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ANALYSIS OF SMART CITY ARCHITECTURE MODELS

Urbanization along with the fast ICTs development and its increasing availability for people around the globe lead to the emerging concept of Smart Sustainable Cities. In order to build a successful model, cities must ensure that there is proper infrastructure in place. Thus, the aim of the article is to look at existing architecture models in the academic environment (multi-layered model, data-based model, etc.), as well as at the real-functioning models in smart cities that are considered to be progressive (Chicago, Singapore, Barcelona) and Kyiv, for comparison. And suggest a summary model for Ukrainian cities that will take into account the studied experience. In addition, the article studies the criteria for architecture efficiency provided by international organizations (UNCTAD, ISO). The international experience in developing the architecture of smart cities is important in the context of the active concept development in Ukrainian cities.
Key words: *smart sustainable city, architecture, multi-layered model, urbanization, ICTs.*

Problem statement. Urbanization along with the fast ICTs development and its increasing availability for people around the globe lead to the emerging concept of Smart Sustainable Cities. The concept aims to connect economic, political, social innovations already happening or just desired in the society with ICTs to solve the pressing urban challenges.

The concept has successfully overcome the limitations of the initial strictly technologically focused model (Smart City 1.0) and currently is focused on creating people-oriented cities with broadening citizens opportunities to affect decision-making process (Smart City 3.0).

Municipalities **aim** to use this model to tackle the issues they encounter on the local level like overpopulation, pollution, traffic, lack of resources and services, etc.

However, to make the model work successfully, it's important to ensure there is an appropriate architecture on the local and national levels to develop and support the model.

The article aims to review different models suggested by academic sector as well as real-life functional city models from Singapore, Chicago, Barcelona, Kyiv, and create a summary model, which can be used as a basis for Ukrainian cities.

Analysis of recent research and publications. The topic is on the agenda of such organizations as UNCTAD, ISO, ITU that contributed greatly to the principles and possible component models of different cities. Also, works of such academics as Anthopoulos and Vakali (connection between urban planning dimensions and smart city layers) [1], Hawkins (data-based framework) [2], Robinson (multi-tier infrastructure) contributed greatly to the topic of our research [3].

Main results of the research. The term "architecture" refers to the art of designing and building structures and their complexes that form a spatial environment for human life and activities. Thus, architecture in general is an abstract idea of a certain system or structure.

Applying the term to smart city concept, the architecture refers to the organization and interconnections between all potential subsystems and elements that allow the provision of all necessary services by a smart city to end users.

Smart city architecture enhances the city's infrastructure and its abilities via the Data layer which previously was not available, see Fig. 1. And right now this layer greatly impacts the quality and the form, in which services are provided to citizens [4].

Taking into account each city tends to develop its own model, the question of common standards and principles development plays an important role in the discussion.

UNCTAD in its Paper on Smart Cities and Infrastructure has outlined the following design principles that are crucial for smart city infrastructure [5]:

– people-centred and inclusive infrastructure, meaning the infrastructure should respond to the needs of people instead of just focusing on "technology-centric" approach. The infrastructure should take into account citizens' lifestyle, culture, behaviour, needs. And it should ensure inclusiveness.

– resilience and sustainability, meaning cities should be able to survive, adapt and thrive in the face of stress and shocks. Moreover, they should be able to transform when conditions require it.

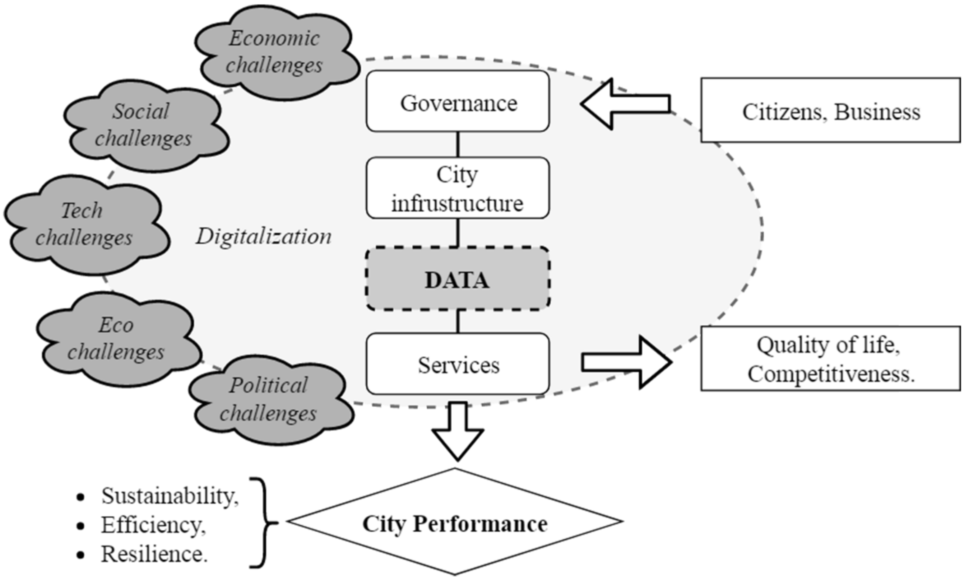

Fig. 1. Smart City Architecture [4]

– interoperability and flexibility should allow in the future easily to replace and enhance smart city infrastructure components.

– managing risks and ensuring safety is important since smart infrastructure can be prone to hacking and illegal access. There are also concerns with regards to citizens' privacy. So, attention should be paid to the development of the needed skills and risk mitigation strategies.

On the other hand, ISO/TS 37151 outlines 14 basic needs that should be met by the efficient city infrastructure, see Fig. 2 [6]. Those can be grouped within 3 dimensions: an ecological, economic, and social perspective. Thus, they aim to cover the needs of citizens, managers, and municipality.

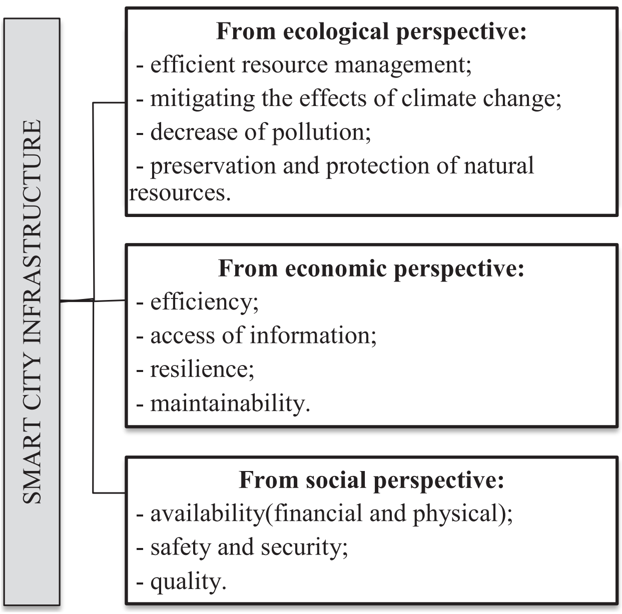

Fig. 2. General principles and requirements for Smart City Infrastructure [6]

Different scholars have contributed greatly to the topic enhancement. For example, Anthopoulos and Vakali (2012) have outlined four levels of a generic multi-tier common architecture:

– users level which includes both those who consume electronic services (end-users) and those who provide/supervise them;

– services level which covers all the e-services provided by smart city;

– infrastructure level, includes networks, informational systems and supporting objects that are required to deliver the services to the users;

– data level which is needed to accommodate all the produced, gathered and spread information [1].

Hawkins (2014) bases his model on "measuring, transferring, and managing data." The layers include: hardware (a combination of devices, sensors, networks that allow the elements to become aware of the surrounding environment), smart software (leverages the data coming from physical hardware and includes data management, analytics, optimization, and control) and supporting elements (security, power provision, communication paths, data quality and veracity) [2].

Rick Robinson, IT director of Smart Cities, Infrastructure & Property Leader at Arup, outlines six layers: "Goals"; "People"; "Ecosystem"; "Soft Infrastructures"; "City Systems" and "Hard Infrastructures". So, as we can see going beyond a simple narrow technical infrastructure term.

The analysis of the real smart cities shows that most of them also rely on multi-tier architecture [3].

McKinsey Global Institute in its research assesses the quality of deployment infrastructure through three dimensions: technology base, applications, public adoption (see Fig. 3) [7].

The assessment is based on three components: the availability of the necessary digital central nervous system; the amount of applications that have been implemented in each city to date; the perspective of the public.

According to the study, New York, Singapore, Seul, Amsterdam, and Chicago are among the leading cities in the world [7].

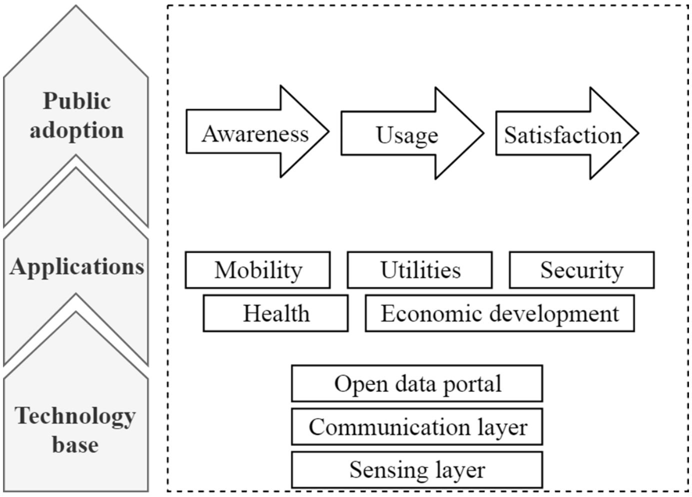

Fig. 3. The quality of deployment infrastructure [7]

Further on, we would like to review the models accepted by different cities. Chicago has started its journey with two goals: making sure everyone has proper access to the Internet and ensuring they know how to use it. Chicago has run a program with federal funding called Smart Communities (SC). The program works to increase digital access and use by families and businesses in five low-income neighbourhoods. Services include computer training classes, family and business centres, and public computer centres [8].

All the data in the city received through the sensors and networks are accumulated on the Open Data portal, applying to which predictive analytics, the city provides more effective services. Based on the open data, Chicago has already launched two IoT platforms: Array of Things and Smart Lightning (see Fig. 4).

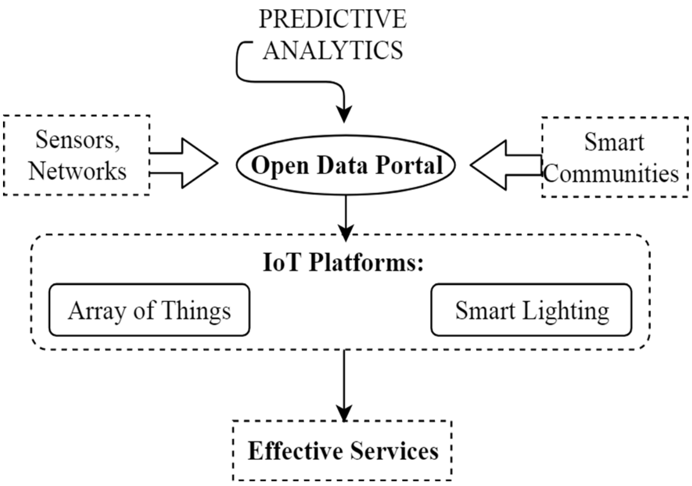

Fig. 4. Chicago Smart City Model

Source: the author's development based on [8]

In Singapore, the Smart Nation Vision comprises urban sectors (such as mobility, environment, healthcare, logistics, etc.), supporting ecosystems such as industry and manpower, and Smart Nation Platform. Smart Nation Platform is divided into two layers: Smart Nation Operating System (SN-OS) and Communications & Sensor Network (see Fig. 5). Communications & Sensor Network is foundational infrastructure for deploying essential field facilities such as smart meters, flood sensors, etc. [9]. Based on Communication & Sensor network, Smart Nation Operating System operates in three layers: sensor management, data exchange, and sense-making platform.

Barcelona's approach aims to begin with the citizens' needs at first instead of just solving a technological problem. The city's Chief Technology Officer decided to look into the ways technology can serve people, which includes such components as "democratisation of data", "digital empowerment", and "technology for the people" [10].

Since 2014, a Sentilo sensors platform was launched which allows gathering data from different sensors employed across a city. Barcelona has also developed CityOS, a standardised ontology for data that integrates with Sentilo. It allows having a single API for services to start building AI and machine learning with analysis.

The whole model is based on three components: Digital Transformations, Digital Empowerment and Digital Innovation (Fig. 6).

In the Kyiv Smart City Strategy 2020, which was developed in 2015 and accepted in 2017, we find a connection between digital infrastructure with municipality and citizens' needs. Using sensors, the city aims to collect open data, which serve as a tool to develop the needed apps and services. The key infrastructure components include but not limited to (Fig. 7):

– broadband connection;
– Internet of Things;
– smart personal devices;
– cloud computations (the city has established a City Data Centre and used cloud computations for the online budget project);
– Big Data Analysis [11].

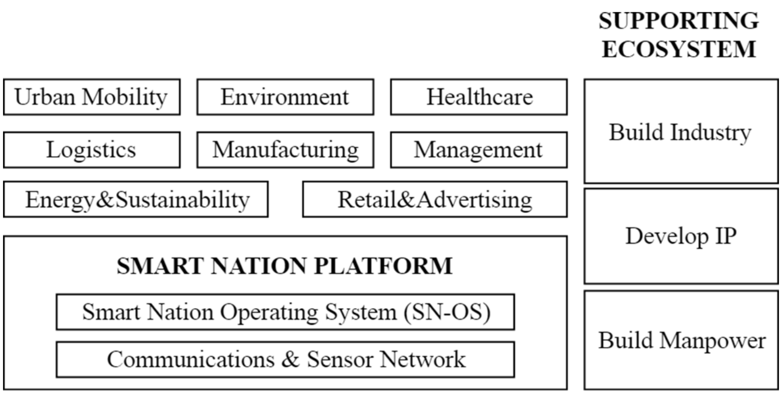

Fig. 5. Singapore Smart City infrastructure [9]

Based on the research performed, we would like to offer the following summary model to be pursued by Ukrainian cities (Fig. 8). The model takes into account not only digital infrastructure but also a physical one. Since for the old cities, this becomes a big issue to connect old physical infrastructure with smart digital infrastructure.

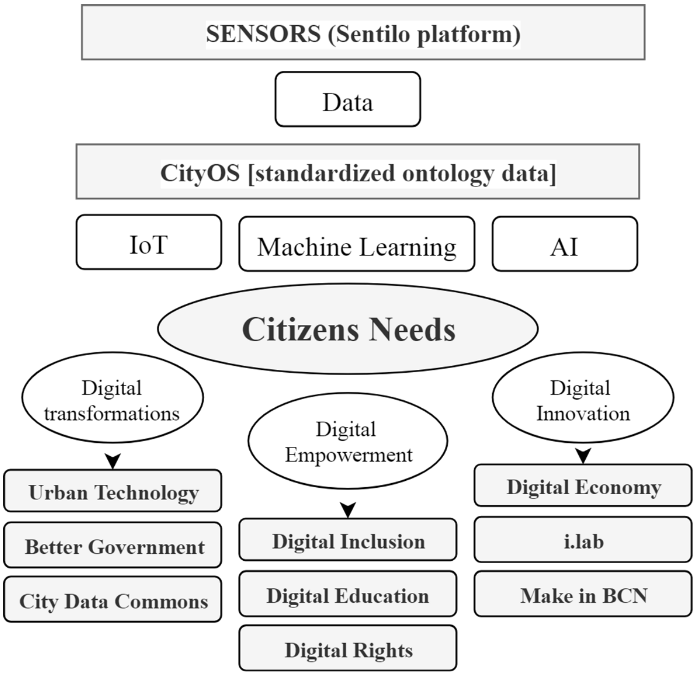

Fig. 6. Barcelona Smart City model

Source: the author's development based on [10]

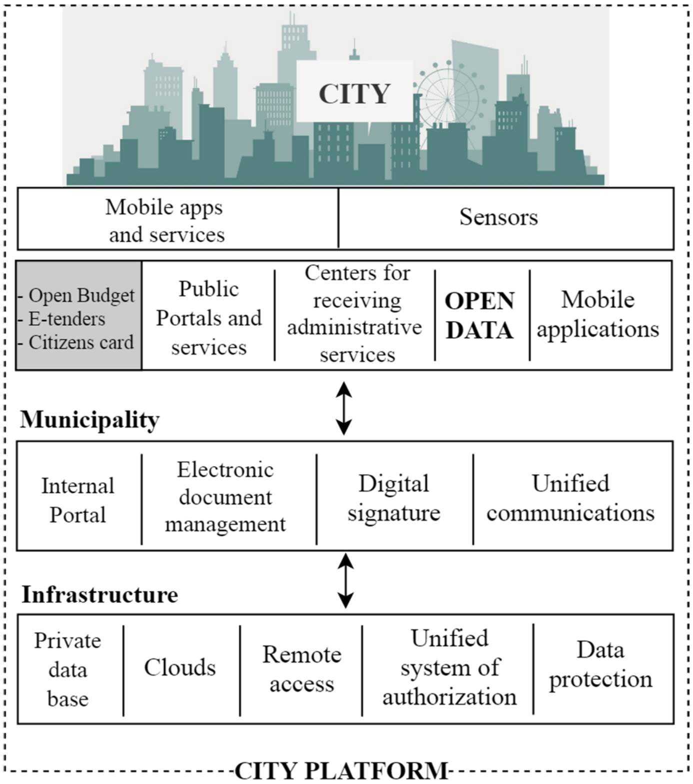

Fig. 7. Kyiv Smart City Model [11]

Fig. 8 also outlines the challenges we expect on the way of integration. Addressing the challenges for each level should contribute greatly to the concept's development success.

Conclusions. The analysis shows that even though cities might have the needed technologies to develop smart cities already available, their deployment is hampered by the technical, social, and administrative challenges [12]. Horizontal integration of infrastructures through technology is essential to reap the benefits of innovation. While the role of nationally and internationally accepted common standards are of high importance here. Since, without common terminology and procedures, stakeholders won't be able to collaborate effectively.

Nowadays the cities are mostly focused on improving the integration of historical verticals, i.e. parts of the existing utilities, improving e.g. energy efficiency or reducing water leakage. While horizontal integration (combined data from different sectors for better management) will be the second step [12].

The results of our study show that smart cities put people along with their needs at the centre of the concept. And use technologies to enhance the possibilities to meet their needs, as a tool and not as a final goal.

All the analysed cities have a pretty similar approach to digital infrastructure, which includes a sensor platform to gather the data, networks to spread it, and open data platform to store the data and use for analysis. IoT platforms are used as a bridge between the digital and physical world for more effective service provision.

In the Ukrainian context, we believe that architecture should cover physical layer, soft component along with the data layer. Material infrastructure very often has quite poor quality while proper skills and communication along with the required expertise seem to be an issue as well. The experience shows that having smart technologies is not enough; cities should also have "smart people" investing in education. And, of course, cities should stay people-focused and ensure citizens approve and understand new approaches and tools. Thus, the main challenges we see are:

– the general acceptance of new services and approaches among the society and what's even more important – inclusiveness;

– the question of integration between the old and new services;

– the level of state intervention into services provision and the question of competition;

– compatibility of the existing infrastructure (usually old) with the new technologies;

– environmental impact;

– funding sources, etc.

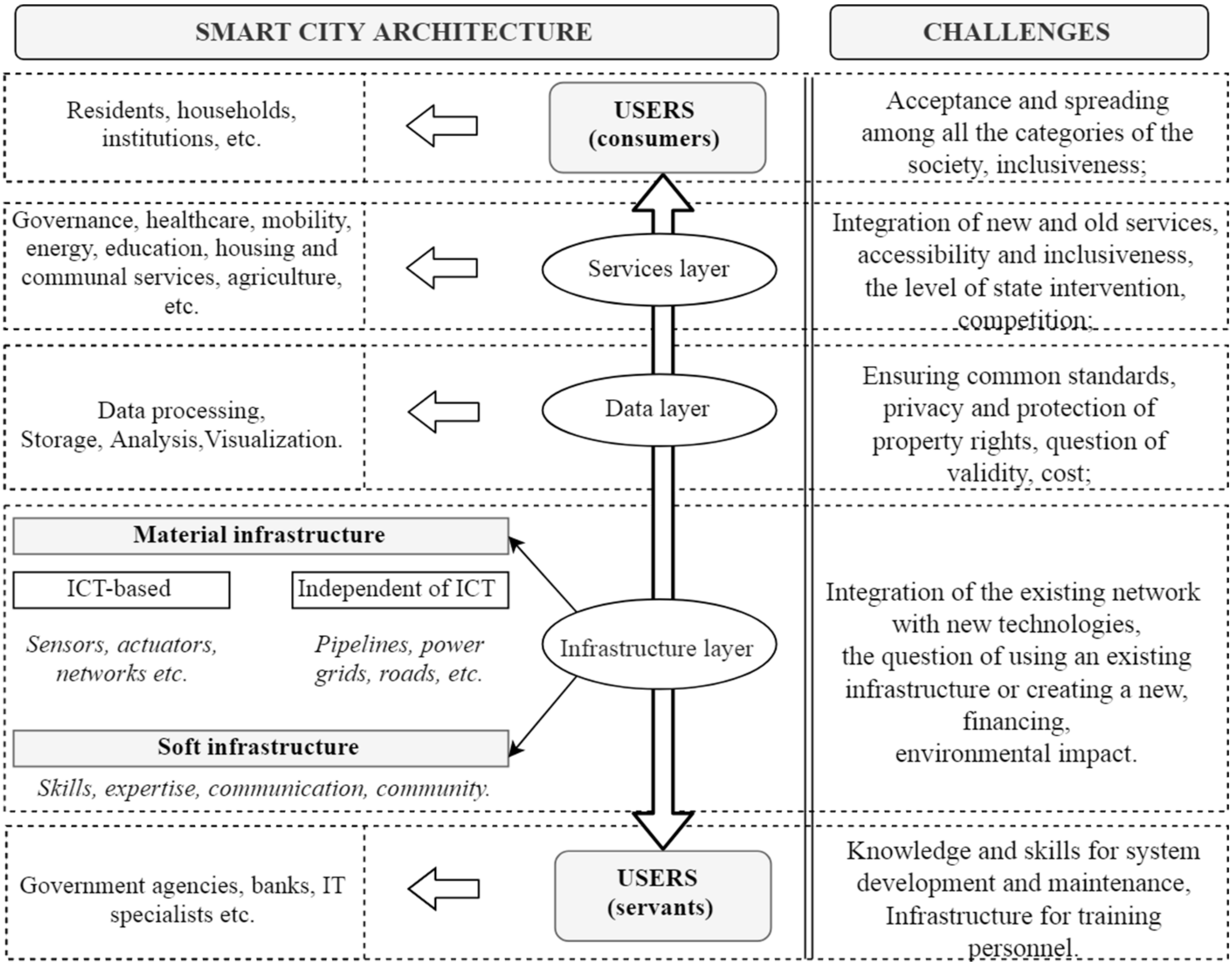

Fig. 8. Smart city infrastructure with challenges

Source: the author's development

References:

1. Anthopoulos L.G., Vakali A. (2012). *Urban Planning and Smart Cities: Interrelations and Reciprocities.* In: Álvarez F. et al. (eds) The Future Internet. FIA 2012. Lecture Notes in Computer Science, vol 7281. Springer, Berlin, Heidelberg.
2. National Institute of Urban Affairs (2015). Explanatory research on smart cities. Available at: http://cidco-smartcity.niua.org/wp-content/uploads/2015/10/Exploratory_Research_on_Smart_Cities.pdf (accessed August 2019).
3. Robinson R. (2012). *The new architecture of Smart Cities.* Available at: https://theurbantechnologist.com/2012/09/26/the-new-architecture-of-smart-cities/ (accessed August 2019).
4. Smart Cities – Management of Smart Urban Infrastructures Matthias Finger. Online course. Available at: https://www.coursera.org/learn/smart-cities (accessed August 2019).
5. UNCTAD (2016). Issues Paper On Smart Cities and Infrastructure. Available at: https://unctad.org/meetings/en/SessionalDocuments/CSTD_2015_Issuespaper_Theme1_SmartCitiesandInfra_en.pdf (accessed August 2019).
6. ISO/TS 37151 (2015). Infrastructure of smart community - General principles and requirements for performance indicators. Available at: https://www.iso.org/obp/ui/#iso:std:iso:ts:37151:ed-1:v1:en (accessed August 2019).
7. McKinsey (2018). Smart Cities: Digital Solutions for a more livable future. Available at: https://www.mckinsey.com/~/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/Smart%20cities%20Digital%20solutions%20for%20a%20more%20livable%20future/MGI-Smart-Cities-Full-Report.ashx (accessed August 2019).
8. Chicago Smart City. Available at: https://www.govtech.com/data/The-Chicago-Tech-Plan-Building-a-Model-for-Cities.html (accessed August 2019).
9. Lee, Sang Keon; Kwon, Heeseo Rain (2016). International Case Studies of Smart Cities Singapore. Available at: https://publications.iadb.org/en/international-case-studies-smart-cities-singapore-republic-singapore (accessed August 2019).
10. How Barcelona's smart city strategy is giving 'power to the people'. Available at: https://news.itu.int/how-barcelonas-smart-city-strategy-is-giving-power-to-the-people/ (accessed August 2019).

11. Kyiv Smart city strategy. Available at: https://www.kyivsmartcity.com/concept/ (accessed August 2019).
12. International Electrotechnical Commission (2014). Orchestrating infrastructure for sustainable Smart Cities. Available at: https://www.iec.ch/whitepaper/pdf/iecWP-smartcities-LR-en.pdf (accessed August 2019).

АНАЛІЗ МОДЕЛЕЙ АРХІТЕКТУРИ РОЗУМНОГО МІСТА

В умовах стрімкої урбанізації та розвитку ІКТ активного поширення набуває концепція Розумного сталого міста, що має на меті допомогти містам у вирішенні урбаністичних проблем XXI ст. (перенаселення, брак ресурсів та послуг, забруднення, старіння населення тощо). Концепція подолала довгий шлях від суто технологічного рішення, що початково просувалося IT компаніями до людиноцентричної концепції, що розширює можливості мешканців впливати на розвиток свого міста. Проте для успішної розбудови моделі міста мають забезпечити існування належної інфраструктури на місцях. Особливістю архітектури Розумних міст є поява рівня із даними, що дозволяє більш ефективно реагувати на запити населення, надавати кращі послуги та попереджати критичні ситуації. Дуже часто проблема полягає у можливості поєднання вже наявної старої інфраструктури із новою діджитал надбудовою. А також відсутності єдиних стандартів та процедур, що спростило б процес комунікацій між усіма зацікавленими сторонами. На сьогоднішній день міста більш зосереджені саме на покращенні вертикальної інтеграції частин існуючих систем (енергетичній ефективності, зменшенні ресурсних втрат тощо), горизонтальна ж інтеграція (тобто поєднання даних із різних секторів для кращого управління) відбувається вже на наступному кроці. Стаття має на меті розглянути існуючі моделі архітектури у науковому середовищі (багатошарова модель, модель заснована на даних тощо), а також у концепціях реально функціонуючих розумних міст, що вважаються передовими у напрямку розбудови розумних сталих міст (Чикаго, Сінгапур, Барселона) та Києва, для порівняння. Та у результаті дослідження запропонувати доцільний варіант для українських міст. Що також враховує виклики, що постають на кожному із етапі, зокрема, проблема сприйняття мешканцями нових послуг та питання інклюзивності суспільства, рівень державного втручання у процес надання послуг, питання поєднання існуючої (дуже часто старої) інфраструктури із новими технологіями та діджитал надбудовою, вплив на довкілля, пошук джерел фінансування і т.д. Крім того, у статті наводяться критерії ефективності архітектури за міжнародними стандартами (ЮНКТАД, ISO). Та оцінка якості інфраструктури за методологією McKinsey. Міжнародний досвід розбудови архітектури розумних міст має важливе значення в умовах активного розвитку концепції в українських містах.

Ключові слова: *розумне стале місто, архітектура, багатошарова модель, урбанізація, ІКТ.*

АНАЛИЗ МОДЕЛЕЙ АРХИТЕКТУРЫ УМНОГО ГОРОДА

В условиях стремительной урбанизации и развития ИКТ активное распространение приобретает концепция умного устойчивого города. Однако для успешного развития модели, города должны обеспечить существование надлежащей инфраструктуры на местах. Статья имеет целью рассмотреть существующие модели архитектуры в научной среде (многошаровая модель, модель основанная на данных и т.п.), а также концепции реально функционирующих умных городов, которые считаются передовыми в направлении развития умных устойчивых городов (Чикаго, Сингапур, Барселона) и Киева, для сравнения. И как результат, предложить модель для украинских городов на основе рассмотренного опыта. Кроме того, в статье приводятся критерии эффективности архитектуры в соответствии с международными стандартам (ЮНКТАД, ISO). Международный опыт развития архитектуры разумных городов имеет важное значение в условиях активного развития концепции в украинских городах.

Ключевые слова: *умный устойчивый город, архитектура, многоуровневая модель, урбанизация, ИКТ.*