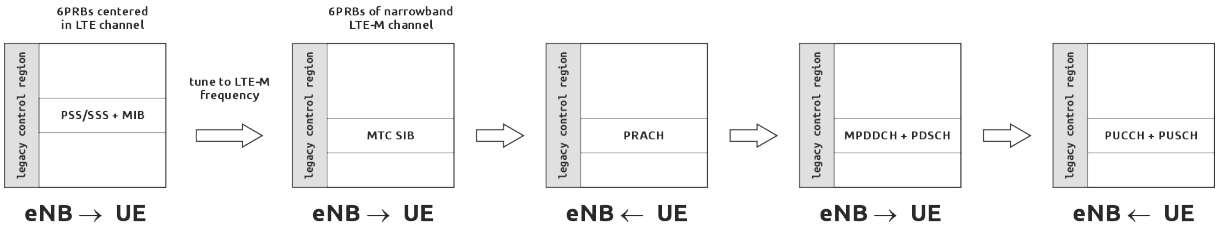

Fig. 12.3. Simplified eMTC Cat-M1 device to base station connection
Rys. 12.3. Schemat połączenia urządzenia Cat-M1 ze stacją bazową

The solution implemented in the specification is shown in Fig. 12.3. The base station, upon recognizing an eMTC device, assigns it a fixed center frequency for 6 PRBs (1.08MHz) and the MPDCCH (MTC Physical Downlink Control Channel) control channel is transmitted within this core band block. Frames directed to eMTC devices skip the first time slots (legacy LTE control region), so the devices using the full available bandwidth are not interfered with by transmissions for IoT devices.

Connecting the Cat-M1 device to the LTE network requires a base station software update to ensure that devices of this category can be properly supported. On the device side, the supported bandwidth is fixed and only tuning to the appropriate channel center frequency is required. Within the dedicated subband (channel group), the base station can support multiple IoT devices, managing the access within the dedicated group of channels as in the full LTE system, allocating channels and time slots within the available resources.

The coverage, in addition to receiver sensitivity, is increased by limiting the constellation size in OFDM (Orthogonal Frequency-Division Multiplexing) subchannels, depending on the mode of operation to 16-QAM (Quadrature Amplitude Modulation) or QPSK (Quadrature Phase-Shift Keying), and by allowing multiple data transmissions (repetitions). In addition, data aggregation within MPDCCH allows more devices to be addressed in terms of a single transmission block (accommodating more Controle Channel Elements, CCEs) or to better protect it against corruptions. Procedures that increase the coverage of devices, i.e. the possibility of correct reception at a lower signal power, on the other hand result in a reduction in the available transmission rate. Expectations of battery life are mainly achieved by the way Cat-M1 devices operate, such as infrequent power-ups to transmit a small amount of data and switching to deep

sleep Power Saving Mode (PSM) after transmission period. In addition to the PSM mode, the eDRX (Extended/Enhanced Discontinuous Reception) mode is supported, where the device goes into sleep mode after agreeing its duration with the base station. If desired, the network stores data for the device for the predetermined period, after which the device wakes up and, after synchronization, performs the initiated transmission or returns to sleep mode.

Subsequent editions of 3GPP technical specifications include improvements related to LTE-M, including in particular the introduction of Cat-M2 devices operating in the 5 MHz band with transmission rates up to 4 Mbps. The functionality of the devices has been enhanced by improving positioning algorithms (based on signals from several base stations) or enabling voice transmission (VoLTE, Voice over LTE, service within Cat-M2 devices). However, these improvements differ from the mainstream applications of IoT devices, i.e. transmission of small amounts of data with low energy consumption, although they are still MTC class devices that require networks with lower performance than available in LTE/LTE-Advanced systems.

12.5. NB-IOT

The 1 Mbps rates offered by Cat-M1 devices are far greater than the requirements of IoT devices. 3GPP Release 13 defines two other standards for devices of this type, the first being NB-IoT (Narrowband IoT). This technology focuses mainly on improving the coverage (also indoors), further reducing costs, prolonging battery life and increasing the number of connected devices (at least 50,000 per cell).

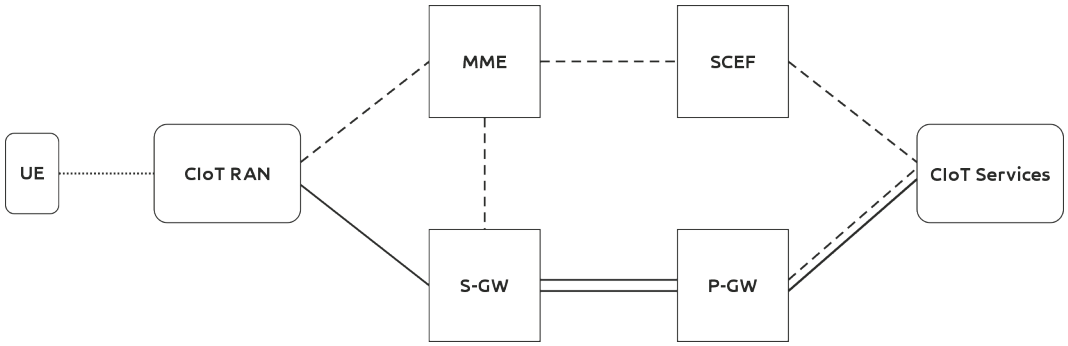

Fig. 12.4. Architecture of NB-IoT Network
Rys. 12.4. Architektura sieci NB-IoT

NB-IoT is based on known technologies, but presents a new perspective of the solutions. Within the 3GPP specification, an optimized architecture for IoT devices has

been defined[14], named Cellular IoT (CIoT), which is shown in Fig. 12.4. The most important thing is that for IoT devices, an independent structure (at least virtually) has been created within the network resources to support them in the scope of CIoT services. This structure is similar to LTE architecture. Data to and from IoT devices can be sent, as in the LTE network, via S-GW (Serving Gateway) and P-GW (Packet Data Network Gateway) in the form of IP packets (Data Path, continuous line in Fig. 12.4) or as part of control data transmission (Control Path, dashed line). The second option is possible due to the small amount of data that is transmitted by IoT devices. When the data is not IP packets, it is routed to the main server via the SCEF (Service Capability Exposure Function). The MME (Mobility Management Entity) is responsible for device authentication and session management. By design, the NB-IoT network does not support mobility and handover, but the network remembers the parameters negotiated during the connection establishment and it is possible to resume them. The resume option only requires new encryption keys to be established, making the time required to reconnect to the network after coming out of the sleep state much shorter.

The similarities to LTE networks concern not only the network structure, but also the radio layer. The concept is based on an assumption that the transmission in the NB-IoT network is carried out in the narrow, 180 kHz band, in Half-Duplex mode, with the use of a single antenna (it lowers the cost of the UE). The maximum connection speed is below 200 kbps, but after activating the mechanisms for coverage enhancements, the actual rates are even lower. This 180 kHz band can be placed either on a released GSM channel (mode: Standalone), or on one of the LTE system sub-channels, occupying a single PRB (mode: In-Band), or within a frequency band that is a guard band for the LTE system (mode: Guard-Band) as shown in Fig. 12.5. An additional requirement is that the center of the channel must be in the 100 kHz grid (with a maximum spacing of 7.5 kHz to this raster), which in the case of In-Band mode is fulfilled only for selected channels of the LTE system.

[14] Buurman B., Kamruzzaman J., Karmakar G. and Islam S.: Low-Power Wide-Area Networks: Design Goals, Architecture, Suitability to Use Cases and Research Challenges, in IEEE Access, vol. 8, pp. 17179–17220, 2020; Ahmadi S.: 5G NR: Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards, Academic Press, London, United Kingdom, 2019; European Telecommunications Standards Institute: ETSI TS 136 104, Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 14.3.0 Release 14), Sophia-Antipolis, France, 2017.

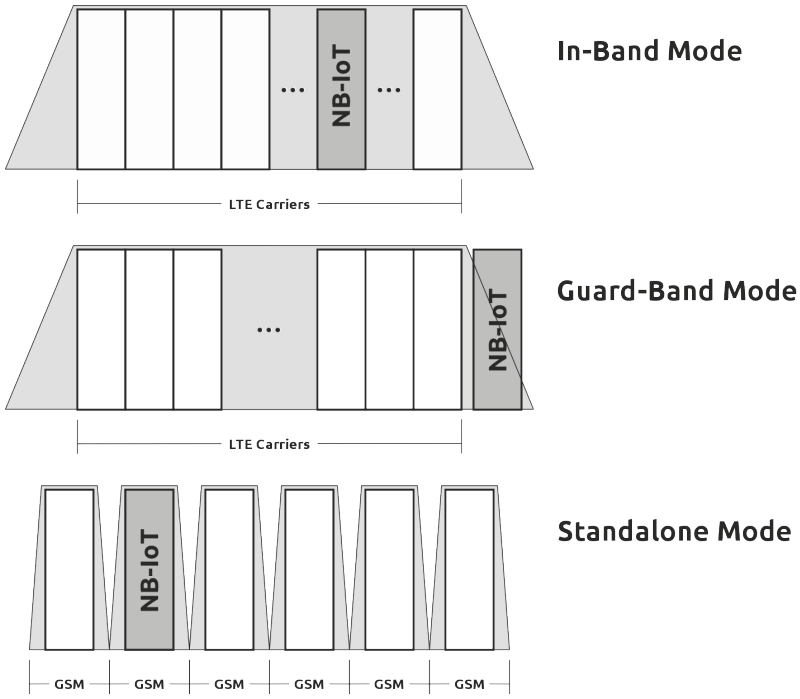

Fig. 12.5. Operation modes for NB-IoT communication
Rys. 12.5. Tryby pracy NB-IoT

From the base station (eNB, Evolved Node B) side, the transmission is carried out with QPSK modulated OFDM on 12 subcarriers with 15 kHz spacing, which corresponds to the structure of a single PRB in LTE networks. In the time domain, as in the LTE system, a full 10 ms frame consists of 10 subframes, each of 14 OFDM symbols. Since control data is sent on the first symbols of the subframe in LTE, the actual transmission in NB-IoT takes place on the last 11 symbols, without interfering with the in-band operation of the LTE system. Since in the LTE system, control data is sent on the first 2–3 symbols of the subframe, the actual transmission in NB-IoT takes place on the last 11 symbols, without interfering the LTE system operation in the In-Band mode. Further similarities to LTE concern the second layer, i.e. the frame structure, and the frame names have been supplemented with the prefix Narrowband. For example, NPSS and NSSS (Narrowband Primary/Secondary Synchronization Signal) frames are sent for synchronization. When the receiver is synchronized and identifies the base station data contained in the Narrowband Physical Broadcast Channel (NPBCH) frame, it can make its resource request in the NPRACH (Narrowband Physical Random--Access Channel) frame. Once the connection is established, the IoT device decodes the information sent by the transmitter by reading in the appropriate frames information about the location of the data sent to the device (NPDCCH, Narrowband Physical Downlik Control Channel, and NPDSCH, Narrowband Physical Downlink Shared Channel), or the space within the available resources for sending its data (NPUSCH, Narrowband Physical Uplink Shared Channel).

The transmission from the device (from the UE) can also, like from the eNB, take place on multiple carriers in multi-tone modulation mode (on 12, 6 or 3 carriers) with QPSK modulation on subchannels, but also single-tone modulation (BPSK, Binary Phase-Shift Keying, or QPSK) is possible in channels spaced every 15 kHz or every 3.7 5kHz. The latter possibility simplifies the design of the transmitting part of the UE device. The number of time slots allocated for transmission depends on the modulation mode offered by the device and is allocated to fit a similar amount of data, i.e. when using multiple channels, the device transmits shorter time.

The power consumption of the device is primarily reduced by autonomous transition to the Power-Saving Mode, when the device is unavailable until it wakes up and reconnects to the network. Additionally, an eDRX mode is available, in which the transition to sleep mode is coordinated with the host network.

12.6. EC-GSM-IOT

The last technology defined in the Release 13 related to IoT devices is EC-GSM--IoT[15]. This name appeared in the Release 13, which defined the previously described standards for IoT devices, but this time it does not refer to the new technology, but sanctions the existence on the market of IoT devices that use the GSM network, that is 2G or more precisely 2.5G, although some improvements were defined. The assumptions for creating this standard are similar to those previously described, namely increased coverage, 10 years of battery life, and support for a large number of devices within a single cell. The main motivation is to implement the technology by changing the software in the existing base stations of the GSM network, so that the change does not affect the devices currently using the network, allowing the interoperability of new and old UEs.

At the radio layer, the system is based on eGPRS (enhanced GPRS, also known as EDGE) transmission, which means that the bandwidth is 200 kHz and the achieved transmission rates can reach up to 70 kbps with GMSK modulation and up to 240 kbps with 8PSK modulation[16]. Extended coverage (EC) for EC-GSM devices is achieved by repetition of transmitted data, and the number of repetitions depends on the EC class,

[15] Selvaraj R., Kuthadi V.M., Baskar S. et al.: Creating Security Modelling Framework Analysing in Internet of Things Using EC-GSM-IoT. Arab J Sci Eng, 2021.

[16] Selvaraj R., Kuthadi V.M., Baskar S. et al.: Creating Security Modelling Framework Analysing in Internet of Things Using EC-GSM-IoT. Arab J Sci Eng, 2021; European Telecommunications Standards Institute: ETSI TS 143 064, Overall description of the GPRS radio interface - Stage 2 (3GPP TS 43.064 version 14.3.0 Release 14), 2018.

which transfers to the coverage. The devices of the EC-GSM-IoT class are intended for the transmission of data and SMS messages, while the voice communication services are not available. In addition to modifications in the radio layer and frame formats for EC-GSM devices, the standard also introduces security system improvements related to mutual authentication, integrity protection, and enforcement of stronger encryption algorithms.

Since the intent was to be able to share resources between the new EC-GSM and traditional GSM devices, the base station after software upgrade (no hardware replacement is required) supports transmission of both types of devices by time multiplexing of data. As in the other systems defined in Release 13, increased battery life is achieved by the ability to enable deep sleep in PSM and as well as eDRX is supported.

12.7. Future of MMTC

All the described standards for IoT devices appeared simultaneously in the Release 13 of the 3GPP standards, which suggests that they are equally important for the developers of the technical specification, although a closer analysis shows slightly different application areas. Subsequent editions of the standards, including the Release 17 announced for this year (2022), contain extensions and enhancements for IoT-related standards. The IoT enhancements defined in Release 13 undergoes little modification, but additional functionality is added: additional services related to device positioning, adding support for mobility and handover between cells, or reducing latency and increasing available connection rates. The last is related to improvements in the physical layer, but marks the creation of a new class of devices that runs in parallel with the previously defined ones within the standard (Cat-M2, Cat-NB2). The 5G enhancements direction also includes many components aimed at power efficiency, like ultra-lean design and band partitioning.

Certain features are common to IoT devices, regardless of which of the described standards they use: they can work in battery mode for a long time, but to save energy they switch into sleep mode, during which they are unreachable, until they initiate a connection after wake up. The low transmission rates and high latency are the side features, but the cost of device production is low.

The EC-GSM-IoT devices are tied to the 2G network, which despite its old age is still in use, widely available and it allows access for older devices using GPRS.

The eMTC systems are related to LTE technology and are currently being deployed, while 5G NR systems are being implemented simultaneously[17]. On the one hand, NR systems are deployed in parallel with LTE in operation and LTE-M devices will be able to connect to the network as long as the operator has made this technology available as part of the 4G network. But according to 3GPP technical reports[18], there is no contraindication to transmit LTE-MTC data in the bandwidth of the NR system in FDM (Frequency-Division Multiplexing) mode under 5G NR, with subcarrier spacing (SCS) 15 kHz. Considering the frame formats of the 5G system (new synchronization frame, SS Block, Synchronization Signal Block – SSB), bands centered on certain subchannels should be defined in the standards that can transmit the 6 PRBs narrowband of the LTE Cat-M1 system in the band occupied by NR.

Looking forward, however, the most sensible choice for the future is NB-IoT. The implementation of the NB-IoT system on the part of the network operator requires the separation of resources related to the construction of Cellular Internet of Things (CIoT) subsystem. But from the side of the radio interface, we have the system that can use cellular infrastructure, while being independent of the technology of cellular network operation. In the currently defined operating modes, the transmitter can operate as part of 4G LTE resources or independently on one of the 2G GSM network channels. As for the cooperation with the 5G NR, it is required to transmit data related to NB-IoT within the physical resource blocks of this network. According to 3GPP technical report[19], NB-IoT system can be implemented in In-Band mode within 5G NR system with SCS 15 kHz. The NB-IoT device does not need information about the mode of operation of the eNodeB (4G) or gNodeB (Next-Generation Node B, 5G) it is connecting to. By detecting the sync signal on one of the supported channels (100 kHz raster) it always connects in the same way.

12.8. Conclusions

Following the recommendations of the ITU-R, the 3GPP organization developing standards for mobile systems as part of increasingly efficient interfaces for radio

[17] Ahmadi S.: 5G NR: Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards, Academic Press, London, United Kingdom, 2019; Dahlman E., Parkvall S., Skold J.: 5G NR: The Next Generation Wireless Access Technology, Second Edition, Academic Press, London, United Kingdom, 2020.
[18] Alliance for Telecommunications Industry Solutions: ATIS.3GPP.37.823.V1600, Coexistence between LTE-MTC and NR (Release 16), 3GPP TR 37.823 V16.0.0, Valbonne, France, 2020.
[19] Alliance for Telecommunications Industry Solutions: ATIS.3GPP.37.824.V1600, Coexistence between NB-IoT and NR (Release 16), 3GPP TR 37.824 V16.0.0, Valbonne, France, 2020.

transmission, defines separate branches for various classes of devices, as shown in Figure 12.2, including the Internet of Things devices. The result of these activities are LPWAN class transmission standards, which operate over a large area and are suitable for implementation in smart cities. Unlike standards for local networks, it is easier to plan and implement a centralized system of access to devices available in a wide network. When choosing a standard for smart city infrastructure, it can be assumed that IoT devices supporting one of the mentioned cellular standards offer similar functionality. Looking forward, however, the most sensible choice for the future is NB-IoT.

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Piotr KŁOSOWSKI[1]

13. IMPROVING RELIABILITY OF DISTANCE EDUCATION INFRASTRUCTURE IN CRISIS SITUATIONS USING ARTIFICIAL INTELLIGENCE AND DEEP LEARNING APPLICATIONS

13.1. Introduction

The planning and development of smart cities involve the integration of various technologies and trends to improve the quality of life for residents, enhance sustainability, and optimize the use of resources. One of the key technologies and trends in smart city planning and development is Information and Communications Technology (ICT). Reliability is an extremely important practical aspect of practically any Information and Communications Technology (ICT) infrastructure in all conditions, with particular regard to a situation when a crisis occurs. We experienced this type of crisis quite recently, namely during the pandemic caused by the coronavirus. Since the beginning of 2020, nearly all countries have been battling a coronavirus pandemic with strict restrictions recommended by the World Health Organization to help minimize the number of infections. The restrictions also affect members of the academic community. Universities have suspended all teaching – except online classes. Most universities have put in place arrangements for remote education. However, organizing remote education requires adequate technological infrastructure. Providing adequate ICT infrastructure is not an easy challenge, as network devices and web servers are experiencing record peak loads during this time. There appear to be potentially many opportunities to use artificial intelligence to improve the performance of the distance education infostructure, information systems, and network infrastructure during this challenging time. Examples of such use of artificial intelligence applications are presented in this chapter. The chapter demonstrates that using artificial intelligence to improve the performance of distance education server infrastructure is possible in many areas. It is also worth noting that the

[1] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: piotr.klosowski@polsl.pl.

use of artificial neural networks and deep learning techniques for this purpose seems very promising. The sample experiments presented in the chapter and the results obtained seem to confirm this thesis.

13.2. Artificial intelligence and deep learning application

Artificial Intelligence (AI) is a field of computer science that deals with the development of models of intelligent behaviours, programs and systems that simulate those behaviours[2]. It includes machine learning, fuzzy logic, evolutionary computing, neural networks, robotics, and artificial life. It is particularly interested in problems that are not effectively algorithmic. The term was coined by John McCarthy in 1956[3]. Andreas Kaplan and Michael Haenlein define artificial intelligence as "the ability of a system to correctly interpret external data, to learn from it, and to use this knowledge to perform specific tasks and achieve goals through flexible adaptation"[4]. Modern practical applications of AI are[5]: fuzzy logic technologies, expert systems, machine translation of texts, neural networks, machine learning, data mining, image recognition, speech and speaker recognition, handwriting recognition (OCR), artificial creativity, in economics, intelligent interfaces.

The most promising applications of artificial intelligence that could be used to solve the problems described in this chapter appear to be: expert systems – systems that use a knowledge base (stored declaratively) and inference mechanisms to solve problems[6]; neural networks - successfully used in many applications[7]; machine learning – a branch of artificial intelligence that deals with algorithms capable of learning to make decisions or acquire knowledge[8]; deep learning – as a subcategory of machine learning[9]; data mining – discusses areas, relationship to information needs, knowledge acquisition,

[2] Poole D., Mackworth A., Mackworth A., Goebel R.: Computational Intelligence: A Logical Approach. Oxford University Press, 1998.
[3] Shannon C.E., McCarthy J.: Automata Studies. Princeton University Press, 1958; McCarthy J.: "Programs with common sense," Computation & intelligence, 1958.
[4] Kaplan A., Haenlein M.: "Siri, siri, in my hand: Who's the fairest in the land? on the interpretations, illustrations, and implications of artificial intelligence," Business Horizons, vol. 62, no. 1, 2019, pp. 15–25.
[5] Russell S., Norvig P.: Artificial Intelligence: A Modern Approach. Always learning, Pearson, 2016.
[6] Leondes C.: Expert Systems: The Technology of Knowledge Management and Decision Making for the 21st Century. Elsevier Science, 2001.
[7] Feldman J., Rojas R.: Neural Networks: A Systematic Introduction. Springer Berlin Heidelberg, 2013.
[8] Gori M.: Machine Learning: A Constraint-Based Approach. Elsevier Science, 2017.
[9] Goodfellow I., Bengio Y., Courville A.: Deep Learning. Adaptive Computation and Machine Learning series, MIT Press, 2016.

analysis techniques used, expected results[10]. These techniques include artificial neural networks. Some of the algorithms underpin deep learning, and also technologies such as image recognition and robot vision. Artificial neural networks are inspired by the neurons of the human brain. They consist of several artificial, interconnected neurons. The higher the number of neurons, the deeper the network. The adjective "deep" in deep learning refers to the use of multiple layers in a network. Early work showed that a linear perceptron cannot be a universal classifier, but a network with an uncountable activation function with a single hidden layer of unlimited width can. Deep learning is a contemporary variation that deals with an unlimited number of layers with limited size, which allows for practical application and optimized implementation while maintaining theoretical universality.

The issues addressed in this chapter relate to the use of artificial intelligence and deep learning techniques to improve the performance of ICT servers, which are part of the Distance Education Platform, during a period of the extremely intense load caused by the operation of distance education during a pandemic emergency.

13.3. Distance education infrastructure of the silesian university of technology

The Silesian University of Technology is a modern university, respected in the Polish and international scientific community, educating approximately 20,000 students, with long traditions and experience in the use of distance learning methods and techniques in the teaching process. Distance education or distance learning is a field of education that focuses on the pedagogy, technology, and instructional systems design that are effectively incorporated in delivering education to students who are not physically on-site to receive their education[11]. Instead, teachers and students may communicate asynchronously (at times of their choosing) by exchanging electronic media, or through technology that allows them to communicate in real-time (synchronously). Distance education courses that require a physical on-site presence for any reason including the taking of examinations are considered to be a hybrid or blended course or program[12]. Development research on creating an integrated distance education system for the Silesian University of Technology was started in 2001, but the Internet was practically

[10] Han J., Pei J., Kamber M.: Data Mining: Concepts and Techniques. The Morgan Kaufmann Series in Data Management Systems, Elsevier Science, 2011.
[11] Moore M.G., Diehl W.C.: Handbook of Distance Education, Reutledge, 2018.
[12] Lok J.: Classroom Teaching Problems. Independently Published, 2020.

been used in education since the nineties of the past century. Technical possibilities using the Internet in education are in existence since 1991, the year of connection of polish academic networks to the worldwide Internet. The Silesian University of Technology was one of several first polish universities connected to the Internet in 1991. For the next years, Internet application in education has been more and more popular, especially in the Faculty of Automatic Control, Electronics and Computer Science and other faculties, where using personal computers in education was necessary[13]. For many years, systematizing and regularising all activities in distance learning at the whole University are necessary. It was the main purpose of the Distance Education Platform at the Silesian University of Technology[14]. Development research on creating an integrated distance education platform for the Silesian University of Technology was started in 2001, at the Institute of Electronics, Faculty of Automatic Control, Electronics and Computer Science. Research on this area was based on: testing the most popular application useful for distance education, checking possibilities of adapting distance learning software to University requirements, and attempting to select one (several) of them to construct a distance education service for the whole University. Tested applications can be classified into 3 categories: authoring applications: the web authoring tools, course authoring tools, media editors, content creators - software to create and integrate e-learning content (courses, web pages, multimedia files); web servers, database servers, media servers – software to make e-learning products (courses) available over a network, hosting, administrating, maintaining, supporting; access applications: e-learning client applications, web browsers, media players, communication tools – software to locate and experience e-learning products.

Distance education systems usually use specialized software such as: Learning Management Systems (LMS), Learning Content Management Systems (LCMS) or Virtual Learning Environments (VLE)[15]. A Learning Management System is a software package that enables the management and delivery of online content to learners. LMS are web-based to facilitate “any time, any place, any pace” access to learning content and administration. The characteristics of LMS include[16]: managing users, roles, courses, instructors, and facilities and generating reports; course calendar; learner messaging and notifications; assessment/testing capable of handling student pre/post-testing; display scores and transcripts; grading of coursework and roster processing; web-based or

[13] Wegerif R.: Education for The Internet Age, Reutledge, 2013.
[14] Kłosowski P. and Doś P.: “Zdalna edukacja – pomoc dla studentów i szansa dla wykładowców,” Biuletyn Politechniki Śląskiej, vol. nr 1/2016, 2016.
[15] Kats Y.: Learning Management System Technologies and Software Solutions for Online Teaching: Tools and Applications: Tools and Applications. IGI Global research collection, Information Science Reference, 2010.
[16] Kats Y.: Learning Management Systems and Instructional Design: Best Practices in Online Education. Premier reference source, IGI Global, 2013.

blended course delivery. As a result of provided research, the Distance Education Platform was created, as an effective, integrated e-learning service for all faculties of the Silesian University of Technology. A few virtual servers are integrated into one e-learning service for all educational units of the University. Currently on the Distance Education Platform at the Silesian University of Technology are available over 10000 online e-learning courses. The number of users exceeds 88000. In recent years, there has been a significant increase in the number of users and courses of the Distance Education Platform. This implies the need for mass distance education during the pandemic period. This trend was presented in Figures 13.1 and 13.2.

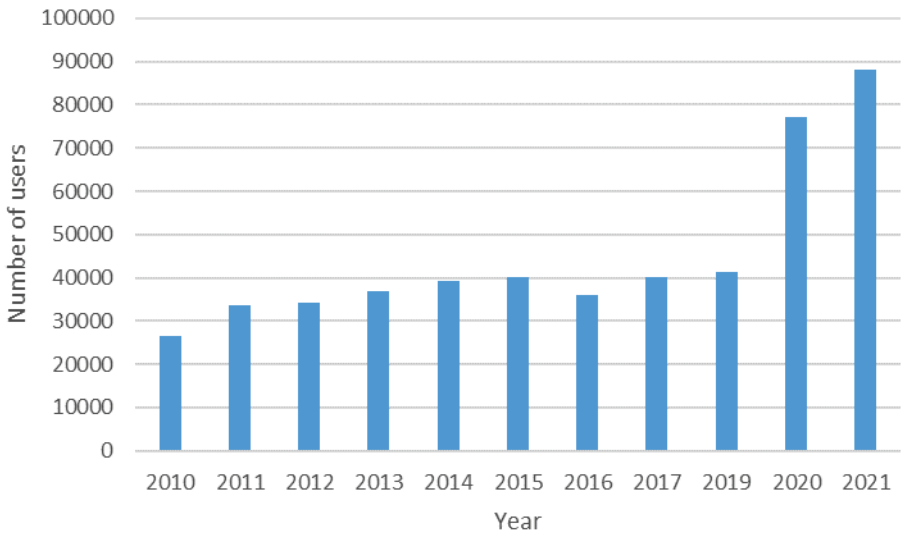

Fig. 13.1. Number of users on the Distance Education Platform in the years 2010–2021
Rys. 13.1. Liczba użytkowników Platformy Zdalnej Edukacji w latach 2010–2021
Source: own research.

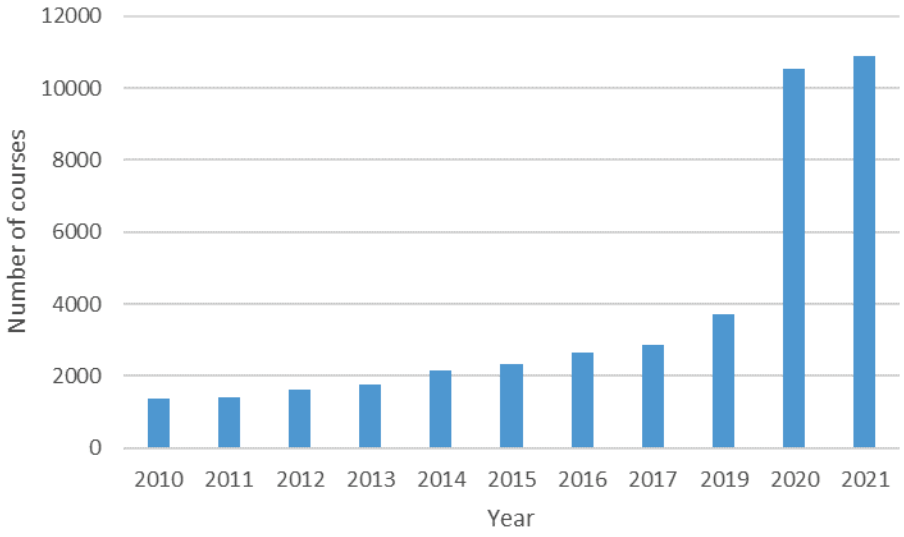

Fig. 13.2. Number of courses on the Distance Education Platform in the years 2010–2021
Rys. 13.2. Liczba kursów Platformy Zdalnej Edukacji w latach 2010–2021
Source: own research.

The Distance Education Platform works as a typically asynchronous e-learning service, but in the future, more synchronous e-learning services will be added. The exception to this is the pandemic period when most of the teaching process was done at a distance and synchronously. The most important features of the Distance Education Platform are: the easy creation of courses from existing resources, course content which can be re-used with different learners, including content from other vendors (Blackboard, WebCT etc.), a user-friendly environment, students enrolment and learner authentication are simple and secure, intuitive online learner and teacher management features. The Distance Education Platform is running on the following software configuration: FreeBSD operating system[17], Apache HTTP Server[18], PHP language interpreter[19], MySQL database server[20], Moodle learning management system[21]. The Distance Education Platform is based on a modular object-oriented dynamic learning environment named Moodle (www.moodle.org)[22], which represents LMS technology, a software package designed to help educators create high-quality online courses[23]. The Moodle software is an alternative to proprietary commercial online learning solutions and is distributed free under open source licensing[24]. The Silesian University of Technology has complete access to the source code and can make changes if needed. Moodle's modular design makes it easy to create new courses, adding content that will engage learners and to create courses for instructors. Students require only basic browser skills to begin learning. The Web front page of the Distance Education Platform of the Silesian University of Technology is presented in Figure 13.3.

The main advantages of Moodle LMS software are[25]: promotes a social constructionist pedagogy (collaboration, activities, critical reflection, etc.); suitable for 100% online classes as well as supplements face-to-face learning; simple, lightweight, efficient, compatible, low-tech browser interface; easy to install on almost any platform that supports PHP; requires only one database; full database abstraction supports all

[17] Lucas M.: Absolute FreeBSD, 2nd Edition: The Complete Guide to FreeBSD. No Starch Press, 2013; The FreeBSD Documentation Project: FreeBSD Porter's Handbook, (https://docs.freebsd.org/en/books/porters-handbook), 2022.
[18] Apache HTTP Server Project: Apache HTTP Server 2.4 Reference Manual, (https://httpd.apache.org/docs/2.4, 2022.
[19] Nixon R.: Learning PHP, MySQL, JavaScript, and CSS: A Step-by-Step Guide to Creating Dynamic Websites. O'Reilly Media, 2012.
[20] Widenius M., Axmark D., Arno K.: MySQL Reference Manual: Documentation from the Source. O'Reilly Series, O'Reilly Media, Incorporated, 2002.
[21] Schinkten O.: Learning Moodle 3.7. linkedin.com, 2019.
[22] Cole J., Foster H.: Using Moodle. Content management, O'Reilly, 2008.
[23] Kłosowski P. and Doś P.: Zdalna edukacja – pomoc dla studentów i szansa dla wykładowców, Biuletyn Politechniki Śląskiej, vol. nr 1/2016, 2016.
[24] Rice W.: Moodle: E-learning Course Development: a Complete Guide to Successful Learning Using Moodle. From technologies to solutions, Packt Publishing, 2006.
[25] Rice W.: Moodle: E-learning Course Development: a Complete Guide to Successful Learning Using Moodle. From technologies to solutions, Packt Publishing, 2006.

major brands of a database; course listing shows descriptions for every course on the server, including accessibility to guests; courses can be categorized and searched – one distance education system can support thousands of courses; emphasis on strong security throughout. Forms are all checked, data validated, cookies encrypted etc.; most text entry areas (resources, forum postings, journal entries etc.) can be edited using an embedded WYSIWYG HTML editor.

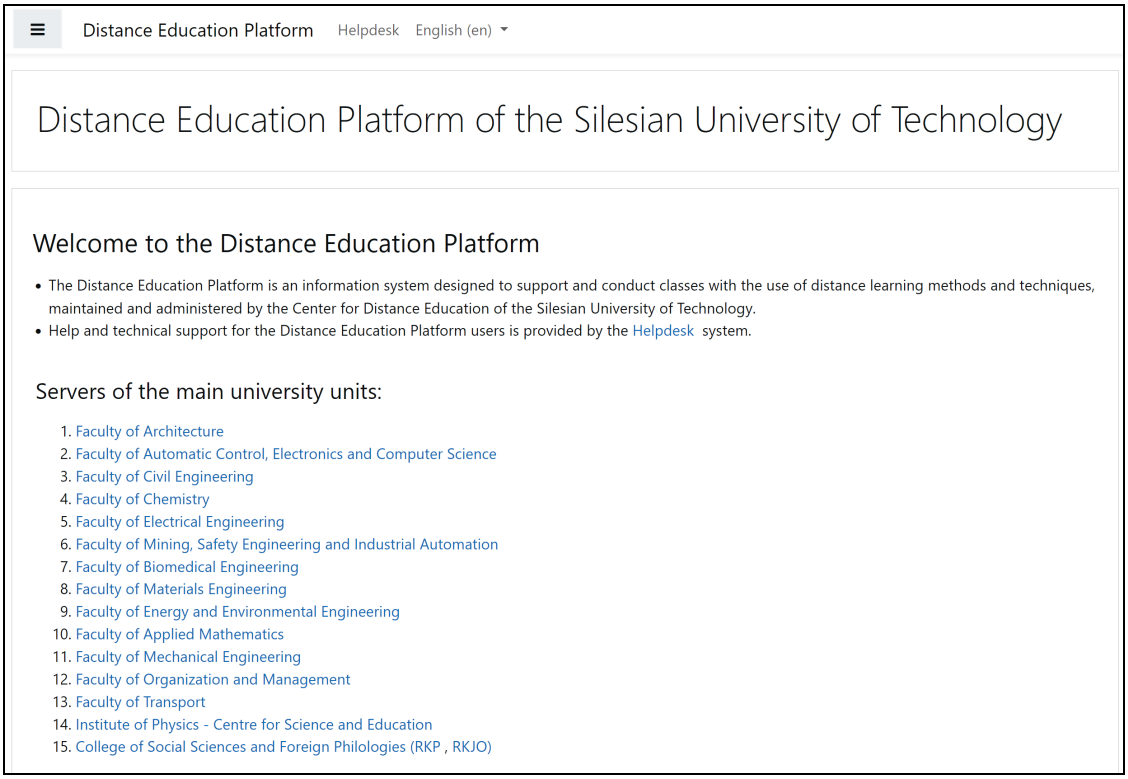

Fig. 13.3. The Web front page of the Distance Education Platform of the Silesian University of Technology
Rys. 13.3. Strona główna WWW Platformy Zdalnej Edukacji Politechniki Śląskiej
Source: https://platforma.polsl.pl/?lang=en

13.4. Preventing distance education infrastructure overload in crisis situation

Poland has fought the coronavirus pandemic with strict restrictions recommended by the World Health Organization to limit the number of infections as much as possible. The restrictions also affect members of the Polish academic community. Universities have suspended classes: lectures, exercises, laboratories and others – with the exception of online classes. Most universities, for the time of suspension of classes, have introduced solutions allowing for distance education. The organization of distance education

requires universities to provide adequate technological infrastructure and support in the use of information and communication technologies and e-learning tools by students. Ensuring adequate IT infrastructure is not an easy challenge as network devices and web servers experience record peak loads during the pandemic period. It can be seen that during this period, the load on servers increased more than 20 times compared to months of normal operation. This situation is presented in Figures 13.4, 13.5 and 13.6. Figures 13.4 and 13.5 show the monthly statistics of the Distance Education Platform in the months of the academic years 2019/20 and 2020/21 (Figure 13.4) and in individual months of September 2019 to February 2022 (Figure 13.5), expressed as the monthly number of distance education server references. The 24-hours server statistics during the period of increased load are presented in Figure 13.6, which shows the average daily number of server accesses in each hour of the day.

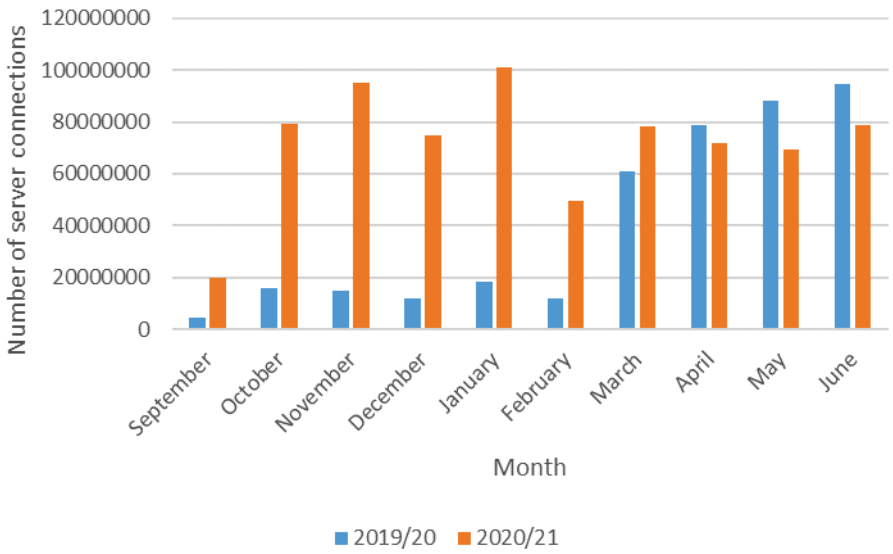

Fig. 13.4. Monthly statistics of the Distance Education Platform in the months of the academic years 2019/20 and 2020/21

Rys. 13.4. Miesięczne statystyki Platformy Zdalnej Edukacji w miesiącach roku akademickiego 2019/20 oraz 2020/21

Source: own research.

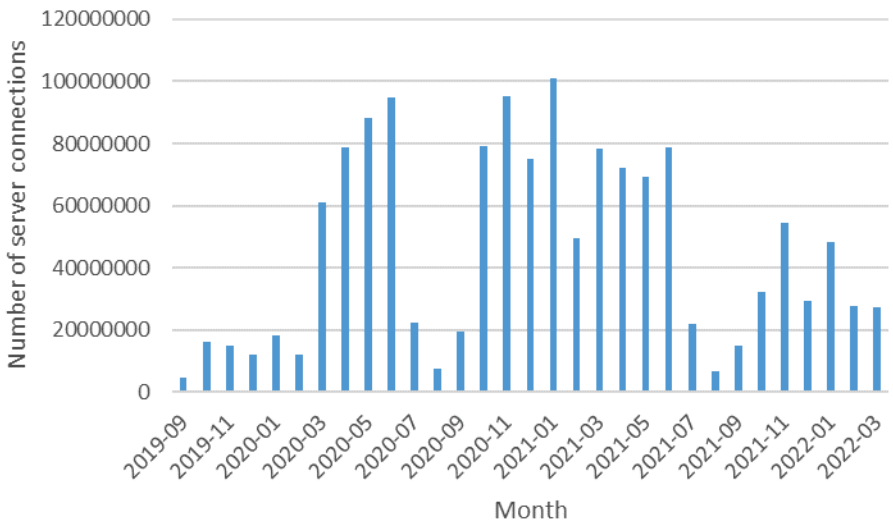

Fig. 13.5. Monthly statistics of the Distance Education Platform in the months of September 2019 to February 2022
Rys. 13.5. Miesięczne statystyki Platformy Zdalnej Edukacji w miesiącach od września 2019 r. do lutego 2022 r.
Source: own research.

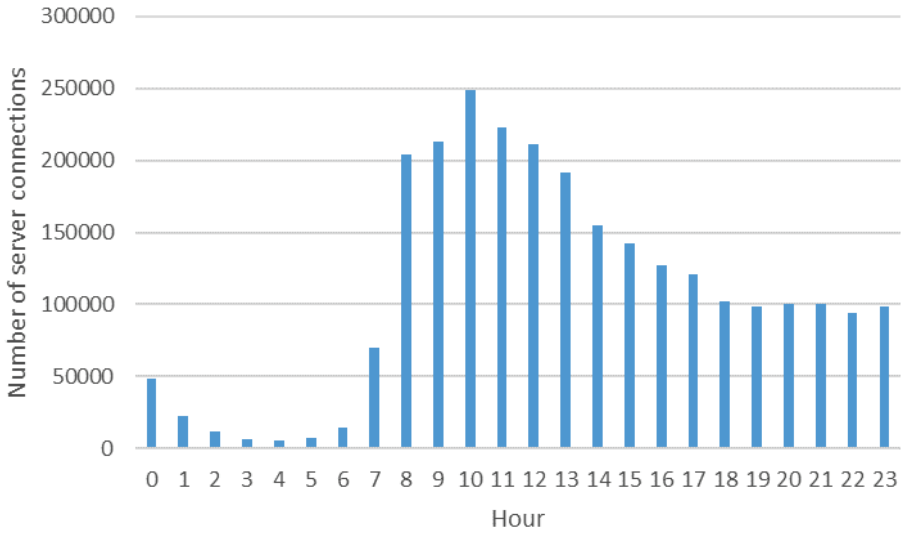

Fig. 13.6. Hourly average statistics of the Distance Education Platform
Rys. 13.6. Średnia dobowa statystyka Platformy Zdalnej Edukacji
Source: own research.

It seems that there are potentially great possibilities for using artificial intelligence to improve the performance of information systems and infrastructure in this difficult and demanding period. The use of artificial intelligence to improve the operation of the Distance Education Platform servers is potentially possible in the following areas: analysis and control of the current server operating parameters: server load, server resource utilization, data transfer rate, network utilization, energy consumption and

operating temperature, etc.; analysis of the server operating parameters in the past; analysis of a current server load; analysis of a server load in the past; prediction of the highest server load: monthly, weekly, daily, hourly; reserving server resources during a period of higher load; moving selected server tasks from periods of higher server load to periods of lower load; server load equalization: monthly, weekly, daily, hourly; balancing a daily server load and avoiding overloads; controlling of security and stability of server operation; improvement of back-end operations; improvement of front-end operations and user interface operation responsiveness.

In recent years, mass data analysis applications have been developed to improve the performance of cloud computing and network server infrastructure[26]. The most common methods of predicting performance are essentially divided into two categories: one of them focuses on building the relationship between performance and time, e.g. neural network (MLP), and the other linear[27], weighted multifactorial linear regression (MVLR)[28], and recursive neural network (RNN)[29] are even used long short-term memory (LSTM)[30]. Recently, deep neural networks are beginning to show their great potential in language processing and modelling[31]. Currently, the field of language modelling is shifting from statistical methods to neural networks and deep learning methods. Recent studies show that the neural network does not realize popular statistical algorithms to a small extent[32]. As a particular type of RNN, the LSTM neural network[33] has proved effective in modelling sequential data such as speech and text[34].

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[26] Buyya R., Ramamohanarao K., Leckie C., Calheiros R.N., Dastjerdi A.V., Versteeg S.: "Big data analytics-enhanced cloud computing: Challenges, architectural elements, and future directions," in Proceedings of the 21st IEEE International Conference on Parallel and Distributed Systems, ICPADS 2015, pp. 75–84.

[27] Islam S., Keung J., Lee K., Liu A.: "Empirical prediction models for adaptive resource provisioning in the cloud," Future Generation Computer Systems vol. 28 no. 1, 2012, pp. 155–162.

[28] Davis I., Hemmati H., Holt R.C., Godfrey M., Neuse D., Mankovskii S.: "Storm prediction in a cloud," in Proceedings of the 2013 5th International Workshop on Principles of Engineering Service-Oriented Systems, PESOS 2013, pp. 37–40.

[29] Luo B., Ye S.: "Server performance prediction using recurrent neural network," Computer Engineering and Design, vol. 8, 2005, p. 57.

[30] Song B., Yu Y., Wang Y.Z.Z., Du S.: "Host load prediction with long short-term memory in cloud computing," The Journal of Supercomputing, 2017, p. 1–15.

[31] Kłosowski P.: "Deep learning for natural language processing and language modelling," in Proceedings of the 22nd IEEE International Conference Signal Processing Algorithms, Architectures, Arrangements, and Applications, September 19–21, 2018, Poznan, Poland, 2018, pp. 223–228; Kłosowski P.: "Polish language modelling based on deep learning methods and techniques," in Proceedings of the 23rd IEEE International Conference Signal Processing Algorithms, Architectures, Arrangements, and Applications, September 18–20, 2019, Poznan, Poland, 2019, pp. 223–228; Auli M., Galley M., Quirk C. and Zweig G.: "Joint language and translation modeling with recurrent neural networks," Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing, 2013, pp. 1044–1054.

[32] Osawa M., Yamakawa H., Imai M.: "In implementation of working memory using stacked half restricted Boltzmann machine: Toward to restricted Boltzmann machine-based cognitive architecture," in Neural Information Processing – 23rd International Conference, ICONIP 2016, Proceedings, vol. 9947 LNCS, (Germany), pp. 342–350, Springer Verlag, 2016. 23rd International Conference on Neural Information Processing, ICONIP 2016 ; Conference date: 16-10-2016 Through 21-10-2016.

[33] Hochreiter S., Schmidhuber J.: "Long short-term memory," Neural Computation, vol. 9, no. 8, 1997, p. 1735–1780.

These previous studies have inspired us to use LSTMs in these predictive tasks, as the user's query data is quantifiable. To improve the predictive performance of the webserver and workload can be used RNN-LSTM with vector queries for this task.

The following sample experiments and results show that it is possible to use artificial intelligence to improve distance education server performance. The purpose of the first experiment is to predict the distance education server load. The obtained results allow providing the second experiment which aims at balancing the daily distance education server load and avoiding overloads. The purpose of the first experiment was to try to predict the hourly load distribution of distance education servers based on load statistics recorded in the past. In the last few months, admins have collected website access logs and server uptime logs and processed these two files, combining transactions and average load that occur at the same interval. The collected data were then used as training samples. Each line of the sample training file contains information about time, number of unique IP addresses, total content size, protocol and average load of the last 1, 5 and 15 minutes. The main goal of the experiment was to predict the distance education server load based on time. The problem of predicting server load based on time alone would be extremely difficult to solve. So we decided to divide this problem into two parts, one designed to predict server load, and the other to predict user activity based on time. The output we tested was selected as a 1-minute average server load because the uptime command was run on the server every 1 minute. Figure 13.7 presents the predicted and real average server load at each hour of a day, calculated based on the experiment results. On the vertical axis, the values of server load are marked and on the horizontal axis the individual hours of server operation.

[34] Sundermeyer M., Ney H., Schluter R.: "From feedforward to recurrent LSTM neural networks for language modeling," IEEE Transactions on Audio, Speech and Language Processing, vol. 23, no. 3, 2015, p. 517–529.

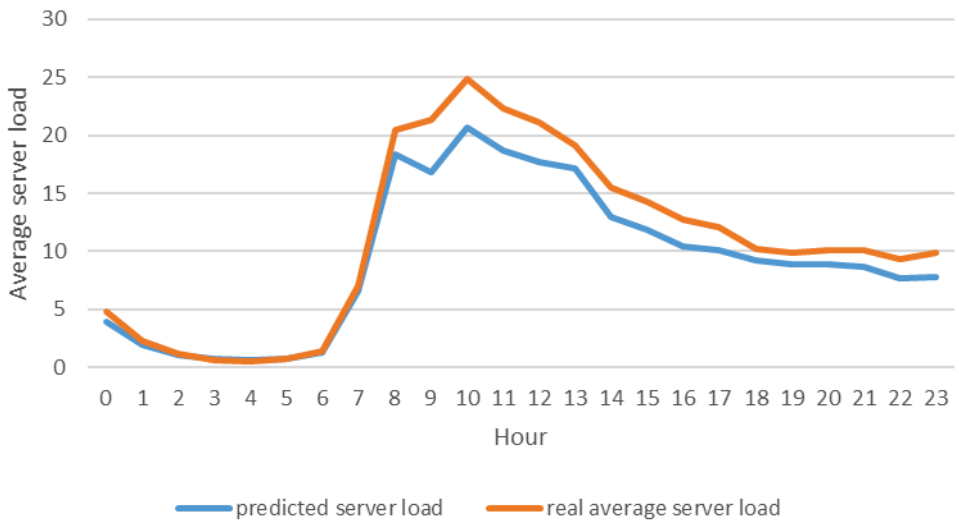

Fig. 13.7. Hourly distance education server load prediction results
Rys. 13.7. Prognozowanie dobowego rozkładu obciążenia serwera zdalnej edukacji
Source: own research.

As can be seen in Figure 13.7, the shape of the server load distribution was predicted correctly, but the real average server load values were higher than expected. The reason is that the real average server load in the tested month was much higher than in the training months. However, it is noteworthy that the server load distribution curve was predicted correctly, and this fact allowed for further actions to be taken using artificial intelligence to improve the performance and better operation of the server during individual hours of the day. An attempt to do so was made in the next experiment described below.

The second experiment part aimed to equalize daily server load to avoid overloads. The experiment involves using artificial intelligence techniques to decide which tasks performed by the server can be postponed and performed when the server is less loaded. This will reduce the probability of server overload and make the load on the server more evenly distributed all day. The basic and essential thing is to choose the time and date of the postponed server tasks. The data obtained in the previous experiment, i.e. prediction of the server load at home, is here necessary and crucial. The results of the following experiment were presented in Figures 13.8 and 13.9. On the vertical axis, the values of server load are marked and on the horizontal axis the individual hours of server operation.

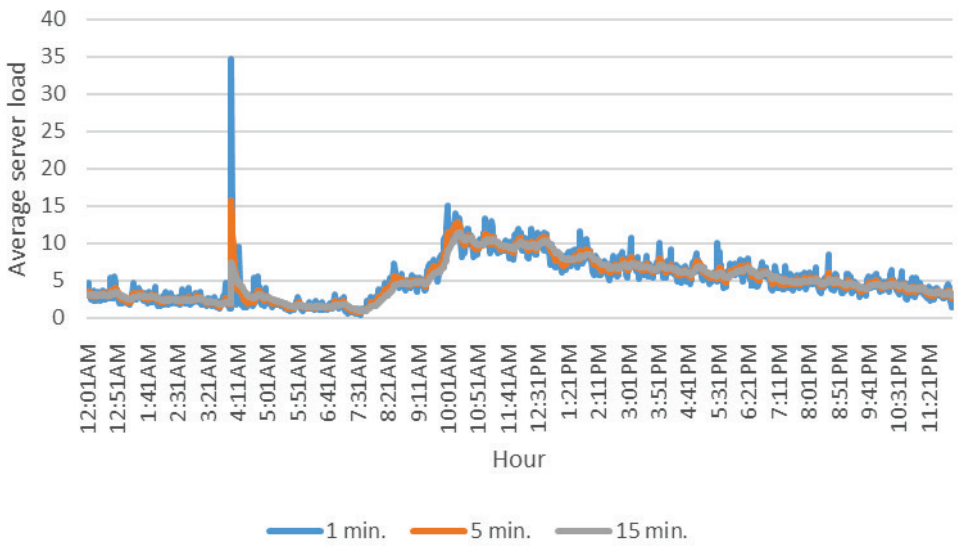

Fig. 13.8. Hourly distance education server load before improvements
Rys. 13.8. Dobowy rozkład obciążenia serwera zdalnej edukacji przed wprowadzeniem usprawnień
Source: own research.

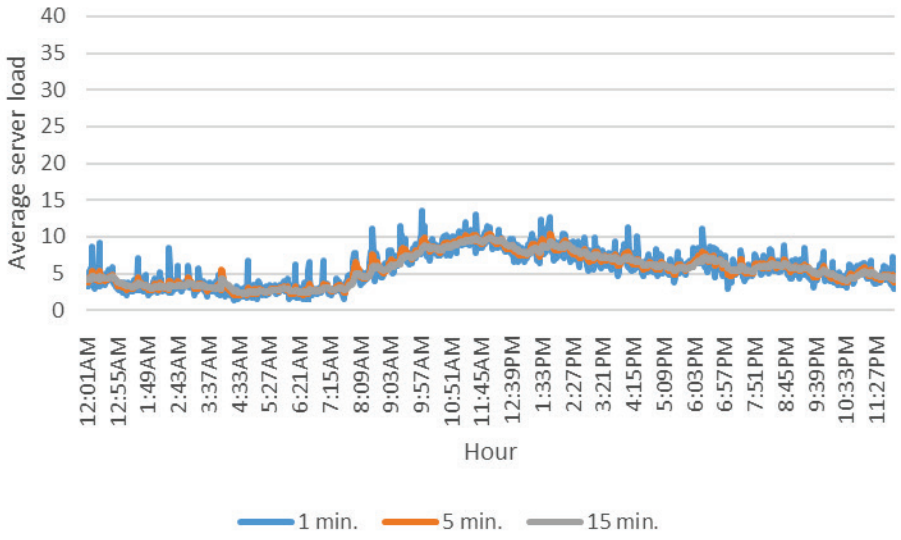

Fig. 13.9. Hourly distance education server load after improvements
Rys. 13.9. Dobowy rozkład obciążenia serwera zdalnej edukacji po wprowadzeniu usprawnień
Source: own research.

Figures 13.8 and 13.9 show the hourly load distribution of the server for the whole day before and after improvements. It is easy to see that the application of the improvements resulted in a more even distribution of the server load during the day and a sudden increase in the server load could have been avoided, even though on the day when the improvements were applied the server load was much higher than on the

day without the improvements. This is evidenced by the data presented in Figures 13.10 and 13.11. Figure 13.10 presents the values of maximum distance education server load before and after improvements, and Figure 13.11 presents average values.

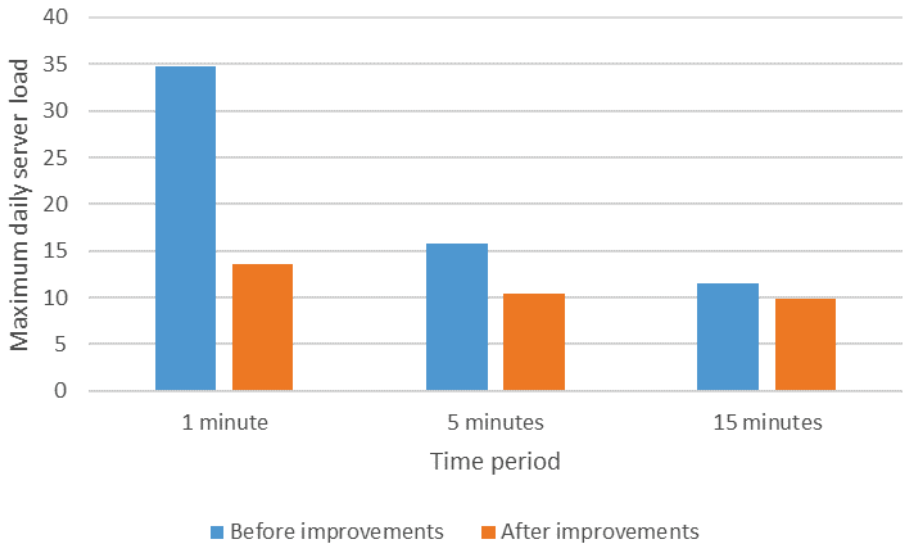

Fig. 13.10. Maximum distance education server load before and after improvements
Rys. 13.10. Maksymalne obciążenie serwera zdalnej edukacji przed i po wprowadzeniu usprawnień
Source: own research.

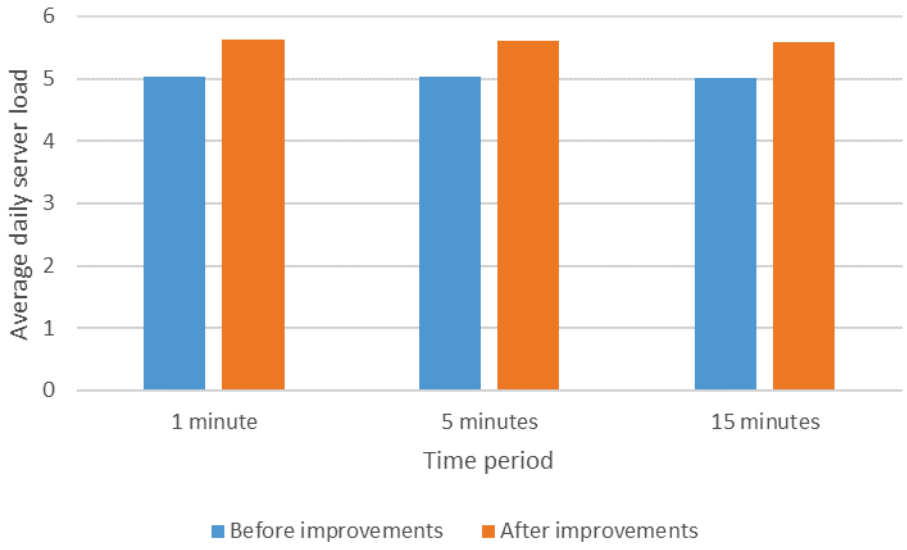

Fig. 13.11. Average distance education server load before and after improvements
Rys. 13.11. Średnie obciążenie serwera zdalnej edukacji przed i po wprowadzeniu usprawnień
Source: own research.

13.5. Conclusions

The efficient provision of network services for a large number of users, as is the case in distance education, depends closely on the performance and reliability of the network and server infrastructure. The situation becomes more complicated when the demand for services increases significantly, as was the case during the coronavirus pandemic. The issues described in the article show that improving server operation and performance, especially in a period of extreme loads, is a complex problem and very difficult to solve effectively. The problem is further compounded by the fact that daily demands for computing power and server resources are a random variable and are not known. The examples of experiments presented in the article show that the use of artificial intelligence techniques helps not only to predict the daily demand for computing power and resources of the distance education server but can also effectively contribute to improving the security of distance education server operation by reserving the computing power of the server and server resources and making them available when necessary. The obtained results are very promising and give the prospect of further research and can be applied in improving the functioning of the ICT infrastructure as a key technology in the development of a smart city. Therefore the research will continue particularly in the area of the use of artificial neural networks and deep learning to model server load and performance prediction of network servers to improve the reliability of ICT infrastructure and the operation of network servers.

13.6. Acknowledgements

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Antonio APIYO[1], Jacek IZYDORCZYK[2]

14. NOMA – AIDED CELL-FREE MASSIVE MIMO – A REVIEW

14.1. Introduction

According to CISCO Annual Internet Report (2018-2023) white paper, over 70% of the global population will have mobile connectivity by 2023 with global mobile devices growing from 8.8 billion to 13.1 billion by 2023 and the number of Internet-enabled devices will have increased to 29.3 billion, with 1.4 billion of those will be Fifth Generation (5G) capable[3]. It further reiterates that the fastest-growing mobile device category is Machine-to-Machine (M2M), which is a key enabler in Smart Cities (SCs).

SC will require a suitable wireless communications system that will provide high data rates, reliability, flexibility, low-latency, massive connectivity, security and among other adaptive functionalities[4]. This growth and demand will eventually overwhelm the network capabilities of the Fourth Generation (4G) and 5G wireless networks. Therefore, there is a need for new targets in terms of network performances for the next generation of wireless networks, also known as Sixth Generation (6G) especially in smart cities (SCs). SC operations can be made possible by faster adoption of strategies brought by the expanded scope of 6G core technologies.

6G networks is expected to have network performance such as increasing the peak data rate to 1 terabit per second, increasing the experienced rate for highly mobile users

[1] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics.
[2] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Department of Telecommunications and Teleinformatics, e-mail: jacek.izydorczyk@polsl.pl.
[3] Cisco: Cisco Annual Internet Report (2018–2023) White Paper, Mar 2020. [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paperc11-741490.html.
[4] Al Amin A., Hong J., Bui V.H., Su W.: Emerging 6G/B6G Wireless Communication for the Power Infrastructure in Smart Cities: Innovations, Challenges, and Future Perspectives. Algorithms, 16(10) 2023, p. 474.

to 1 Gbps, increasing connection density to 10^7 devices/km^2, decreasing air latency to 0.1 ms, and improving network reliability to 10^{-7} [5].

To achieve the above-mentioned stringent targets, 6G wireless communications networks will require advanced physical layer solutions, new advanced modulation schemes, advanced multiple access techniques, energy harvesting, edge computing, new spectral bands, integration of terrestrial and non-terrestrial communications, cell-free massive Multiple Input Multiple Output (MIMO), blockchain and quantum technologies and adoption of artificial intelligence and machine learning techniques[6].

In conventional mobile networks, a coverage area is divided into cells, with each cell served by one Base Station (BS). One of the key limitations of cellular networks is intercell interference. In addition, users at the cell boundaries perform badly due to strong inter-cell interference limiting the performance of the whole network. Cell-Free Massive MIMO first appeared in 2015[7]. It was proposed to overcome the inter-cell interference in cellular networks[8]. Cell-Free Massive MIMO (CF-mMIMO) has attracted a lot of interest as a potential enabling technology for the envisioned 6G network[9]. In addition, it suggests[10] a cell-free and mesh connectivity as possible 6G architectures. Cell-free massive MIMO (CF-mMIMO) systems and integration between terrestrial and non-terrestrial communications are effective techniques to increasing connectivity and providing full coverage. CF-mMIMO solution is a suitable technique for the next generation indoor and outdoor scenarios. In cell-free systems, the users are surrounded by Access Points (APs) eliminating cell-edges and the traditional notion of edge user suffering the worst performance. Importantly, CF-mMIMO reaps all the benefits of

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[5] You X., Wang C.X., Huang J. et al.: Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts. Sci. China Inf. Sci. 64, 2021, 110301. https://doi.org/10.1007/s11432-020-2955-6; Saghezchi F.B., Rodriguez J., Vujicic Z., Nascimento A., Huq K.M.S., Gil-Castiñeira F.: Drive Towards 6G. [In:] Rodriguez J., Verikoukis C., Vardakas J.S., Passas N. (eds): Enabling 6G Mobile Networks. Springer, Cham 2022. https://doi.org/10.1007/978-3-030-74648-3_1.

[6] Alsabah M. et al.: 6G Wireless Communications Networks: A Comprehensive Survey, in IEEE Access, Vol. 9, 2021, pp. 148191–148243, DOI: 10.1109/ACCESS.2021.3124812.

[7] Ngo H.Q., Ashikhmin A., Yang H., Larsson E.G., Marzetta T.L.: Cell-Free Massive MIMO: Uniformly great service for everyone, 2015 IEEE 16th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 2015, pp. 201-205, DOI: 10.1109/SPAWC.2015.7227028; Nayebi E., Ashikhmin A., Marzetta T.L. Yang H.: Cell-Free Massive MIMO systems, 2015 49th Asilomar Conference on Signals, Systems and Computers, 2015, pp. 695–699, DOI: 10.1109/ACSSC.2015.7421222.

[8] Ngo H.Q., Ashikhmin A., Yang H., Larsson E.G., Marzetta T.L.: Cell-Free Massive MIMO: Uniformly great service for everyone, 2015 IEEE 16th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 2015, pp. 201–205, DOI: 10.1109/SPAWC.2015.7227028.

[9] Akyildiz I.F., Kak A., Nie S.: 6G and Beyond: The Future of Wireless Communications Systems, in IEEE Access, Vol. 8, pp. 133995–134030, 2020, DOI: 10.1109/ACCESS.2020.3010896; Tataria H., Shafi M., Molisch A.F., Dohler M. Sjöland H., Tufvesson F.: 6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities, in Proceedings of the IEEE, Vol. 109, no. 7, pp. 1166–1199, July 2021, DOI: 10.1109/JPROC.2021.3061701.

[10] Viswanathan H., Mogensen P.E.: Communications in the 6G Era, in IEEE Access, Vol. 8, pp. 57063-57074, 2020, DOI: 10.1109/ACCESS.2020.2981745; Ziegler V., Viswanathan H., Flinck H., Hoffmann M., Räisänen V., Hätönen K.: 6G Architecture to Connect the Worlds, in IEEE Access, Vol. 8, pp. 173508-173520, 2020, DOI: 10.1109/ACCESS.2020.3025032.

network MIMO solutions and key properties of massive MIMO can be beneficially exploited for supporting scalable implementations. In addition to these, further improvements on the system performance in-terms of achievable data-rates, reliability, security among others can be achieved to ensure path to target requirements of 6G networks by integrating CF-mMIMO systems with emerging technologies, such as non-orthogonal multiple-access (NOMA), reconfigurable intelligent surfaces, radio stripes, machine learning, and many others.

On the other hand, NOMA, also as an emerging technology, is a promising one in the next generations wireless communications. While orthogonal multiple access schemes have number of served users limited by the available orthogonal resources, NOMA enables serving of more users than the available resources at the expense of increasing complexity of the receivers. NOMA benefits include massive connectivity, low latency, improved spectral performance and relaxed channel feedback[11].

Given the distinctive benefits of Cell-free massive MIMO and NOMA, the integration of these two techniques is worth investigating to inherit the important advantages of both in order to achieve the stringent demands of 6G and SCs. However, the coexistence of the two technologies remains an issue worth researching especially as key technology applications for 6G wireless communication in SCs.

In the next section, we provide literature of Cell-free massive MIMO and NOMA. In addition, we analyze the state-of-art and provide a simple system model of NOMA-aided Cell-Free massive MIMO.

14.2. Literature review

14.2.1. Cell-Free Massive MIMO Fundamentals

CF-mMIMO networks consist of many distributed Access Points (APs) connected to a central processing unit (CPU) and they jointly serve all the user equipment (UEs)

[11] Shin W., Vaezi M., Lee B., Love D.J., Lee J., Poor H.V.: Non-Orthogonal Multiple Access in Multi-Cell Networks: Theory, Performance, and Practical Challenges, in IEEE Communications Magazine, Vol. 55, no. 10, pp. 176–183, Oct. 2017, DOI: 10.1109/MCOM.2017.1601065; Saito Y., Kishiyama Y., Benjebbour A., Nakamura T., Li A., Higuchi K.: Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access, 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), 2013, pp. 1–5, DOI: 10.1109/VTCSpring.2013.6692652; Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558; Cai Y. , Qin Z., Cui F., Li G.Y., McCann J.A.: Modulation and Multiple Access for 5G Networks, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 1, pp. 629–646, Firstquarter 2018, DOI: 10.1109/COMST.2017.2766698.

within the network simultaneously[12]. Each AP is connected via a fronthaul link to a CPU which is responsible for AP cooperation. The Cell-Free network can be divided into an edge or a core. The edge is comprised of the APs, CPUs, and the fronthaul links, while the core network facilitates all the services requested by UE. The connections between core and edge are called backhaul links. Thence the CPU communicates with the core network via backhaul links. The figure below shows a simple CF-mMIMO network architecture[13].

The word "Cell-Free" means that there are no cell boundaries that exist from a UE perspective during uplink and downlink transmission since all APs that affect a UE will take part in the communication[14]. CF-mMIMO can be viewed as an overarching concept focused on CF networks but which contains convectional massive MIMO, convectional coordinated multipoint (COMP), and convectional ultra-dense networks as three special cases.

[12] Ngo H.Q., Ashikhmin A., Yang H., Larsson E.G., Marzetta T.L.: Cell-Free Massive MIMO Versus Small Cells, in IEEE Transactions on Wireless Communications, Vol. 16, no. 3, pp. 1834–1850, March 2017, DOI: 10.1109/TWC.2017.2655515; He H., Yu X., Zhang J., Song S.H., Letaief K.B.: Cell-Free Massive MIMO for 6G Wireless Communication Networks. arXiv 2021 preprint arXiv:2110.07309; Shaik Z.H., Björnson E., Larsson E.G.: Cell-Free Massive MIMO with Radio Stripes and Sequential Uplink Processing, 2020 IEEE International Conference on Communications Workshops (ICC Workshops), 2020, pp. 1–6, DOI: 10.1109/ICCWorkshops49005.2020.9145164; Yang H., Marzetta T.L.: Energy Efficiency of Massive MIMO: Cell-Free vs. Cellular, 2018 IEEE 87th Vehicular Technology Conference (VTC Spring), 2018, pp. 1–5, DOI: 10.1109/VTCSpring.2018.8417645; Interdonato G., Björnson E., Ngo H.Q., Frenger P., Larsson E.G.: Ubiquitous cell-free massive MIMO communications. EURASIP Journal on Wireless Communications and Networking, 2019(1), 1–13; Ngo H.Q., Tran L., Duong T.Q., Matthaiou M., Larsson E.G.: On the Total Energy Efficiency of Cell-Free Massive MIMO, in IEEE Transactions on Green Communications and Networking, Vol. 2, no. 1, pp. 25–39, March 2018, DOI: 10.1109/TGCN.2017.2770215; Demir Ö.T., Björnson E., Sanguinetti L.: Foundations of User-Centric Cell-Free Massive MIMO, Foundations and Trends in Signal Processing: Vol. 14, No. 3–4, 2021, pp. 162–472. DOI: 10.1561/2000000109; Zhang J., Chen S., Lin Y., Zheng J., Ai B., Hanzo L.: Cell-Free Massive MIMO: A New Next-Generation Paradigm, in IEEE Access, Vol. 7, 2019, pp. 99878–99888, DOI: 10.1109/ACCESS.2019.2930208; Elhoushy S., Ibrahim M. Hamouda W.: Cell-Free Massive MIMO: A Survey, in IEEE Communications Surveys & Tutorials, DOI: 10.1109/COMST.2021.3123267.

[13] Interdonato G., Björnson E., Ngo H.Q., Frenger P., Larsson E.G.: Ubiquitous cell-free massive MIMO communications. EURASIP Journal on Wireless Communications and Networking, 2019(1), 1–13; Zhang J., Chen S., Lin Y., Zheng J., Ai B., Hanzo L.: Cell-Free Massive MIMO: A New Next-Generation Paradigm, in IEEE Access, Vol. 7, 2019, pp. 99878–99888, DOI: 10.1109/ACCESS.2019.2930208.

[14] Demir Ö. T., Björnson E., Sanguinetti L.: Foundations of User-Centric Cell-Free Massive MIMO, Foundations and Trends in Signal Processing: Vol. 14, No. 3–4, 2021, pp. 162–472. DOI: 10.1561/2000000109.

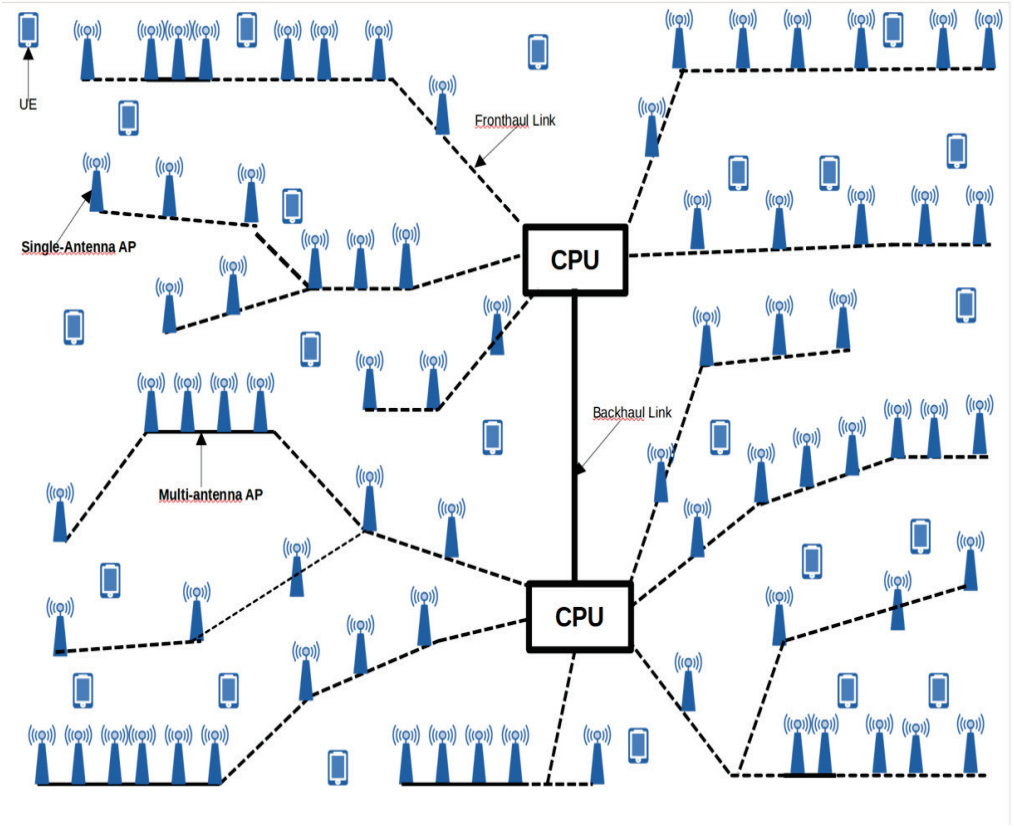

Fig. 14.1. Cell-Free Massive MIMO network
Rys. 14.1. Masywna sieć MIMO bez komórek
Source: based on Interdonato G., Björnson E., Ngo H.Q., Frenger P., Larsson E.G.: Ubiquitous cell--free massive MIMO communications. EURASIP Journal on Wireless Communications and Networking, 2019(1), 1–13; Zhang J., Chen S., Lin Y., Zheng J., Ai B., Hanzo L.: Cell-Free Massive MIMO: A New Next-Generation Paradigm, in IEEE Access, Vol. 7, 2019, pp. 99878–99888, DOI: 10.1109/ACCESS.2019.2930208.

The distinguishing features of Cell-Free architecture are: firstly, Time Division Duplex (TDD) protocol used to exploit channel reciprocity on the uplink and downlink. Secondly, uplink channels estimate computed locally at each AP based on the pilot signals transmitted from users and exploited locally, so that they are not sent on the backhaul link. Third, the beamformers used at the APs, computed locally and not at the CPU. Lastly, the backhaul is used to send data symbols on the downlink and sufficient statistics on the uplink to perform centralized uplink data decisions.

Communication Protocol: TDD Operation

As in convectional mMIMO, in CF-mMIMO, TDD operation is preferred because the channel estimation overhead in TDD operation is independent of the number of APs. It only depends on the number of users. This makes CF-mMIMO scalable since adding more APs will not affect the operation of the channel estimation and is always beneficial for increased data rate. Through reciprocity principle, the uplink channel estimates are

treated as the downlink channels thus the uplink channels can be used for detection in the uplink and for processing the transmit signals in the downlink. The TDD transmission protocol is shown in Figure 14.2.

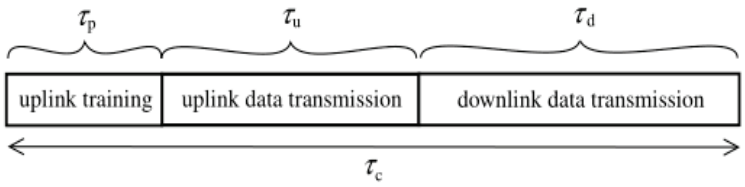

Fig. 14.2. TDD Transmission protocol
Rys. 14.2. Protokół transmisji TDD

The coherence interval which its length is denoted by τ_c has three activities: uplink training (τ_p symbols), uplink data transmission (τ_u symbols) and downlink data transmission (τ_d).

In uplink training phase, all users first send their pilot sequences of length τ_p symbols to the APs. Then each AP estimates all its channels to the users for the received pilot signals. As in[15], we denote by $\phi_k \in C^{N_{UE}\times\tau_p}$ the pilot sequence sent by the k-th UE, and the rows of ϕ_k are assumed to be orthogonal, i.e., $\phi_\kappa \phi_\kappa^D = I_s$. Since more than one UE might be assigned to each pilot sequence, we denote the index of pilot assigned to UE k as $t_k \in \{1, \dots, \tau_p\}$. The received signal at AP l during the entire pilot transmission is denoted as $y_l^{PILOT} \epsilon^{N\times\tau_p}$ and is given by:

$$Y_l^{PILOT} = \sum_{i=1}^{K} \sqrt{\eta_i} h_{il} \phi_{t_i}^T + N_l \tag{2.1}$$

where $N_l \in \mathbb{C}^{N\times\tau_p}$ is the receiver noise with i.i.d elements distributed as $N_C(0, \sigma_{UL}^2)$. The received uplink signal is the observation that AP l can use to estimate the channel. The estimation can either be carried out directly at AP l or be delegated to the CPU where the AP acts as the relay and sends the received pilot signals to the CPU via the fronthaul link.

To estimate the channel, h_{kl} (either at AP or at the CPU), based on the received pilot signal Y_l^{PILOT}, we remove the interference from UEs using orthogonal pilots by

[15] Akyildiz I.F., Kak A., Nie S.: 6G and Beyond: The Future of Wireless Communications Systems, in IEEE Access, Vol. 8, pp. 133995-134030, 2020, DOI: 10.1109/ACCESS.2020.3010896.

multiplying the received signal y_l^{PILOT} with the normalized conjugate of the associated pilot ϕ_{tk} yielding:

$$y_{t_k l}^{PILOT} = y_l^{PILOT} \phi_{t_k}^H = \sqrt{\eta_k \tau_p} h_{k_l} + \sum_{i \in P_k / \{K\}} \sqrt{\eta_i \tau_p} h_{il} + n_{t_k l} \tag{2.2}$$

where the first term is the desired part, the second is interference and the third is the noise. Usually, linear minimum mean-square error estimation (MMSE) technique is used. It exploits channel statistics to obtain good estimates. When the coherence interval is large, compared to the number of users, then we choose $\tau_p > K$, and the pilot sequence can then be assigned for the K users' pair wisely orthogonally. Or else, nonorthogonal pilot sequences must be used throughout the network. The channel estimates of a given user will then be contaminated by pilot signals transmitted from other users, degrading the system performance even if the number of APs is very large. This effect is called the Pilot Contamination.

In the uplink payload data transmission, all users simultaneously send their signals to the APs. The data bearing signal $x_{u,k} \in \mathbb{C}$ with $\mathbb{E}\left\{\left|x_{u,k}\right|^2\right\} = 1$ is sent by the k-th user and is mutually independent, and independent of noise and channel coefficients. The normalized transmit power is denoted by ρ_u. The received signal at the m-th AP is:

$$y_{u,m} = \sqrt{\rho_u} \sum_{k=1}^{K} g_{mk} \sqrt{\eta_k} x_{u,k} + n_{u,m} \tag{2.3}$$

where $n_{u,m} \sim \mathcal{CN}(0,1)$ is additive noise. Each AP uses its local channel estimates to process the received signals and sends the processed signals to the CPU. The APs m multiplies $y_{u,m}$ by $\hat{g}_{mk}^*$ (conjugate beamforming/matched filtering). The CPU then detects all signals transmitted from all M APs the signal of the k-th user as:

$$r_{u,k} = \sum_{m=1}^{M} \hat{g}_{mk}^* y_{u,m} = \sqrt{\rho_u} \sum_{k'=1}^{K} \sum_{m=1}^{M} \hat{g}_{mk}^* g_{mk'} x_{u,k'} + \sum_{m=1}^{M} \hat{g}_{mk}^* n_{u,m} \tag{2.4}$$

Simple linear processing like maximum ratio processing is recommended at each AP. Also, signal processing can be done at the CPUs. The APs need to forward their channel estimates and record data to the CPU for signal detection.

Finally, in the downlink payload data transmission, the APs use their local channel estimates to precode the symbols intended for all K users and broadcast the precoded versions to the users. The data symbol is $x_{d,k} \in \mathbb{C}$ with $\mathbb{E}\left\{\left|x_{d,k}\right|^2\right\} = 1$. The m-th AP sends the data-bearing signal for all K users as:

$$y_{dm} = \sqrt{\rho_d} \sum_{\kappa=1}^{K} \hat{g}_{mk}^{*} x_{d,k} \tag{2.5}$$

Each user then detects the desired symbol from the received signals. Linear processing such as maximum ratio/conjugate beamforming can be use at each AP. The received signal is given by:

$$r_{dk} = \sum_{m=1}^{M} g_{mk} y_{d,m} + n_{d,k} = \sqrt{\rho_d} \sum_{m=1}^{M} \sum_{k^{+}=1}^{K} g_{mk} \hat{g}_{mk'}^{*} x_{dk'} + n_{d,k} \tag{2.6}$$

CF-mMIMO is expected to bring important benefits such as huge data throughput, ultra-low latency, ultra-high reliability, high energy efficiency and uniform coverage, flexible and cost-efficient deployment, channel hardening and favorable propagation conditions and appealing uniform quality of service[16].

Despite the benefits, CF-mMIMO still faces some challenges and limitations. First, they are practical implementations in which the system requires huge backhaul connections, especially when the number of APs is very large hence suitable transmission approaches are required. User-centric approach is a possible solution, though the performance can't outperform traditional CF-mMIMO in overloaded cases, where the number of UEs is larger than APs. Also, multiple CPUs can be used. Secondly, synchronization of the system is needed so that all APs can coherently serve all the users. Finally, CF-mMIMO is susceptible to pilot contamination which significantly degrades the system performance.

Suggestions have been made to further improve the performance of CF-mMIMO in-terms of achievable data rates, reliability, security, and connection density by integrating CF-mMIMO systems with emerging technologies[17]. These technologies include Non-Orthogonal Multiple Access (NOMA) – our focus, Physical Layer Security

[16] Interdonato G., Björnson E., Ngo H.Q., Frenger P., Larsson E.G.: Ubiquitous cell-free massive MIMO communications. EURASIP Journal on Wireless Communications and Networking, 2019(1), 1–13; Zhang J., Chen S., Lin Y., Zheng J., Ai B., Hanzo L.: Cell-Free Massive MIMO: A New Next-Generation Paradigm, in IEEE Access, Vol. 7, 2019, pp. 99878–99888, DOI: 10.1109/ACCESS.2019.2930208.

[17] He H., Yu X., Zhang J., Song S.H., Letaief K.B.: Cell-Free Massive MIMO for 6G Wireless Communication Networks. arXiv 2021 preprint arXiv:2110.07309; Elhoushy S., Ibrahim M. Hamouda W.: Cell-Free Massive MIMO: A Survey, in IEEE Communications Surveys & Tutorials, DOI: 10.1109/COMST.2021.3123267.

(PLS), Reconfigurable Intelligent Surfaces (RIS), Radio Stripes system, Federated Learning, Machine Learning and Unmanned Aerial Vehicle (UAV).

Features of CF-mMIMO

CF-mMIMO inherits the benefits and features of mMIMO and provides more features than mMIMO. In addition to channel hardening and favourable propagation that it inherits from mMIMO, it has macro diversity and signal spatial sparsity as two more distinctive features than mMIMO.

- Channel Hardening – it is the effect of small-scale fading which is averaged out, and devices' channels behave a deterministic like wired channel as the number of antennas approaches infinity.
- Favourable Propagation – it is the channel of different devices become orthogonal as number of antennas approaches infinity, which makes different devices distinguishable in space.
- Macro Diversity – it is a signal combination method that combines multiple copies of the same signal into one powerful signal. Macro diversity gain is increased as APs are geographically distributed with several neighbouring APs each surrounding each device other. This leads to a reduced distance from device to any nearest AP as compared to mMIMO.
- Signal Spatial Sparsity – the signal of a device to different APs undergoes different levels of large-scale fading with neighbouring APs in the vicinity of a device usually capture more significant signal energy than other APs. This results in only neighbouring APs within a communication range of a device have non-negligible channel gains due to macro diversity leading to signal spatial sparsity.

13.2.2. NOMA Fundamentals

Multiple Access Schemes are used to allow mobile users to share simultaneously a finite amount radio spectrum to achieve high capacity by simultaneously allocating available bandwidth to multiple users. This should be done without degradation in the performance of the system.

Generally, Multiple Access Schemes can be broadly categorized into orthogonal and non-orthogonal approaches. Different multiple access schemes are discussed in [18].

[18] Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558; Cai Y., Qin Z., Cui F., Li G.Y., McCann J.A.: Modulation and Multiple Access

In Orthogonal Multiple Access (OMA) system, orthogonal resource allocation is used among users to avoid intra-cell (inter-user) interference. The number of users that can be supported in then limited by the number of orthogonal resources available.

Non-Orthogonal Multiple Access (NOMA) can support multiple users within a single resource and thus can improve user and overall system throughput at the expense of increased receiver complexity which is required for separating the non-orthogonal signal[19]. The Figure 14.3 shows a simple comparison between basic downlink NOMA and OMA (OFDMA).

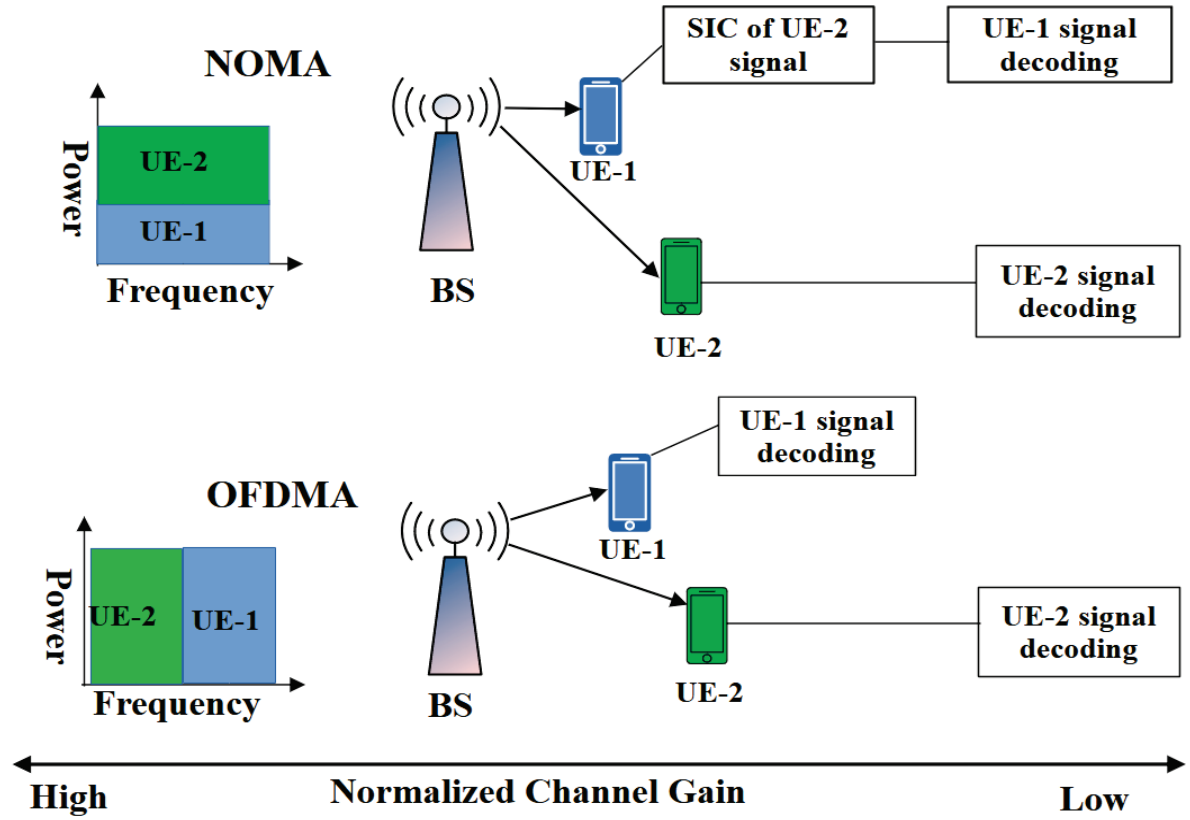

Fig. 14.3. Simple comparison between basic downlink NOMA and OMA (OFDMA)
Rys. 14.3. Proste porównanie pomiędzy NOMA I OMA

for 5G Networks, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 1, pp. 629–646, Firstquarter 2018, DOI: 10.1109/COMST.2017.2766698; He H., Yu X., Zhang J., Song S.H., Letaief K.B.: Cell-Free Massive MIMO for 6G Wireless Communication Networks. arXiv 2021 preprint arXiv:2110.07309.

[19] Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558.

Some of the possible benefits of NOMA are[20]:

- Massive connectivity – unlimited number of users.
- Low latency – NOMA can support flexible scheduling and grant-free transmission.
- Improved spectral efficiency – Every NOMA user can utilize the entire bandwidth; the data rates of properly grouped users can be increased.
- Relaxed channel feedback – perfect uplink CSI is not required at the BS.
- Instead, only the received signal strength needs to be included in the channel feedback.

The NOMA cellular system components are: Multi-user grouping, Resource Allocation (power, code, etc.) and Successive Interference Cancellation (SIC) or Multi--user detection (MUD) techniques to remove the controlled NOMA additions.

The following definitions and viewpoints are used to define non-orthogonality in NOMA:

a) *Superposition Coding (SC) and Successive Interference Cancellation (SIC)*

Downlink NOMA employs superposition coding at the transmitter and successive interference cancellation at the receiver making it possible to utilize the same spectrum for all users[21]. SIC is also mentioned in uplink transmission[22].

The objective of SC is to communicate two messages simultaneously by encoding them into a single signal in two layers. In SC, the source node creates two different messages, namely the basic message and the superposed message. For example, assuming a BS is communicating with two end users in a downlink communication, the messages are broadcasted to two receivers, the receiver with the strongest channel can decode both the messages while the receiver with the worse channel can only decode the basic message[23].

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[20] Shin W., Vaezi M., Lee B., Love D.J., Lee J., Poor H.V.: Non-Orthogonal Multiple Access in Multi-Cell Networks: Theory, Performance, and Practical Challenges, in IEEE Communications Magazine, Vol. 55, no. 10, pp. 176–183, Oct. 2017, DOI: 10.1109/MCOM.2017.1601065; Saito Y., Kishiyama Y., Benjebbour A., Nakamura T., Li A., Higuchi K.: Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access, 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), 2013, pp. 1–5, DOI: 10.1109/VTCSpring.2013.6692652; Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558; Cai Y. , Qin Z., Cui F., Li G.Y., McCann J.A.: Modulation and Multiple Access for 5G Networks, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 1, pp. 629–646, Firstquarter 2018, DOI: 10.1109/COMST.2017.2766698.

[21] Kizilirmak R.C., Hossein K.B.: Non-orthogonal multiple access (NOMA) for 5G networks. Towards 5G Wireless Networks-A Physical Layer Perspective 83, 2016, pp. 83–98; Liu Y., Qin Z., Elkashlan M., Ding Z., Nallanathan A., Hanzo, L.:Nonorthogonal multiple access for 5G and beyond. Proceedings of the IEEE, 2017.

[22] Liu Y., Qin Z., Elkashlan M., Ding Z., Nallanathan A., Hanzo, L.:Nonorthogonal multiple access for 5G and beyond. Proceedings of the IEEE, 2017.

[23] Liu Y., Qin Z., Elkashlan M., Ding Z., Nallanathan A., Hanzo, L.:Nonorthogonal multiple access for 5G and beyond. Proceedings of the IEEE, 2017; Wang L., Şaşoğlu E., Bandemer B., Kim Y.: A comparison of superposition coding schemes, 2013 IEEE International Symposium on Information Theory, 2013, pp. 2970–2974, DOI: 10.1109/ISIT.2013.6620770;

On the other hand, SIC is a physical technique with a capability that allows a receiver to decode packets that arrive simultaneously. It is the ability of a receiver to receive two or more signal concurrently. SIC is possible because the receiver may be able to decode the stronger signal, subtract (cancel) it from combined signal and extract the weaker one from residue[24]. The method of NOMA that employ SC and SIC is known as Power Domain NOMA (PD-NOMA). The PD-NOMA has been proposed to 3GPP LTE[25].

b) *Overloading*

In this context, NOMA can support multiple transmission within the same time, frequency resource block by assigning different codes to different users, adopt unique user specific spreading sequence[26]. This concept is inspired by the classic CDMA systems. Examples of NOMA schemes developed with this view are Low-density spreading (LDS) CDMA, LDS-OFDM, Sparse Code Multiple Access (SCMA), and Multi-user shared access (MUSA) which are collectively known as Code Domain NOMA.

c) *Linear Transform Decoding*

This involves definition of NOMA based on the complexity of multi-user detection. In this view, in an OMA scheme, the signals of different users can be separated in orthogonal subspaces using linear transform. Then any scheme that does meet this definition can be categorized as NOMA.

d) *Information-theoretical view*

In this, NOMA may refer to any technique in which concurrent transmission is allowed over the same resources in time/frequency/code/space, achieving a better rate region when compared to orthogonalization of one or some of the resources. This includes SC and SIC, rate-splitting (RS) and dirty paper coding (DPC)[27].

From the different definitions and points of view above, we have so many kinds of NOMA. Different kinds of NOMA have been investigated. Basically, there two

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[24] Liu Y., Qin Z., Elkashlan M., Ding Z., Nallanathan A., Hanzo, L.:Nonorthogonal multiple access for 5G and beyond. Proceedings of the IEEE, 2017; Sen S., Santhapuri N., Choudhury R.R., Nelakuditi S.:Successive interference cancellation: a back-of-the-envelope perspective. In Proceedings of the 9th ACM SIGCOMM Workshop on Hot Topics in Networks (Hotnets-IX). Association for Computing Machinery, New York, NY, USA, Article 17, 2010, pp. 1–6. DOI: https://doi.org/10.1145/1868447.1868464.

[25] Liu Y., Qin Z., Elkashlan M., Ding Z., Nallanathan A., Hanzo, L.:Nonorthogonal multiple access for 5G and beyond. Proceedings of the IEEE, 2017.

[26] Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558; Cai Y., Qin Z., Cui F., Li G.Y., McCann J.A.: Modulation and Multiple Access for 5G Networks, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 1, pp. 629–646, Firstquarter 2018, doi: 10.1109/COMST.2017.2766698.

[27] Liu Y., Qin Z., Elkashlan M., Ding Z., Nallanathan A., Hanzo, L.:Nonorthogonal multiple access for 5G and beyond. Proceedings of the IEEE, 2017.

dominating categories of NOMA namely: – Power Domain NOMA and Code Domain NOMA[28]. The Figure 14.4 shows a simple category of NOMA techniques.

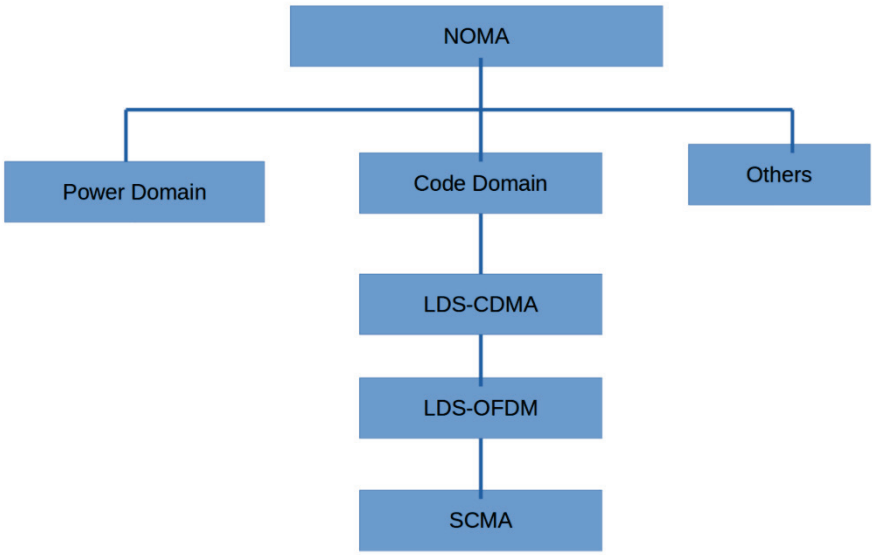

Fig. 14.4. A simple category of NOMA techniques
Rys. 14.4. Kategoria technik NOMA

- To understand NOMA with SIC, let us consider Figure 14.4 that illustrates the basic NOMA scheme applying SIC for UE receivers in the cellular downlink. The overall system transmission bandwidth is assumed to be 1 Hz. The base station transmits a signal for user 1 and user 2, x_i (i = 1,2), where $E[|x_i|2] = 1$, with transmission power P_i. The sum of P_i is restricted to P at maximum[29]. The transmitted signal is represented, x_1 and x_2 are superposition coded as:

$$x = \sqrt{P_1}x_1 + \sqrt{P_2}x_2 \tag{2.7}$$

The received signal at UE-*I* is represented as

$$y_i = h_i x + w_i \tag{2.8}$$

where hi is the complex channel coefficient between UE-i and the base station. w_i denotes the receiver Gaussian noise including inter-cell interference. The power density of w_i is $N_{o,I}$.

[28] Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558.
[29] Interdonato G., Björnson E., Ngo H.Q., Frenger P., Larsson E.G.: Ubiquitous cell-free massive MIMO communications. EURASIP Journal on Wireless Communications and Networking, 2019(1), 1–13.

In the NOMA downlink, the SIC process is implemented at the UE receiver. The optimal order for decoding is in the order of the increasing channel gain normalized by the noise and the inter-cell interference power, $|h_i|^2/ N_{o,i.}$ Based on this order, any user can correctly decode the signals of the other users whose decoding order comes before that user for interference cancellation. Thus, UE-*i* can remove the inter-user interference from the *j*-th user whose $|h_j|^2/ N_{o,j}$ is lower than $|h_i|^2/ N_{o,I.}$ In UE-2 case, it does not perform interference cancellation since it comes first in the decoding order $h_1|^2/N_{0,1} > |h_2|^2/ N_{o,2}$. UE-2 first decodes x_2 and subtracts its component from the received signal y_1. Then, UE-1 can decode x_1 without interference from x_2. Assuming error-free detection of x_2 at UE-1, the throughput of UE-*i*, R_i, is represented as

$$\begin{aligned} R_1 &= \log_2\left[1+\frac{P_1|h_1|^2}{N_{0,1}}\right] \\ R_2 &= \log_2\left[1+\frac{P_2|h_2|^2}{P_1|h_2|^2+N_{0,2}}\right] \end{aligned} \tag{2.9}$$

In comparison with OFDMA, when we assume OFDMA with orthogonal user multiplexing, where the bandwidth of α (0 < α < 1) Hz is assigned to UE 1 and the remaining bandwidth, $1-\alpha$ Hz, is assigned to UE 2, R_i is represented as:

$$\begin{aligned} R_1 &= \alpha\log_2\left[1+\frac{P_1|h_1|^2}{\alpha N_{0,1}}\right] \\ R_2 &= (1-a)\log_2\left[1+\frac{P_2|h_2|^2}{(1-a)N_{0,2}}\right] \end{aligned} \tag{2.10}$$

In NOMA, the performance gain compared to OFDMA increases when there is difference in channel gains. It can be shown in Fig. 14.5 that this NOMA scheme can achieve higher rates than OFDMA. A UE-2 case with a cell-interior UE and a cell-edge UE are assumed, where $P_1|h_1|^2/N_{0,1}$ and $P_2|h_2|^2/N_{0,2}$ is set to 20 and 0 dB respectively. At the same time, this NOMA scheme makes full use of the natural difference of channel gains among users, implying that the near far effect is effectively harnessed to achieve higher spectral efficiency. Consequently, both the attainable sum capacity and the cell--edge user rate can be improved.

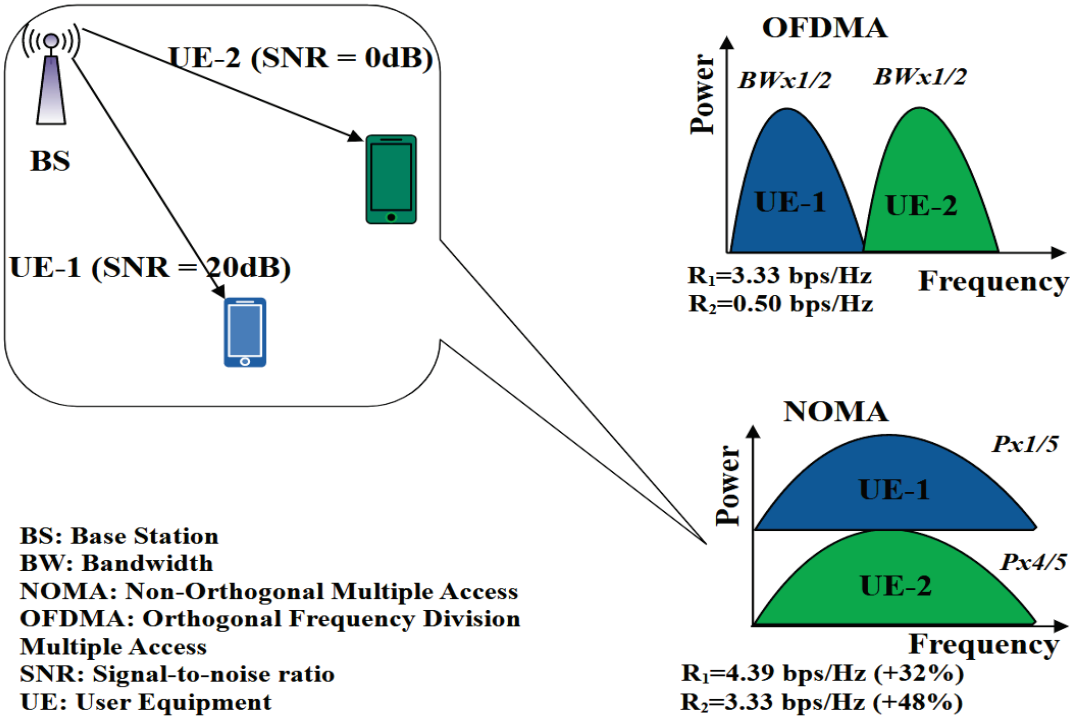

Fig. 14.5. OFDMA vs NOMA (Simple example)
Rys. 14.5. Przykład porównujący OFDMA i NOMA
Source: based on Saito Y., Kishiyama Y., Benjebbour A., Nakamura T., Li A., Higuchi K.: Non--Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access, 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), 2013, pp. 1–5, DOI: 10.1109/VTCSpring.2013.6692652

From Tse et al. (2005)[30], the boundaries of the rate regions achievable with superposition coding and optimal orthogonal schemes for asymmetric, downlink AWGN channel (with SNR1 = 0dB and SNR2 = 20bB) is compared as shown in figure below. We observe that the results of the superposition coding outperform that of the orthogonal signals.

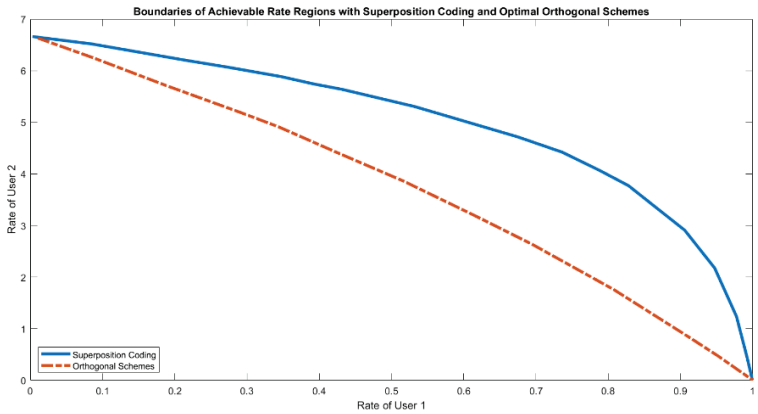

Fig. 14.6. Two user downlink asymmetric AWGN rates achievable by superposition coding (solid line) and orthogonal schemes (dashed line)
Rys. 14.6. Asymetryczne szybkości AWGN w łączu w dół dla dwóch użytkowników osiągalne dzięki kodowaniu superpozycji (linia ciągła) i schematom ortogonalnym (linia przerywana)

[30] D. Tse, P. Viswanath, Fundamentals of Wireless Communication. Cambridge University Press, 2005.

In investigation of performance gain of NOMA in practical assumptions[31], conducts a multi-cell system-level simulation. The performance gain of NOMA using wideband scheduling and power allocation is evaluated. The wideband case is evaluated since the system performance not relying on the frequency-selective channel information is important for practical wide area deployments. To further illustrate this, Figure 14.7 shows the CDF of the user throughput for OFDMA and NOMA with SIC. From the figure we can conclude that the user throughput performance of NOMA is improved compared to that of OFDMA and an approximate gain of 27% for NOMA in is obtained both the cell throughput and cell-edge user throughput.

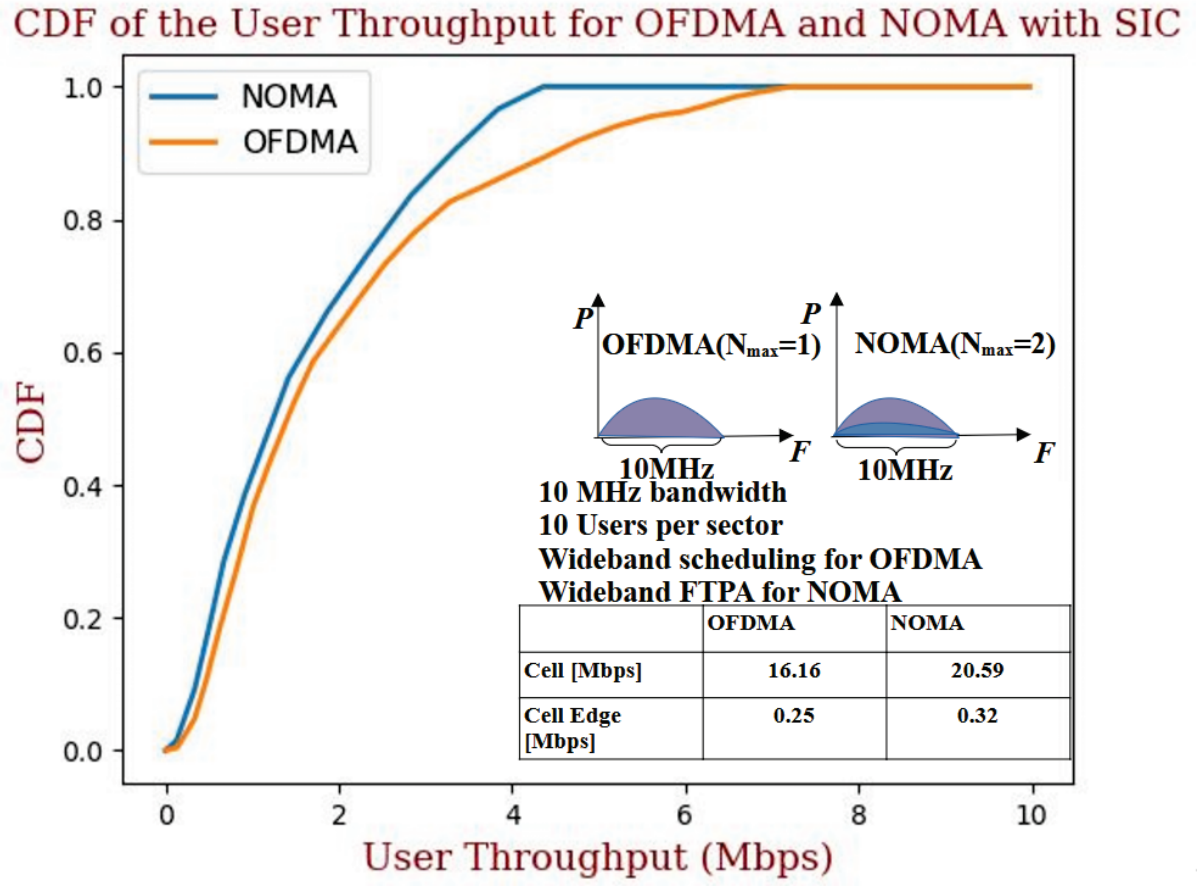

Fig. 14.7. System-level evaluation for OFDMA and NOMA when using wideband scheduling and power allocation

Rys. 14.7. Ocena na poziomie systemu dla OFDMA i NOMA przy użyciu szerokopasmowego harmonogramu i alokacji mocy

Source: based on Dai L., Wang B., Ding Z., Wang Z., Chen S., Hanzo L.: A Survey of Non--Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558.

[31] Dai L., Wang B., Ding Z., Wang Z., Chen S. Hanzo L.: A Survey of Non-Orthogonal Multiple Access for 5G, in IEEE Communications Surveys & Tutorials, Vol. 20, no. 3, pp. 2294–2323, thirdquarter 2018, DOI: 10.1109/COMST.2018.2835558.

14.3. NOMA-Aided Cell-Free Massive MIMO

14.3.1. State-of-Art

Despite its advantages and potential, there are only a few works on NOMA in Cell-Free Massive MIMO systems in literature. In this section, we survey the integration of NOMA with cell-free massive MIMO systems.

The first research work on CF-mMIMO-NOMA was done in (Li Y. et al. 2018)[32], where a closed-form achievable sum-rate of PD-NOMA is derived under consideration of the effects of intra-cluster pilot contamination, inter-cluster interference, and imperfect SIC. The system model used consist of a downlink communication with single antenna APs and single antenna users, operating in TDD protocol, and the APs employ conjugate beamforming. Numerical results showed the superior performance of NOMA compared to OMA. The authors in Zhang Y. et al. (2019) [33] were the first to investigate the uplink scenario in CF-mMIMO-NOMA and derived closed-form expression of spectral efficiency for conjugate beamforming considering the effect of intra-cluster pilot contamination, inter-cluster interference and imperfect SIC, and power optimization. It maximizes the SE through an iterative Geometric programming (GP) algorithm based on Sequential Convex Approximation (SCA). The simulation results demonstrated that CF-mMIMO-NOMA can utilize the scarce spectrum more efficiently. In Zhang X. et al. (2020)[34], an optimal backhaul combining process is suggested which maximizes the uplink SINR.

In terms of communication protocol, all the recent works have been based on TDD protocol. None has focused on FDD as a transmission protocol. Just as CF-mMIMO, CF-mMIMO-NOMA system consists of M single/multiple antenna(s) APs and K users. While most literature focuses on single antenna AP[35], present multi-antenna APs.

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[32] Li Y., Baduge G.A.A.: NOMA-Aided Cell-Free Massive MIMO Systems, in IEEE Wireless Communications Letters, Vol. 7, no. 6, pp. 950–953, Dec. 2018, DOI: 10.1109/LWC.2018.2841375.

[33] Zhang Y., Cao H., Zhou M., Yang L.: Spectral Efficiency Maximization for Uplink Cell-Free Massive MIMO--NOMA Networks, 2019 IEEE International Conference on Communications Workshops (ICC Workshops), 2019, pp. 1–6, DOI: 10.1109/ICCW.2019.8756881.

[34] Zhang X., Wang J., Poor H.V.: Statistical QoS Provisioning Over Cell-Free M-MIMO-NOMA Based 5G+ Mobile Wireless Networks in the Non-Asymptotic Regime, 2020 IEEE 21st International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 2020, pp. 1–5, DOI: 10.1109/SPAWC48557. 2020.9154222.

[35] Zhang Y., Cao H., Zhou M., Yang L.: Non-orthogonal multiple access in cell-free massive MIMO networks, in China Communications, Vol. 17, no. 8, pp. 81–94, Aug. 2020, DOI: 10.23919/JCC.2020.08.007; Rezaei F., Heidarpour A.R., Tellambura C., Tadaion A.: Underlaid Spectrum Sharing for Cell-Free Massive MIMO--NOMA, in IEEE Communications Letters, Vol. 24, no. 4, pp. 907–911, April 2020, DOI: 10.1109/LCOMM.2020.2966195; Rezaei F., Tellambura C., Tadaion A.A., Heidarpour A.R.: Rate Analysis of Cell-Free Massive MIMO-NOMA With Three Linear Precoders, in IEEE Transactions on Communications, 2020, Vol. 68, no. 6, pp. 3480-3494, doi: 10.1109/TCOMM.2020.2978189;Zhang J., Fan J., Ai B., Ng D.W.K.: NOMA-Based Cell-Free Massive MIMO Over Spatially Correlated Rician Fading Channels, ICC 2020 – 2020

The channel between users and APs is modelled by most as a Rayleigh fading channel assuming non-line-of-sight (NLOS) links between users and APs. The majority of the work focuses on Rayleigh fading channel, only models[36] the channel using Rician fading channel. Specifically Zhang J. et al. (2020)[37] focuses on a system with multi-antenna APs and single-antenna UEs over spatially correlated Rician fading channels.

While most works use conjugate beamforming precoders at Aps[38], employ Maximum ratio transmission (MRT) precoders employ full-pilot zero-forcing (fpZF) precoders[39] and compares the performance of the three practical linear decoders[40]. Specifically, Rezaei F. et al. (2020)[41], comprehensively evaluates the system performance with MRT, fpZF and modified regularized ZF (mRZF) and derives a closed-form sum-rate expression while considering Rayleigh fading channel, the effects of intra-cluster pilot contamination, inter-cluster interference and imperfect SIC. From the analytical results, mRZF and fpZF significantly outperform MRT with perfect SIC despite having the same fronthauling overhead. mRZF achieved the highest rates compared to fpZF and MRT in perfect SIC, because it tries to balance the inter-cluster interference mitigation and intra-cluster power enhancement. However, with the very large number of users, MRT outperforms fpZF. In addition, Bashar M. et al. (2020)[42] derives a closed-form SINR using both conjugate beamforming and normalized conjugate beamforming taking into consideration the effects of pilot contamination and imperfect SIC with an objective of

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IEEE International Conference on Communications (ICC), 2020, pp. 1–6, DOI: 10.1109/ICC40277.2020.9148861.

[36] Zhang X., Wang J., Poor H.V.: Statistical QoS Provisioning Over Cell-Free M-MIMO-NOMA Based 5G+ Mobile Wireless Networks in the Non-Asymptotic Regime, 2020 IEEE 21st International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 2020, pp. 1–5, DOI: 10.1109/SPAWC48557.2020.9154222; Zhang J., Fan J., Ai B., Ng D.W.K.: NOMA-Based Cell-Free Massive MIMO Over Spatially Correlated Rician Fading Channels, ICC 2020 - 2020 IEEE International Conference on Communications (ICC), 2020, pp. 1–6, DOI: 10.1109/ICC40277.2020.9148861.

[37] Zhang J., Fan J., Ai B., Ng D.W.K.: NOMA-Based Cell-Free Massive MIMO Over Spatially Correlated Rician Fading Channels, ICC 2020 – 2020 IEEE International Conference on Communications (ICC), 2020, pp. 1-6, DOI: 10.1109/ICC40277.2020.9148861.

[38] Rezaei F., Heidarpour A.R., Tellambura C., Tadaion A.: Underlaid Spectrum Sharing for Cell-Free Massive MIMO-NOMA, in IEEE Communications Letters, Vol. 24, no. 4, pp. 907–911, April 2020, DOI: 10.1109/LCOMM.2020.2966195; Nguyen T.K., Nguyen H.H., Tuan H.D.: Max-Min QoS Power Control in Generalized Cell-Free Massive MIMO-NOMA With Optimal Backhaul Combining, in IEEE Transactions on Vehicular Technology, 2020, Vol. 69, no. 10, pp. 10949–10964, DOI: 10.1109/TVT.2020.3006054.

[39] Le Q., Nguyen V.-D., Dobre O.A., Nguyen P.N., Zhao R., Chatzinotas S.: Learning-Assisted User Clustering in Cell-Free Massive MIMO-NOMA Networks, in IEEE Transactions on Vehicular Technology, DOI: 10.1109/TVT.2021.3121217.

[40] Rezaei F., Tellambura C., Tadaion A.A., Heidarpour A.R.: Rate Analysis of Cell-Free Massive MIMO--NOMA With Three Linear Precoders, in IEEE Transactions on Communications, 2020, Vol. 68, no. 6, pp. 3480-3494, DOI: 10.1109/TCOMM.2020.2978189.

[41] Rezaei F., Tellambura C., Tadaion A.A., Heidarpour A.R.: Rate Analysis of Cell-Free Massive MIMO--NOMA With Three Linear Precoders, in IEEE Transactions on Communications, 2020, Vol. 68, no. 6, pp. 3480–3494, DOI: 10.1109/TCOMM.2020.2978189.

[42] Bashar M., Cumanan K., Burr A.G., Ngo H.Q., Hanzo L., Xiao P.: On the Performance of Cell-Free Massive MIMO Relying on Adaptive NOMA/OMA Mode-Switching, in IEEE Transactions on Communications, 2020, Vol. 68, no. 2, pp. 792–810, DOI: 10.1109/TCOMM.2019.2952574.

maximizing the bandwidth efficiency. The results show that the performance of conjugate beamforming is superior to that of normalized conjugate beamforming.

While most authors consider static APs and users, Kusaladharma S. et al. (2019)[43] consider random APs and users. Categorically, they investigate how to improve achievable rates of CF-mMIMO-NOMA systems under random AP/user deployments using stochastic geometry-based modelling to obtain an accurate network-wide characterization of performance. They consider a Poisson point process (PPP) of APs and users along Rayleigh fading and log-distance path loss. Some major observations are that the rate gain of NOMA diminishes as density of APs become smaller and for higher path loss exponents, NOMA provides reduced latency at the cost of reduced overall rate.

One of the major challenges in NOMA are user clustering (UC) and user ordering. As studied in NOMA theory, user clustering is a key technique in NOMA systems, in that it facilitates the implementation of NOMA for many users by reducing the complexity of SIC[44]. In typical NOMA works form the literature, the user clustering schemes have opted to group two users per cluster with random pairing[45]. In Bashar M. et al. (2020)[46], three paring schemes, far-, near-, and random paring, are implemented with two users in each cluster. In Rezaei F. et al. (2020)[47], the authors use the Jaccard coefficient to calculate the similarity between each user's large scale fading profile with a predetermined centroid. The users having strong similarity are assigned into different groups. This is user clustering with low complexity optimal method. Nguyen T.K. et al. (2020)[48] propose an iterative user location algorithm that requires the large-scale fading correlation coefficients and the large-scale fading profiles of two users within

[43] Kusaladharma S., Zhu W.-P., Ajib W., Amarasuriya G.: Achievable Rate Analysis of NOMA in Cell-Free Massive MIMO: A Stochastic Geometry Approach, ICC 2019–2019 IEEE International Conference on Communications (ICC), 2019, pp. 1–6, DOI: 10.1109/ICC.2019.8761506; Kusaladharma S., Zhu W.-P., Ajib W., Baduge G.A.A.: Achievable Rate Characterization of NOMA-Aided Cell-Free Massive MIMO With Imperfect Successive Interference Cancellation, in IEEE Transactions on Communications, Vol. 69, no. 5, pp. 3054–3066, May 2021, DOI: 10.1109/TCOMM.2021.3053613.

[44] Bashar M., Cumanan K., Burr A. G., Ngo H. Q., Hanzo L., Xiao P.: On the Performance of Cell-Free Massive MIMO Relying on Adaptive NOMA/OMA Mode-Switching, in IEEE Transactions on Communications, 2020, Vol. 68, no. 2, pp. 792–810, DOI: 10.1109/TCOMM.2019.2952574.

[45] Bashar M., Cumanan K., Burr A.G., Ngo H.Q., Hanzo L., Xiao P.: On the Performance of Cell-Free Massive MIMO Relying on Adaptive NOMA/OMA Mode-Switching, in IEEE Transactions on Communications, 2020, Vol. 68, no. 2, pp. 792–810, DOI: 10.1109/TCOMM.2019.2952574; Bashar M., Cumanan K., Burr A.G., Ngo H.Q., HanzoL., Xiao P.: NOMA/OMA Mode Selection-Based Cell-Free Massive MIMO, ICC 2019–2019 IEEE International Conference on Communications (ICC), 2019, pp. 1–6, DOI: 10.1109/ICC.2019.8761072.

[46] Bashar M., Cumanan K., Burr A.G., Ngo H.Q., Hanzo L., Xiao P.: On the Performance of Cell-Free Massive MIMO Relying on Adaptive NOMA/OMA Mode-Switching, in IEEE Transactions on Communications, 2020, Vol. 68, no. 2, pp. 792–810, DOI: 10.1109/TCOMM.2019.2952574.

[47] Rezaei F., Heidarpour A.R., Tellambura C., Tadaion A.: Underlaid Spectrum Sharing for Cell-Free Massive MIMO-NOMA, in IEEE Communications Letters, Vol. 24, no. 4, pp. 907–911, April 2020, DOI: 10.1109/LCOMM.2020.2966195.

[48] Nguyen T.K., Nguyen H.H., Tuan H.D.: Max-Min QoS Power Control in Generalized Cell-Free Massive MIMO-NOMA With Optimal Backhaul Combining, in IEEE Transactions on Vehicular Technology, 2020, Vol. 69, no. 10, pp. 10949–10964, DOI: 10.1109/TVT.2020.3006054.

a group is minimized. At the same time, Rezaei F. et al. (2020)[49] propose a User-location aware clustering algorithm where each AP needs to only know the user's location and according to the location CPU puts each two nearest users in a common cluster, so that the path-loss between them is significantly reduced. In Wang Z. et al. (2020)[50], a novel user clustering algorithm using cooperative links between users that does not require complex optimization is studied. It guarantees the existence of reliable channels among the users within the same NOMA cluster. However, all the above clustering schemes don't consider any learning features and random user clustering certainly results in a suboptimal solution while an exhaustive search method comes at a cost of high complexity. Le Q. et al. (2021)[51], proposes the use of unsupervised machine learning based UC algorithms, namely K-means++ and improved k-means++ to effectively cluster users into disjoint clusters. The provided numerical results confirm the effectiveness of the UC algorithms over far-, near-, and random pairing schemes and Jaccard-based UC scheme.

Different power optimization techniques are used in CF-mMIMO NOMA. For instance, whereas Zhang Y. et al. (2019)[52] aims at maximizing the uplink spectral efficiency using an iterative geometric programming (GP) algorithm based on sequential convex approximation (SCA), in[53] SCA is used to maximize sum SE subject to each AP power constraint and SIC power constraint. Apart from the max-min power method in Nguyen T.K. et al. (2020 and 2021)[54], the authors consider a max-min algorithm with adaptive SIC while Galappaththige D.L. et al. (2020)[55] proposes a max-min transmit

[49] Rezaei F., Heidarpour A.R., Tellambura C., Tadaion A.: Underlaid Spectrum Sharing for Cell-Free Massive MIMO-NOMA, in IEEE Communications Letters, Vol. 24, no. 4, pp. 907–911, April 2020, DOI: 10.1109/LCOMM.2020.2966195.

[50] Wang Z., Zhang D., Xu K., Xie W., Xv J., Li X.: NOMA in Cell-Free mMIMO Systems with AP Selection, 2020 International Conference on Wireless Communications and Signal Processing (WCSP), 2020, pp. 430–435, DOI: 10.1109/WCSP49889.2020.9299790.

[51] Le Q., Nguyen V.-D., Dobre O.A., Nguyen P.N., Zhao R., Chatzinotas S.: Learning-Assisted User Clustering in Cell-Free Massive MIMO-NOMA Networks, in IEEE Transactions on Vehicular Technology, DOI: 10.1109/TVT.2021.3121217.

[52] Zhang Y., Cao H., Zhou M., Yang L.: Spectral Efficiency Maximization for Uplink Cell-Free Massive MIMO--NOMA Networks, 2019 IEEE International Conference on Communications Workshops (ICC Workshops), 2019, pp. 1–6, DOI: 10.1109/ICCW.2019.8756881.

[53] Zhang Y., Cao H., Zhou M., Yang L.: Non-orthogonal multiple access in cell-free massive MIMO networks, in China Communications, Vol. 17, no. 8, pp. 81–94, Aug. 2020, DOI: 10.23919/JCC.2020.08.007.

[54] Nguyen T.K., Nguyen H.H., Tuan H.D.: Max-Min QoS Power Control in Generalized Cell-Free Massive MIMO-NOMA With Optimal Backhaul Combining, in IEEE Transactions on Vehicular Technology, 2020, Vol. 69, no. 10, pp. 10949–10964, DOI: 10.1109/TVT.2020.3006054; Nguyen T.K., Nguyen H. ., TuanH. D.: Cell-Free Massive MIMO-NOMA with Optimal Backhaul Combining, 2020 IEEE Eighth International Conference on Communications and Electronics (ICCE), 2021, pp. 455–460, DOI: 10.1109/ ICCE48956.2021.9352089; Nguyen T.K. , Nguyen H.H., Tuan H.D.: Adaptive Successive Interference Cancellation in Cell-free Massive MIMO-NOMA, 2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall), 2020, pp. 1–5, DOI: 10.1109/VTC2020-Fall49728.2020.9348505.

[55] Galappaththige D.L., Amarasuriya G.: NOMA-Aided Cell-Free Massive MIMO with Underlay Spectrum--Sharing, ICC 2020–2020 IEEE International Conference on Communications (ICC), 2020, pp. 1–6, DOI: 10.1109/ICC40277.2020.9149105.

power control problem that is a quasi-concave problem, and the optimal solution is found by bisection method. In Le Q. et al. (2021)[56], to maximize the sum spectral efficiency, it uses an inner approximation (IA) based iterative algorithm to solve the optimization problem, whose aim is to optimize the normalized transmit power to maximize the sum spectral efficiency under the constrains of the transmit power budget at the APs, SIC conditions, and all minimum required SE at UEs. Bashar M. et al. (2019, 2020)[57] formulate a max-min problem BE optimization problem under per-AP power constraints. Specifically, in[58], a bisection scheme is conceived for optimally solving the optimization problem. The power minimization problem of conjugate beamforming is solved using second order cone programming (SOCP), whereas for normalized conjugate beamforming standard semidefinite programming (SDP) is utilized. To further enhance the performance, the authors propose a mode switching technique based on the average BE. In Bashar M. et al. (2020)[59], a dynamic intra-cluster power allocation method which leads to dynamic power coefficients with different AP is considered. Investigates Sayyari R. et al. (2021)[60] an adaptive switching algorithm between OMA, non--cooperative NOMA, and cooperative NOMA modes to maximize the achievable sum rate and energy efficiency of the system. The system which initially operates in OMA mode, utilizes all the benefits of the different modes at different scenarios that suits each mode. Hua M. et al. (2021)[61]utilizes a Dinkelbach's method-based algorithm to solve its non-convex optimization to obtain an optimal solution with an aim of maximizing the EE. The algorithm is two layered with the bottom layer aiming to solve the power control optimization. It is based on the difference of convex functions programming. The Authors further expounds on the complexity of the algorithms. Finally, Wang Z. et al.

[56] Le Q., Nguyen V.-D., Dobre O.A., Nguyen P.N., Zhao R., Chatzinotas S.: Learning-Assisted User Clustering in Cell-Free Massive MIMO-NOMA Networks, in IEEE Transactions on Vehicular Technology, DOI: 10.1109/TVT.2021.3121217.

[57] Bashar M., Cumanan K., Burr A.G., Ngo H.Q., Hanzo L., Xiao P.: On the Performance of Cell-Free Massive MIMO Relying on Adaptive NOMA/OMA Mode-Switching, in IEEE Transactions on Communications, 2020, Vol. 68, no. 2, pp. 792–810, DOI: 10.1109/TCOMM.2019.2952574; Bashar M., Cumanan K., Burr A.G., Ngo H.Q., HanzoL., Xiao P.: NOMA/OMA Mode Selection-Based Cell-Free Massive MIMO, ICC 2019–2019 IEEE International Conference on Communications (ICC), 2019, pp. 1–6, DOI: 10.1109/ICC.2019.8761072.

[58] Bashar M., Cumanan K., Burr A.G., Ngo H.Q., HanzoL., Xiao P.: NOMA/OMA Mode Selection-Based Cell--Free Massive MIMO, ICC 2019–2019 IEEE International Conference on Communications (ICC), 2019, pp. 1–6, DOI: 10.1109/ICC.2019.8761072.

[59] Zhang J., Fan J., Ai B., Ng D.W.K.: NOMA-Based Cell-Free Massive MIMO Over Spatially Correlated Rician Fading Channels, ICC 2020–2020 IEEE International Conference on Communications (ICC), 2020, pp. 1–6, DOI: 10.1109/ICC40277.2020.9148861.

[60] Sayyari R., Pourrostam J., Niya M.J.M.: Cell-Free Massive MIMO System With an Adaptive Switching Algorithm Between Cooperative NOMA, Non-Cooperative NOMA, and OMA Modes, in IEEE Access, Vol. 9, pp. 149227–149239, 2021, DOI: 10.1109/ACCESS.2021.3124816.

[61] Hua M., Ni W., Tian H., Nie G.: Energy-Efficient Uplink Power Control in NOMA Enhanced Cell-Free Massive MIMO Networks, 2021 IEEE/CIC International Conference on Communications in China (ICCC Workshops), 2021, pp. 7–12, DOI: 10.1109/ICCCWorkshops52231.2021.9538877.

(2020)[62] consider a power optimization technique for user-centric based CF-mMIMO--NOMA. Specifically, while Zhang X. et al. (2020)[63] uses particle swarm algorithm to distribute transmit power for the APs. In Wang Z. et a. (2020)[64], a joint power optimization technique is adopted in the AP-tiered AP selection-based CF-mMIMO--NOMA in which when the APs in the same group performing SC to derive their own superimposed signals, they use the same power allocation firstly to enable CPU to only optimize the power allocation strategy of each AP group and the amount of calculation for joint power optimization can be reduced.

14.3.2. System, Channel and Signal Models

System and Channel Model

In this model we shall consider a downlink transmission of a NOMA-aided Cell-Free massive MIMO system in which M single antenna APs serve KN single antenna users spatially distributed in N clusters under Time Division Duplexing (TDD) protocol at the same time-frequency resource block. Each cluster consists of K users. APs are connected to a central processing unit (CPU) via a perfect and error free fronthaul network with unlimited capacity. Figure 14.8 below shows a NOMA-Aided Cell-Free Massive MIMO network with two users in each cluster.

[62] Wang Z., Zhang D., Xu K., Xie W., Xv J., Li X.: NOMA in Cell-Free mMIMO Systems with AP Selection, 2020 International Conference on Wireless Communications and Signal Processing (WCSP), 2020, pp. 430–435, DOI: 10.1109/WCSP49889.2020.9299790; Zhang X., Zhu Q.: NOMA and User-Centric Based Cell-Free Massive MIMO Over 6G Big-Data Mobile Wireless Networks, GLOBECOM 2020–2020 IEEE Global Communications Conference, 2020, pp. 1–6, DOI: 10.1109/GLOBECOM42002.2020.9322423.

[63] Zhang X., Zhu Q.: NOMA and User-Centric Based Cell-Free Massive MIMO Over 6G Big-Data Mobile Wireless Networks, GLOBECOM 2020 - 2020 IEEE Global Communications Conference, 2020, pp. 1–6, DOI: 10.1109/GLOBECOM42002.2020.9322423.

[64] Wang Z., Zhang D., Xu K., Xie W., Xv J., Li X.: NOMA in Cell-Free mMIMO Systems with AP Selection, 2020 International Conference on Wireless Communications and Signal Processing (WCSP), 2020, pp. 430–435, DOI: 10.1109/WCSP49889.2020.9299790.

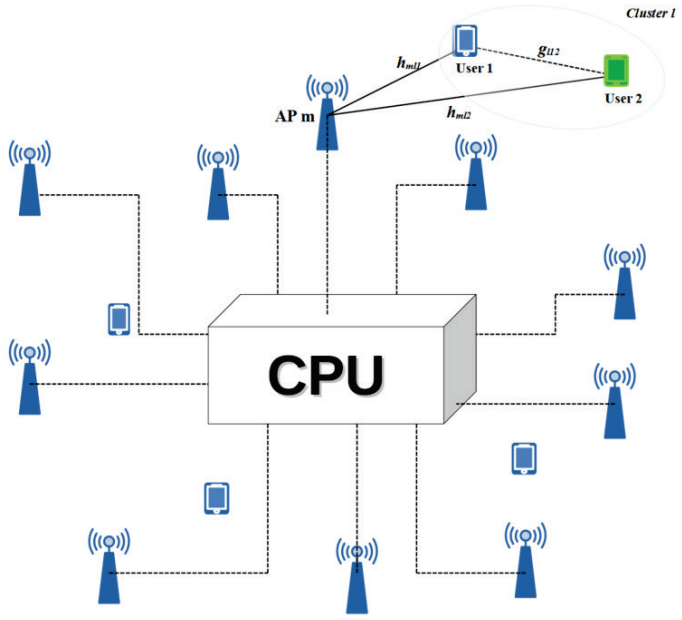

Fig. 14.8. NOMA-Aided Cell-Free Massive MIMO network with two users in each cluster
Rys. 14.8. Masywna sieć MIMO bez komórek wspomagana przez NOMA z dwoma użytkownikami w każdym klastrze
Source: based on Sayyari R., Pourrostam J., Niya M.J.M.: Cell-Free Massive MIMO System With an Adaptive Switching Algorithm Between Cooperative NOMA, Non-Cooperative NOMA, and OMA Modes, in IEEE Access, Vol. 9, pp. 149227–149239, 2021, DOI: 10.1109/ACCESS.2021.3124816.

The downlink channel between the m-th AP and the k-th user in the n-th cluster, where $m \in \{1, \cdots M\}$, $k \in \{1, \cdots K\}$ and $n \in \{1, \cdots N\}$ can be modeled as:

$$h_{mnk} = \zeta_{mnk}^{1/2} \tilde{h}_{mnk} \tag{3.1}$$

where ζ_{mnk} captures the large-scale fading, which is assumed to be known a priori as it changes very slowly and hence needs to be estimated once about every 40 coherence time intervals and $\tilde{h}_{mnk} \sim \mathcal{CN}(0,1)$ is circularly symmetric Gaussian distributed with zero mean unit variance and accounts for quasi-static Rayleigh fading[65]. Thus, $h_{mnk} \sim \mathcal{CN}(0, \tilde{h}_{mnk})$ is a complex normal random distribution variable with zero mean and covariance ζ_{mnk} [66].

[65] Li Y., Baduge G.A.A.: NOMA-Aided Cell-Free Massive MIMO Systems, in IEEE Wireless Communications Letters, Vol. 7, no. 6, pp. 950–953, Dec. 2018, DOI: 10.1109/LWC.2018.2841375.
[66] Sayyari R., Pourrostam J., Niya M.J.M.: Cell-Free Massive MIMO System With an Adaptive Switching Algorithm Between Cooperative NOMA, Non-Cooperative NOMA, and OMA Modes, in IEEE Access, Vol. 9, pp. 149227–149239, 2021, DOI: 10.1109/ACCESS.2021.3124816.

Also, users within the same NOMA cluster are arranged according to their channel conditions:

$$\sum_{m=1}^{M}|h_{mn1}|^2 \geq \sum_{m=1}^{M}|h_{mn2}|^2 : 1 \leq n \leq N \tag{3.2}$$

The location of users and APs can be modeled with homogenous PPP[67]. The following equation shows the probability of having M APs with a density of λ within an area of B:

$$[z(B) = M] = \frac{(\lambda_B)^M e^{-\lambda_B}}{M!} \tag{3.3}$$

If λ_u is the density of users and $\lambda_a$is the density of APs, then $\lambda_a \geq \lambda_u$. K is the total number of users within the same NOMA cluster.

Notably, the estimation of the DL channel can be performed by uplink pilots and channel reciprocity assumption in the Time Division Duplexing (TDD) Protocol. Hence the first part of each coherence block is allocated to uplink pilots and the remaining part is used for data transmission. [68] shows that the assumption of channel reciprocity doesn't put into consideration the hardware mismatches at AP and UE side, which are not reciprocal but impacts the system performance.

Channel State Information Acquisition/ Uplink Pilot Training

The APs estimate uplink channels via the pilots transmitted by the users and thereby, the downlink channels are obtained by exploiting TDD channel reciprocity. The users within the same cluster are allocated the same pilot sequence with τ symbols in length to minimize the channel estimation overhead. The N pilot sequences allocated for N clusters are mutually orthogonal hence $\tau \geq N$. The pilot sequence allocated for K users in the n-th cluster is denoted as $\phi_n \in \mathbb{C}^{\tau \times 1}$ satisfying $\|\phi_n\|^2 = 1$ and $\phi_n^H \phi_l = 0$ for $n \neq l$. The pilot signal received at the m-th AP during the UL channel estimation can be written as:

$$y_m^P = \sqrt{\tau p_p} \sum_{n=1}^{N} \sum_{k=1}^{K} h_{mnk} \phi_n + n_m \tag{3.4}$$

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[67] Sayyari R., Pourrostam J., Niya M.J.M.: Cell-Free Massive MIMO System With an Adaptive Switching Algorithm Between Cooperative NOMA, Non-Cooperative NOMA, and OMA Modes, in IEEE Access, Vol. 9, pp. 149227–149239, 2021, DOI: 10.1109/ACCESS.2021.3124816.

[68] Ohashi A.A. et al.: Cell-Free Massive MIMO-NOMA Systems With Imperfect SIC and Non-Reciprocal Channels, in IEEE Wireless Communications Letters, 2021, Vol. 10, no. 6, pp. 1329–1333, DOI: 10.1109/LWC.2021.3066042.

where: p_p is the pilot transmit power (UL normalized SNR), $n_m \sim \mathcal{C}N_{\tau\times1}(O_{\tau\times1}, I_i)$ represents the Additive White Gaussian Noise (AWGN) vector at the m-th AP.

In order to estimate the channel h_{mnk}, the received pilot signal at the m-th AP (y_m^P) is projected onto ϕ_n as:

$$\tilde{y}_{mn}^P = \phi_n^H y_m^P = \sqrt{\tau p_p}\sum_{k=1}^K h_{mnk} + \phi_n^H n_m \tag{3.5}$$

In the case that any two pilot sequences are either identical or orthogonal, $\tilde{y}_{mn}^P$ becomes a sufficient statistic. Thence, the Minimum Mean Square Sequence Error (MMSE) estimate h_{mnk} given $\tilde{y}_{mn}^P$ can be given as:

$$\tilde{h}_{mnk} = \frac{\mathbb{E}\left[\tilde{y}_{mn}^{P^*} h_{mnk}\right]}{\mathbb{E}\left[\left|\bar{y}_{mn}^P\right|^2\right]}\tilde{y}_{mn}^P = \frac{\sqrt{\tau p_p}\,\zeta_{mnk}}{1+\tau p_p\sum_{k=1}^K \zeta_{mnk}}\tilde{y}_{mn}^P \tag{3.6}$$

By using the fact that $\tilde{y}_{mn}^P$ is Gaussian distributed, $\hat{h}_{mnk}$ can be written as

$$\tilde{h}_{mnk} = \sqrt{\eta_{mnk}}v_{mn} \tag{3.7}$$

where $v_{mn} \sim \mathcal{CN}(0,1)$, and η_{mnk} is defined as:

$$\eta_{mnk} = E\left[\left|\hat{h}_{mnk}\right|^2\right] = \frac{\tau p_p \zeta_{mnk}^2}{1+\tau p_p\sum_{k=1}^K \zeta_{mnk}} \tag{3.8}$$

The channel estimation error is defined as $\varepsilon_{mnk} = h_{mnk} - \hat{h}_{mnk}$ where ε_{mnk} and $\hat{h}_{mnk}$ are statistically independent. Moreover, $\mathbb{E}[|\varepsilon_{mnk}|^2] = \zeta_{mnk} - \eta_{mnk}$. η_{mnk} is the power control coefficient for each AP to serve each user in each cluster. They are determined by CPU and will be delivered to the APs through the fronthaul networks.

Signal Model

In the downlink data transmission, the APs employ a conjugate beamformer designed based on the locally estimated CSI, which is acquired via a channel reciprocity and uplink MMSE channel estimation.

The data signal intended for the K users in the n-th cluster is superposition coded as:

$$x_n = \sum_{k=1}^{K} \sqrt{P_{nk}} x_{nk} \tag{3.9}$$

where x_{nk} and P_{nk} are data signal and transmit power allocated for the k-th user in the n-th cluster for $n \in \{1, \cdots N\}$ and $k \in \{1, \cdots K\}$. Furthermore, x_{nk} and x_{ml} for $m, n \in \{1, \cdots N\}$ and $k, l \in \{1, \cdots K\}$ satisfy

$$\mathbb{E}\{x_{nk} x_{ml}\} = \begin{cases} 1, & if \;\; n = m \; and \; k = l \\ 0, & otherwise \end{cases} \tag{3.10}$$

Therefore, $\mathbb{E}[|x_n|^2] = \sum_{k=1}^{K} P_{nk} = P_n$, where P_n accounts for the total signal power allocated for the n-th cluster.

The transmitted signal at the m-th AP can be written as

$$t_m = \sum_{n=1}^{N} \frac{\hat{h}_{mnk}^*}{|\hat{h}_{mnk}|} x_n = \sum_{n=1}^{N} \frac{v_{mn}^*}{|v_{mn}|} x_n \tag{3.11}$$

where a short-term power constraint (STPC) is used in the conjugate beamformer design. The total average transmit power at the m-th AP for all N clusters can be written as $P_{tm} = E[|t_m|^2] = \sum_{n=1}^{N} P_n$.

The KN users in N cluster are served simultaneously by M APs, hence the signal at the k-th user in the n-th cluster can be written as:

$$y_{nk} = \Sigma_{m=1}^{M} h_{mnk} + n_{nk} \tag{3.12}$$

$$= \sqrt{P_{nk}} c_{nk} x_{nk} + c_{nk} \sum_{k'=1, K \neq 14}^{K} \sqrt{P_{nk'}} x_{nk'} + \sum_{n^1=1, n' \neq n}^{N} c_{n'k} x_{n'} + n_{nk}$$

where $c_{nk} = \sum_{k=1}^{K} h_{mnk} \frac{v_{mn}^*}{|v_{mn}|}$, $\quad c_{n'k} = \sum_{k=1}^{K} h_{mnk} \frac{v_{mn}^*}{|v_{mn'}|}$ and $n_{nk} \sim \mathcal{CN}(0,1)$.

In power domain NOMA, higher powers are allocated for the users with lower channel strengths yielding $P_{n1} \leq \cdots P_{nk} \leq \cdots \leq P_{nk}$. Hence, within the n-th cluster, the k-th user is always able to decode the signal intended for the l-th user for $\forall l \geq k$ provided that the k-th user can decode its own signal. Thus, the k-th user can

successively cancel the intra-cluster interference from the l-th user before decoding its own signal for $\forall l \geq k$. The k-th user treats the signal from users for $\forall l \geq k$ as interference. The optimal power allocation and optimal user-clustering are as open problem for sake of brevity.

It is important to note that in TDD CF-mMIMO, the instantaneous CSI is not available at the user nodes. However, as the number of APs grows sufficiently large, the underlaying channels harden. Hence $\mathbb{E}[c_{nk}]$ can be used as the effective channel gain for decoding x_n at the k-th user in the n-th cluster. The acquisition of $\mathbb{E}[c_{nk}]$ is not practically difficult because it depends only on the statistical properties of the channels and remains fixed for several coherence intervals. Again, due to intra-cluster pilot contamination, channel estimation errors and statistical CSI knowledge at the users, perfect SIC is not perfectly viable. Hence post-processed signal at the k-th user node in the n-th cluster after the imperfect SIC can be written as:

$$\tilde{y}_{nk} = \sqrt{P_{nk}} c_{nk} x_{nk} + C_{nk} \sum_{k'=1}^{k-1} \sqrt{P_{nk'}} x_{nk'} + \sum_{n'=1, n' \neq n}^{N} c'_{n'k} x_{n'} + \sum_{k''=k+1}^{K} \sqrt{P_{nk''}} [c_{nk''} x_{nk''} - \mathbb{E}[C_{nk}] \hat{x}_{nk''}] + n_{nk} \tag{3.13}$$

where $\hat{x}_{nk}$ is an estimate of x_{nk} for $\forall_{n,k}$, x_{nk} is assumed to be drawn from a Gaussian distribution with zero-mean and unit variance. Hence, $\hat{x}_{nk}$ and x_{nk} are assumed to be jointly Gaussian distributed with a normalized correlation coefficient ρ_{nk} as:

$$x_{nk} = \rho_{nk} \hat{x}_{nk} + e_{nk} \tag{3.14}$$

where $x_{nk} \sim \mathcal{CN}(0,1)$, $e_{nk} \sim \mathcal{CN}(0, \sigma^2_{e_{nk}} / [1 + \sigma^2_{e_{nk}}])$ and $\rho_{nk} = 1 / \sqrt{1 + \sigma^2_{e_{nk}}}$.

Furthermore, x_{nk} and e_{nk} are statistically independent.

The upper bound ergodic sum rate is given by[69]:

$$\tilde{R} < \bar{R} = \phi \sum_{n=1}^{N} \sum_{k=1}^{K} \mathbb{E}[\log(1 + \gamma_{nk})] \tag{3.15}$$

[69] Li Y., Baduge G.A.A.: NOMA-Aided Cell-Free Massive MIMO Systems, in IEEE Wireless Communications Letters, Vol. 7, no. 6, pp. 950–953, Dec. 2018, DOI: 10.1109/LWC.2018.2841375.

where the $\bar{\tilde{R}}$ is the achievable sum rate given of NOMA-aided Cell-Free Massive MIMO and written as:

$$\tilde{R} = \sum_{n=1}^{N} \sum_{k=1}^{K} \tilde{R}_{n,k} \tag{3.16}$$

Plotting the achievable sum rate compared to OMA counterpart as shown in figure below, we find that NOMA offers a better performance in cell-free massive MIMO.

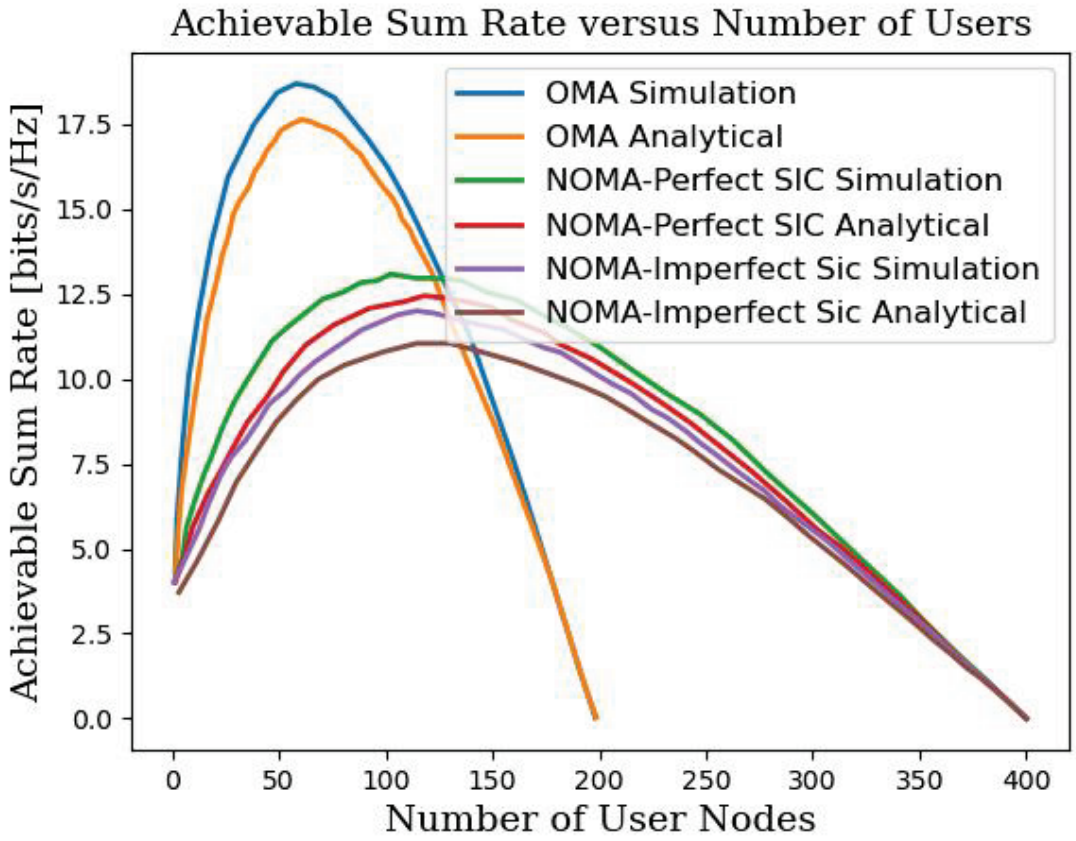

Fig. 14.9. The achievable sum rate versus the number of users
Rys. 14.9. Suma szybkości w zależności od liczby użytkowników
Source: based on Li Y., Baduge G.A.A.: NOMA-Aided Cell-Free Massive MIMO Systems, in IEEE Wireless Communications Letters, Vol. 7, no. 6, pp. 950–953, Dec. 2018, DOI: 10.1109/LWC.2018.2841375.

14.4. Conclusion

This chapter provides first a literature review of Cell-free massive MIMO and NOMA. Then we review the state-of-art of available literature on integrating the two. Finally, we study a simple system channel and signals and the achievable rate of NOMA-

-Aided Cell-free massive MIMO. NOMA is prioritized as one of the possible next-generation Multiple Access, while Cell-free massive MIMO should solve the current problems of cellular communications while ensuring broader coverage. In conclusion, integration of the two would reap the benefits of both and would satisfy the stringent requirements of the subsequent mobile wireless communications and would likely to solve various connectivity problems that are encountered by existing and future smart city systems.

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TECHNOLOGIES AND TRENDS IN PLANNING AND DEVELOPMENT OF SMART CITY

Summary

The subject matter of the monograph, which we present to the readers, is an attempt to introduce the concept of smart cities (SC). It should be emphasized that this concept, which in the authors' intention is presented in this monograph, can be understood very broadly and refer to very different areas of science. The whole monograph consists of fourteen chapters covering a wide range of issues, ranging from the philosophical and sociological concept of SC (the first three chapters), urban planning and design problems (chapters 4–6) and the issues of modern material, digital and telecommunications technologies.

Chapter 1 by Zbigniew Orbik "On the axiological foundations of the smart city concept" attempts to capture the issues of the values underlying the SC concept. The development of SC is treated as an example of sustainable development. One can find certain philosophical assumptions, axiological, underpinning both of these projects. Selected concepts of the axiology of sustainable development and the basic emerging problems are presented. The paper also proposes to build the axiological foundation of the title concept based on the Platonic triad: the Good, Truth, Beauty supplemented with the values of Freedom and Justice.

Chapter 2 by Waldemar Czaikowski "Ontology of (smart) city and its practical relevance" focuses on the specific concept of the smart city. The main idea is to present the concept of the ontology of the city as a tool for the assessment/evaluation of knowledge about the city as a whole and the concept of the possibility of assessing the completeness/incompleteness of this knowledge is presented. According to the concept, ontology can also serve as a kind of "knowledge map" indicating which part of academic knowledge is most relevant for diagnosing and solving this or that practical problem. The perspective offered by ontology can help make such debates more substantive and rational.

Chapter 3 by Anna Lessaer-Kentzer “The smart city and smart urbanism using the master plan method in the planning and design process of implementing smart urbanism solutions” focuses on the study of possible relationships between the concept of a SC and the planning and design process. The author points out that the creation of the city's space has not yet found its proper place in scientific queries. The aim of this chapter is to try to fill this gap and to embed the planning and design processes within the concept of the SC. In order to identify what a SC is from an urban planning perspective; the author analyses the impact of demographic growth on urban development with the characteristics and factors that constitute the criteria for evaluating a SC. At the same time, the author points to the need to introduce an additional area of activity within the concept of the Smart City, which takes into account the process of creating urban space, in a creative and non-standard approach. This is defined as Smart Urbanism. The accepted understanding is that this term refers to a range of planning and design activities in the urban domain that technology cannot replace.

Chapter 4 by Grażyna Osika “Ambient design as a social innovation for smart cities of society 5.0” focuses on the analysis of the development strategy announced in Japan in 2016 referred to as Society 5.0. This strategy has become a kind of vision of the society of the future around the world and is referred to as Society 5.0. This concept implies a strong human focus that balances economic development with solving social problems, thanks to the widespread use of digital technology. This vision must take into account another global trend – urbanization, the high density of life in the city will force the introduction of solutions to preserve the well-being of its inhabitants. In this study, the potential of ambient design as a valuable complement to the SC for Society 5.0 concept is analyzed. It is assumed that the proposed approach can help to develop theoretical reflection resulting in the introduction of specific solutions within the framework of city management with the use of smart technological solutions.

Chapter 5 by Mateusz Piegza “Repurposing empty spaces as a part of municipal programs for urban regeneration” focuses on the literature of the subject. The chapter analyze mainly expert studies prepared by the Institute of Urban and Regional Development and selected Polish local programs for the revitalization of Polish cities, and then to determine the potential and barriers to the adaptation of vacant buildings as part of their revitalization programs. The paper has been enriched with illustrations

showing examples of projects implemented as part of revitalization programs. The chapter recommends extending the research on revitalization programs to include housing projects that are based on the adaptation of empty spaces into residential space.

Chapter 6 by Paulina Gama Marques "Nature-based solutions for urban water management. Analysis of housing estates in Gdańsk, Gdynia and Warsaw" focuses on nature-based solutions for urban water management. These solutions provide important contribution in mitigation to climate change and therefore research in this area has increased exponentially in the last years. The persistent gap between theory and practice continuous to pervade the design of rainwater management systems (RMS). The study conducts a systemic review of three contemporary housing estates in Gdańsk, Gdynia and Warsaw to investigate whether presented design meets criteria of nature-based solutions in the background of climate mitigation. RMS is defined as elements infiltrating, temporary retaining or infiltrating and temporary retaining rainwater that are connected together by the water flow. An innovative design-oriented approach is subsequently applied to critically review housing estates considering comprehensive spectrum of definition of RMS and criteria of NBS. The specific objects are: overall evaluation of the area division into use, identification of the terrain profile, description of the RMS for every estate, presentation of the typical element of each system. The results support a call that implementation of elements of RMS doesn't shape the system itself.

Chapter 7 by Sandra Przepiórkowska, Aleksandra Śliwa and Jakub Świdziński "Mycelium-based insulation materials as an ecological alternative to mineral wool" focuses on the use of modern insulation materials. Organic materials such as mycelium, which originates from fungi, are a promising alternative to the commonly used polymers, mineral wools and glass-based insulations. With comparable technical parameters it is possible to produce insulation with significantly lower energy consumption and with the possibility of subsequent natural decomposition. Technical parameters of materials based on mycelium are comparable to those represented by mineral wools. The research includes comparative analyses of both materials on the basis of conventional solutions using mineral and glass wools in order to verify the possibility of changing existing technologies to more ecological and sustainable ones.

Chapter 8 by Grzegorz Peruń "Review and development of data sources used in geographic information systems" focuses on geographic information system (GIS) sources. The overview of geographic data sources used in GIS presented in this chapter of the monograph was aimed at showing the diversity of data acquisition

methods. It is preceded by the characteristics of geographical data and all the basic information that allows you to understand the whole issue. The characteristics of the discussed data are largely determined by the way they are obtained and the form in which they feed the databases. A different set of data can be obtained with the help of data obtained during field measurements, another with the help of aerial and satellite images. The main selection factor here is the form of the data (vector or raster data) and how much additional information, the so-called metadata, accompanies it. The analysis of the development of data sources focuses mainly on satellite images, presenting the characteristics of the most famous satellites used for data acquisition, both public and private. A lot of space was devoted to the presentation of the achievements of the Landsat program, which has set certain standards for the last 50 years.

Chapter 9 by Aleksander Śliwa "Virtual reality technology in the context of smart living" focuses on virtual world. The author draws attention to the constant evolution of the idea of SC, including successive issues rooted in urbanization. The idea of SC is constantly evolving in order to address further issues of urbanization. Expansion of the field of research results from the specificity of cities themselves, which are multidimensional creations with difficult to define boundaries, both in the material and abstract sense. Contemporary agglomerations are formulated by two parallel realities: physical and virtual. The basic elements of cities understood as complex systems are dwellings that enable existence in both these spheres. Smart homes contribute to SC by using ICT technologies to create a useful environment. However, the usefulness of cyberspace is not limited to the modernization of real structures but constitutes an autonomous reality capable of satisfying selected needs of users. The research includes analyses of inhabitation processes in the context of the application of virtual reality technologies. The results indicate that cyberspace can complement the physical substance of dwellings.

Chapter 10 by Adam Dustor "Biometric systems in smart cities" examines biometric verification systems. According to the author, SC will make extensive use of identity verification and identification systems based on artificial intelligence algorithms and biometric features of residents. Despite many risks associated with this it seems that with the provision of adequate supervision of sensitive information, the potential benefits outweigh the drawbacks of such "permanent" surveillance. The paper discusses the issue of biometric recognition of people based on both physical and behavioral characteristics with particular emphasis on voice identification and verification. The classification of voice recognition systems is presented, basic

functional blocks such as parameter extraction and voice modelling are discussed, the problem of errors in voice recognition systems is also addressed. An example of identity verification system based on unique features of human voice and implemented using open-source software written in Python language was presented. Advanced statistical modelling based on Gaussian mixtures was applied to create voice models. The obtained recognition error values allow such a biometric system to be implemented as an additional security level, for example in access control systems.

Chapter 11 by Grzegorz Dziwoki, Marcin Kucharczyk and Wojciech Sułek "IMT 2020 mobile networks as universal wireless transmission platform" focuses on international mobile telecommunications systems (IMT). The authors point out that the current deployed wireless mobile systems and their future upgrades are designed to provide users with universal access to a wide range of digital services. The variety of these services influences a large variation in the nature of the processed data and thus requires a flexible approach to their transmission. In order to effectively use the available bandwidth, the system should adjust the amount of resources necessary for the transmission taking into account, among others, the required transmission speed, delay or reliability of transmitted data. It is also important to reduce the energy consumption in the case of end terminals. This chapter will present the requirements for IMT 2020 systems in relation to the type of services for which the information exchange process is carried out. In addition, the basic information processing techniques used in these systems will be discussed using the example of 5th generation (5G) networks.

Chapter 12 by Marcin Kucharczyk, Grzegorz Dziwoki and Wojciech Sułek "Wireless connectivity standards for Internet of Things devices in smart cities" focuses on the Internet of Things (IoT). IoT is one of the technologies that changes physical objects into smart objects, with the possibilities to improve live in cities. IoT needs wireless communication protocols designed and optimized specifically for massive machine type communications, with energy efficiency and massive number of devices being the main desired features. Wireless IoT architecture standardization is important, because it enables manufacturers to deliver versatile and high-quality products. This chapter summarizes the latest wireless technology developments that play an important role in the IoT landscape. Specifically, it concentrates on the standardized technologies that are supported by the existing and developed cellular networks infrastructure, namely the EC-GSM-IoT, LTE-M and NB-IoT standards.

Chapter 13 by Piotr Kłosowski “Improving reliability of distance education infrastructure in crisis situations using artificial intelligence and deep learning applications” focuses on the assessment of the performance of the IT infrastructure. The main objective of the research presented in this paper was to try to use artificial intelligence and deep learning techniques to improve the performance of ICT servers, which are part of the Distance Education Platform of the Silesian University of Technology, during a period of the extremely intensive load caused by the operation of distance education during a pandemic. The issues described in the article show that improving server operation and performance, especially in a period of extreme loads, is a complex problem and very difficult to solve effectively. The examples of experiments presented in the article show that the application of artificial intelligence techniques may be a chance for a more effective solution to this type of problem, allowing not only to predict the daily demand for computing power and resources of servers responsible for supporting distance education but also may effectively contribute to improving the safety of server operation by properly reserving computing power and resources of servers and making them available when necessary. The results obtained appear to be very promising and offer the prospect of further research towards the use of artificial intelligence and deep machine learning techniques to improve the reliability of ICT infrastructure and the operation of network servers.

Chapter 14 by Antonio Apiyo and Jacek Izydorczyk “NOMA – aided cell-free massive MIMO – a review” presents a complex analysis of network capacity. This paper is written to systematize readers' knowledge of non-orthogonal multiple-access (NOMA) networks and massive cell-free multiple-input multiple-output (MIMO) networks. In addition to presenting the state of the art based on the analysis of current research work, a complete model of the system is provided in the chapter. According to the authors, due to its performance superior to orthogonal multi-input OMA networks, the integration of NOMA networks with cell-free massive MIMO technology is promising for future wireless communications.

TECHNOLOGIE I TRENDY W PLANOWANIU I ROZWOJU INTELIGENTNEGO MIASTA

Streszczenie

Tematyka pracy, którą oddajemy w ręce czytelników, stanowi pewną próbę wprowadzenia do koncepcji inteligentnych miast (SC – smart city). Należy podkreślić, że pojęcie to – co w zamyśle Autorów pokazuje niniejsza monografia – może być rozumiane bardzo szeroko i dotyczyć bardzo różnych obszarów nauki. Na całość pozycji składa się czternaście artykułów obejmujących rozległe spektrum zagadnień, począwszy od filozoficznej i socjologicznej koncepcji inteligentnych miast (pierwsze trzy rozdziały), problemów urbanistyczno-projektowych (rozdziały 4–6), a skończywszy na zagadnieniach nowoczesnych technologii materiałowych, cyfrowych i telekomunikacyjnych.

W rozdziale 1 autorstwa Zbigniewa Orbika „O aksjologicznych podstawach koncepcji smart city" przedmiotem rozważań jest próba uchwycenia problematyki wartości leżących u podstaw idei inteligentnego miasta. Rozwój inteligentnych miast traktuje się jako egzemplifikację rozwoju zrównoważonego. Podwaliny obu tych projektów to pewne założenia natury filozoficznej i aksjologicznej. W pracy zaprezentowano wybrane koncepcje aksjologii zrównoważonego rozwoju oraz podstawowe wyłaniające się przy tym problemy. Artykuł zawiera również propozycję budowy aksjologicznego fundamentu tytułowej koncepcji na podstawie Platońskiej triady: dobro, prawda, piękno, uzupełnioną o wartości, jakimi są wolność oraz sprawiedliwość.

W rozdziale 2 przedstawiona została praca autorstwa Waldemara Czajkowskiego „Ontologia (inteligentnego) miasta i jej praktyczne znaczenie". W opisywanym rozdziale zaprezentowano koncepcję ontologii miasta jako narzędzia do oceny/ewaluacji wiedzy o mieście jako całości oraz koncepcję możliwości oceny kompletności/niekompletności tej wiedzy. Zgodnie z przedstawioną koncepcją ontologia może również służyć jako swego rodzaju „mapa wiedzy" wskazująca, która część wiedzy akademickiej jest najbardziej istotna dla diagnozy i rozwiązania tego czy

innego problemu praktycznego. Perspektywa oferowana przez ontologię może pomóc uczynić takie debaty bardziej rzeczowymi i racjonalnymi.

W rozdziale 3 „Inteligentne miasto i inteligentna urbanistyka. Metoda master planu w procesie planowania, projektowania i wdrażania rozwiązań smart urbanism" Anna Lessaer-Kentzer koncentruje się na badaniu możliwych związków pomiędzy koncepcją inteligentnego miasta a procesem planistyczno-projektowym. Autorka zwraca uwagę, że kreacja przestrzeni miasta nie znalazła dotychczas właściwego miejsca w kwerendach naukowych. Celem artykułu jest próba uzupełnienia tej luki i osadzenia procesów planistycznych i projektowych w koncepcji inteligentnego miasta. W celu przedstawienia, czym jest tak rozumiane miasto z perspektywy urbanistycznej, Autorka analizuje wpływ zjawiska wzrostu demograficznego na rozwój miast, a także cechy i czynniki tworzące ramy do jego oceny. Autorka wskazuje przy tym potrzebę wprowadzenia dodatkowego obszaru działań w ramach strategii inteligentnego miasta, która uwzględnia proces tworzenia przestrzeni miasta w sposób kreatywny i niestandardowy. Autorka określa te działania mianem inteligentna urbanistyka.

W przyjętym rozumowaniu pojęcie to odnosi się do licznych działań planistycznych i projektowych w obszarze miasta, których technologia nie jest w stanie zastąpić.

W rozdziale 4 autorstwa Grażyny Osiki „Ambient design jako innowacja społeczna dla inteligentnych miast „społeczeństwa 5.0" skupiono się na analizowaniu ogłoszonej w Japonii w 2016 roku strategii rozwojowej określanej mianem społeczeństwa 5.0. Strategia ta jest swoistą wizją społeczeństwa przyszłości na całym świecie. Koncepcja ta zakłada silne skoncentrowanie się na człowieku, które zrównoważy rozwój gospodarczy z rozwiązywaniem problemów społecznych przez wykorzystanie technologii cyfrowej. W wizji tej musi zostać uwzględniony inny globalny, trend jakim jest urbanizacja. Duże zagęszczenie życia w mieście będzie wymuszało wprowadzanie rozwiązań pozwalających zachować dobrostan jego mieszkańców. W niniejszych rozważaniach przeanalizowano pod kątem potencjału „ambient design" jako cenne uzupełnienie koncepcji inteligentnego miasta dla społeczeństwa 5.0. Wykorzystano tu analizę konceptualną, przyjmując, że proponowane podejście może pomóc w rozwijaniu teoretycznej koncepcji skutkującej w efekcie wprowadzaniem konkretnych rozwiązań w ramach zarządzania miastem z wykorzystaniem technologicznych rozwiązań SMART.

W rozdziale 5 przedstawiona została praca autorstwa Mateusza Piegzy „Zmiana przeznaczenia pustych przestrzeni w ramach miejskich programów rewitalizacji

obszarów miejskich”. Celem artykułu jest analiza literatury przedmiotu, głównie opracowań eksperckich przygotowanych przez Instytut Rozwoju Miast i Regionów, oraz wybranych polskich lokalnych programów rewitalizacji polskich miast, a następnie określenie potencjału i barier adaptacji pustostanów w ramach programów ich rewitalizacji. Artykuł wzbogacony został o ilustracje przedstawiające przykładowe projekty realizowane w ramach programów rewitalizacyjnych. W pracy rekomenduje się poszerzenie badań nad programami rewitalizacyjnymi o projekty mieszkaniowe, które opierają się na adaptacji pustych przestrzeni na przestrzeń mieszkalną.

W rozdziale 6 przedstawiona została praca autorstwa Pauliny Gama Marques „Nature-based solutions w zarządzaniu miejską wodą deszczową. Analiza osiedli mieszkaniowych w Gdańsku, Gdyni i Warszawie”. Przedmiotem badań są tu naturalne rozwiązania w zakresie gospodarki wodnej w miastach, wnoszące istotny wkład w łagodzenie zmian klimatu. W opracowaniu dokonano systemowego przeglądu trzech współczesnych osiedli mieszkaniowych w Gdańsku, Gdyni i Warszawie pod kątem zgodności projektu z kryteriami rozwiązań naturalnych w kontekście łagodzenia zmian klimatu. Systemy zagospodarowania wody deszczowej (SZWD) definiuje się jako elementy infiltrujące, czasowo zatrzymujące lub infiltrujące i czasowo zatrzymujące wodę deszczową, które są ze sobą połączone dzięki przepływającym strumieniom wody. Innowacyjne podejście zorientowane na projektowanie jest następnie stosowane do krytycznego przeglądu osiedli mieszkaniowych z uwzględnieniem szerokiego spektrum definicji SZWD i kryteriów NBS (nature-based solutions). Poszczególne elementy oceny to: ogólna ocena podziału powierzchni do wykorzystania, identyfikacja profilu terenu, opis SZWD dla każdego osiedla, prezentacja typowego elementu systemu.

W rozdziale 7 autorstwa Sandry Przepiórkowskiej, Aleksandry Śliwy i Jakuba Świdzińskiego „Materiały izolacyjne na bazie mycelium jako ekologiczna alternatywa dla wełny mineralnej” skupiono się na zastosowaniu nowoczesnych materiałów izolacyjnych. Materiały pochodzenia organicznego, takie jak mycelium, stanowią obiecującą alternatywę dla stosowanych powszechnie polimerów, wełny mineralnej oraz izolacji na bazie szkła. Przy zachowaniu porównywalnych parametrów technicznych możliwa jest produkcja izolacji przy znacznie mniejszym zużyciu energii oraz z możliwością późniejszego naturalnego rozkładu. Parametry techniczne materiałów na bazie mycelium są porównywalne z tymi reprezentowanymi przez wełnę mineralną. Badania obejmują analizy porównawcze obu materiałów na podstawie konwencjonalnych rozwiązań wykorzystujących wełny mineralne w celu weryfikacji możliwości zmiany istniejących technologii.

W rozdziale 8 autorstwa Grzegorza Perunia „Przegląd i rozwój źródeł danych wykorzystywanych w systemach informacji geograficznej” skupiono się na źródłach GIS (Geographic Information System). Przedstawiony w niniejszym rozdziale monografii przegląd źródeł danych geograficznych wykorzystywanych w GIS miał na celu ukazanie różnorodności sposobów pozyskiwania danych. Poprzedza go charakterystyka danych geograficznych oraz wszystkich podstawowych informacji pozwalających zrozumieć całe zagadnienie. Charakterystyka omawianych danych jest w dużej mierze zdeterminowana przez sposób ich pozyskiwania oraz formę, w jakiej zasilają bazy danych. Inny zestaw danych można uzyskać za pomocą danych pozyskanych podczas pomiarów terenowych, inny za pomocą zdjęć lotniczych i zdjęć satelitarnych. Głównym czynnikiem wyboru jest tutaj forma danych (dane wektorowe czy rastrowe) oraz ile dodatkowych informacji, tzw. metadanych, im towarzyszy. Analiza rozwoju źródeł danych skupia się głównie na zdjęciach satelitarnych, prezentujących charakterystykę najsłynniejszych satelitów wykorzystywanych do pozyskiwania danych zarówno publicznych, jak i prywatnych. Wiele miejsca poświęcono prezentacji osiągnięć programu Landsat, który przez ostatnie 50 lat wyznaczał pewne standardy.

W rozdziale 9 autorstwa Aleksandra Śliwy „Technologia wirtualnej rzeczywistości w kontekście inteligentnego zamieszkiwania” skupiono się na wirtualnej rzeczywistości. Autor zwraca uwagę na stałą ewolucję idei inteligentnych miast obejmującą kolejne zagadnienia zakorzenione w urbanizacji. Rozszerzanie pola badań wynika tu ze specyfiki samych miast stanowiących wielowymiarowe twory o trudnych do zdefiniowania granicach tak w sensie materialnym, jak i abstrakcyjnym. Współczesne aglomeracje są formułowane przez dwie równoległe rzeczywistości: fizyczną oraz wirtualną. Podstawowymi elementami miast rozumianych jako złożone systemy są mieszkania umożliwiające egzystencję w obu tych sferach. Inteligentne domostwa współtworzą inteligentne miasta, wykorzystując technologie ICT (Information and Communications Technology) do kreacji użytecznego środowiska. Użyteczność cyberprzestrzeni nie ogranicza się jednak do modernizacji realnych struktur, ale stanowi autonomiczną rzeczywistość zdolną do zaspokajania wybranych potrzeb użytkowników. Badania przedstawione w pracy obejmują analizy procesów zamieszkiwania w kontekście wykorzystania technologii wirtualnej rzeczywistości. Wyniki badań wskazują, że cyberprzestrzeń może uzupełniać fizyczną tkankę mieszkań.

W rozdziale 10 autorstwa Adama Dustora „Systemy biometryczne w inteligentnych miastach” analizowano systemy weryfikacji biometrycznej. Zdaniem Autora inteligentne miasta w szerokim zakresie wykorzystywać będą systemy weryfikacji i identyfikacji tożsamości oparte na algorytmach sztucznej inteligencji oraz wykorzystujących biometryczne cechy mieszkańców. Pomimo wielu zagrożeń z tym związanych wydaje się, że przy zapewnieniu odpowiedniego nadzoru nad informacjami wrażliwymi potencjalne korzyści przeważają nad wadami takiej permanentnej inwigilacji. W pracy omówiono problematykę biometrycznego rozpoznawania osób opartego na cechach zarówno fizycznych, jak i behawioralnych ze szczególnym uwzględnieniem głosowej identyfikacji i weryfikacji tożsamości. Przedstawiona została klasyfikacja systemów rozpoznawania głosu, omówiono podstawowe bloki funkcjonalne, takie jak ekstrakcja parametrów i modelowanie głosu, oraz poruszono zagadnienie błędów w systemach rozpoznawania głosu. Zaprezentowany został przykładowy system weryfikujący tożsamość, opierający się na unikalnych cechach głosu ludzkiego i zrealizowany za pomocą otwartego oprogramowania napisanego w języku Python. Do stworzenia modeli głosu użyto zaawansowanego modelowania statystycznego opartego na mieszaninach gaussowskich. Uzyskane wartości błędów rozpoznawania pozwalają na zastosowanie takiego systemu biometrycznego jako dodatkowego zabezpieczenia przykładowo w systemach kontroli dostępu.

W rozdziale 11 autorstwa Grzegorza Dziwoki, Marcina Kucharczyka i Wojciecha Sułka „Sieci mobilne IMT 2020 jako uniwersalna bezprzewodowa platforma” skupiono się na systemach mobilnych (IMT – International Mobile Telecommunications). Autorzy zwracają uwagę, że obecnie wdrażanym bezprzewodowym systemom mobilnym oraz ich przyszłym aktualizacjom stawia się za zadanie zapewnienie użytkownikom powszechnej dostępności do szerokiego wachlarza usług cyfrowych. Różnorodność tych usług wpływa na duże zróżnicowanie charakteru przetwarzanych danych, a tym samym wymaga elastycznego podejścia do ich transmisji. Aby efektywnie wykorzystać dostępną przepustowość, system powinien dostosować ilość zasobów niezbędnych do przeprowadzenia transmisji, uwzględniając m.in. wymaganą prędkość transmisji, opóźnienie czy wiarygodność przesyłanych danych. Nie bez znaczenia jest także redukcja zapotrzebowania energetycznego w przypadku terminali końcowych. W niniejszym rozdziale przedstawiono wymagania stawiane systemom IMT 2020 w odniesieniu do rodzaju usług, na rzecz których

realizowany jest proces wymiany informacji. Ponadto omówione zostały podstawowe techniki przetwarzania informacji zastosowane w tych systemach na przykładzie sieci 5 generacji (5G).

W rozdziale 12 autorstwa Marcina Kucharczyka, Grzegorza Dziwoki i Wojciecha Sułka „Standardy łączności bezprzewodowej dla urządzeń internetu rzeczy w inteligentnych miastach" skupiono się na internecie rzeczy (IoT – Internet of Things). Internet rzeczy to jedna z technologii, która zmienia obiekty fizyczne w inteligentne obiekty, z możliwością poprawy życia w miastach. Wymaga on protokołów komunikacji bezprzewodowej zaprojektowanych i zoptymalizowanych specjalnie pod kątem masowej komunikacji urządzeń, przy czym głównymi pożądanymi cechami są efektywność energetyczna i obsługa ogromnej ich liczby. Standaryzacja architektury bezprzewodowego IoT jest ważna, ponieważ umożliwia producentom dostarczanie wszechstronnych produktów wysokiej jakości. W tym rozdziale podsumowane zostały najnowsze osiągnięcia w dziedzinie technologii bezprzewodowych, które odgrywają ważną rolę w krajobrazie IoT. W szczególności skoncentrowano się na ustandaryzowanych technologiach, które są wspierane przez istniejącą i rozwijaną infrastrukturę sieci komórkowych, a mianowicie na standardach EC-GSM-IoT, LTE-M i NB-IoT.

W rozdziale 13 autorstwa Piotra Kłosowskiego „Poprawa niezawodności infrastruktury informatycznej platformy zdalnej edukacji w sytuacjach kryzysowych z wykorzystaniem sztucznej inteligencji oraz głębokiego uczenia maszynowego" skupiono się na ocenie wydajności infrastruktury informatycznej. Głównym celem badań przedstawionych w niniejszym rozdziale była próba wykorzystania sztucznej inteligencji i technik głębokiego uczenia maszynowego do poprawy wydajności infrastruktury informatycznej, wchodzącej w skład Platformy Zdalnej Edukacji Politechniki Śląskiej, w okresie niezwykle intensywnego wzrostu obciążenia spowodowanego koniecznością masowej obsługi kształcenia na odległość w czasie pandemii spowodowanej koronawirusem. Opisane w artykule zagadnienia pokazują, że poprawa działania i wydajności serwerów, zwłaszcza w okresie ekstremalnych obciążeń, jest problemem złożonym i bardzo trudnym do skutecznego rozwiązania. Przedstawione w pracy przykłady eksperymentów pokazują, że zastosowanie technik sztucznej inteligencji może być szansą na skuteczniejsze rozwiązanie tego typu problemów. Zastosowanie sztucznej inteligencji może również pozwalać na przewidywanie dziennego zapotrzebowania na moc obliczeniową i zasoby serwerów odpowiedzialnych za obsługę nauczania na odległość, przyczynić się do poprawy bezpieczeństwa ich pracy oraz dostępności w sytuacji, gdy zachodzi taka konieczność.

Uzyskane w pracy wyniki są perspektywiczne i stwarzają możliwość dalszych badań w kierunku zastosowania sztucznej inteligencji oraz technik głębokiego uczenia maszynowego w zagadnieniach poprawy niezawodności infrastruktury informatycznej.

W rozdziale 14 autorstwa Antonio Apiyo i Jacka Izydorczyka „Integracja sieci NOMA z masywną bezkomórkową siecią MIMO – stan wiedzy" przedstawiono złożoną analizę dotyczącą przepustowości sieci. Celem rozdziału jest tu usystematyzowanie wiedzy czytelników na temat nieortogonalnych sieci wielowejściowych NOMA oraz masywnych bezkomórkowych sieci MIMO. W rozdziale oprócz przedstawienia stanu wiedzy na podstawie analizy aktualnych prac badawczych dostarczono kompletny model systemu. Zdaniem autorów ze względu na wydajność przewyższającą ortogonalne wielowejściowe sieci OMA integracja sieci NOMA z bezkomórkową technologią massive MIMO jest obiecująca dla przyszłej komunikacji bezprzewodowej.

WYDAWNICTWO POLITECHNIKI ŚLĄSKIEJ
ul. Akademicka 5, 44-100 Gliwice
tel. (32) 237-13-81,
wydawnictwo@polsl.pl

www.wydawnictwopolitechniki.pl

UIW 48600

Sprzedaż i Marketing
tel. (32) 237-18-48
wydawnictwo_mark@polsl.pl

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