UDC 004.738.5

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**ІНТЕГРАЦІЯ PHYGITAL РІШЕНЬ У РОЗУМНИХ МІСТАХ ДЛЯ ПІДВИЩЕННЯ ДОСТУПНОСТІ**

**Анотація.** Розумні міста — це нова концепція, яка спрямована на покращення життя кожного громадянина за допомогою передових технологій та збору даних. Концепція phygital є наріжним каменем імплементації розумного міста. Вона дозволяє додати функції для людей з обмеженими можливостями через взаємодію з містом за допомогою різних пристроїв. У цій роботі ми розглядаємо кілька провідних прикладів з різних країн, щоб проаналізувати їхнє впровадження та потенціал для покращення життя громади. Це дослідження використовує пошуковий та описовий підхід для вивчення phygital-рішень у розумних містах. Робота містить огляд основних додатків та розширень до вже існуючих застосунків, що використовують phygital функціонал для підвищення доступності міст та окремих локацій для осіб з інвалідністю. Проаналізовано phygital рішення для людей з порушення інтелекту; опорно-рухового апарату; функцій зору (сліпі та слабозорі). Приклади, розглянуті в цій роботі, дозволяють відстежити новітні досягнення у цій галузі. Зокрема, що концепція автономних транспортних засобів є важливою для розумних міст, оскільки транспорт завжди був однією з проблем для людей з обмеженими можливостями. Сучасним прикладом впровадження таких технологій в Україні є Карта доступного міста у Львові. Що містить список із понад 100 місць. Компанія таксі Uklon створює phygital досвід, впроваджуючи інклюзивний клас таксі для людей з фізичними вадами, які користуються на кріслі колісному. Такі проєкти створюють phygital досвід і мають значний вплив на життя людей з інвалідністю та роблять реальність розумних міст ближчою.

**Ключові слова:** phygital, розумне місто, міський розвиток, інклюзивність, автономний автомобіль.

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**INTEGRATING PHYGITAL SOLUTIONS IN SMART CITIES TO ENHANCE ACCESSIBILITY**

**Abstract.** Smart cities are an innovative concept that aims to improve life for every citizen using leading edge technologies and data collection. In this paper, we address some of the leading examples from various countries to analyze the implementation and their potential to benefit the community. The phygital concept is a cornerstone of smart city implementation. It enables the additional functions for people with disabilities through interaction with the city using various devices. This paper reviews several leading examples from different countries and analyzes their implementation and potential to improve community life. This study uses an exploratory and descriptive research approach to analyze the data and investigate trends and applications of phygital solutions in smart cities. The examples covered in the paper allow to trace the latest developments in the field. We believe that autonomous vehicles as a concept is vital for smart cities as transportation has always been one of the challenges for the disabled. The paper includes an overview of the main applications and extensions to existing applications that utilize phygital functionality to enhance the accessibility of cities in general and specific locations in particular for people with disabilities. It analyzes phygital solutions for individuals with intellectual disabilities, mobility impairments, and visual impairments (blind and low-vision individuals). The examples covered in the paper allow to trace the latest developments in the field. We believe that autonomous vehicles as a concept is vital for smart cities as transportation has always been one of the challenges for the disabled. A contemporary example of implementing such technologies in Ukraine is the Accessible City Map in Lviv, which contains a list of over 100 locations. Another example is Uklon, a taxi company, which creates phygital experience through implementing inclusive class taxi for physically impaired people who use wheelchair. The study showes the significant role of phygital technologies in the advancement of the smart cities. Overall, projects like these create phygital experience and have a significant impact on life of disabled people, making the reality of smart cities closer, demonstrating the potential of such technologies.

**Keywords**: phygital, smart city, urban development, inclusivity, autonomous vehicle.

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**INTEGRATING PHYGITAL SOLUTIONS IN SMART CITIES TO ENHANCE ACCESSIBILITY**

It is stated that the population of the Earth is above 8 billion now. According to the World Health Organization (WHO), 16% or 1,3 billion live with disabilities [1]. Furthermore, more than half of the impaired people live in cities. The key to improving their quality of life is smart cities. According to International Business Machines Corporation (IBM), smart city means an urban area where technology and data collection help improve quality of life as well as the sustainability and efficiency of the city operations. It involves upgraded means of transportation, water supply and waste disposal facilities and more efficient ways to light and heat buildings. Technologies are the heart of this city type. The question is what can be done to alleviate the living conditions of the disabled people. The proposed solution is the Phygital concept.

This study employs an exploratory and descriptive research approach to investigate phygital solutions in smart cities. The research primarily relies on secondary data gathered from various sources, which provides real-world examples of phygital implementations. By analyzing existing case studies and developments, the research highlights current trends and potential benefits of integrating phygital technologies to enhance urban accessibility.

The smartphone boom in the 2000s significantly accelerated the birth of the digital era. Ever since, the companies have faced the question of how to enhance the experience of using gadgets even more. Furthermore, only a few years later, the term 'phygital' began to emerge. The concept is a synthesis of the terms ‘physical' and 'digital’, suggesting the idea of a union of two worlds in the smooth, safe and simple way [2]. According to the marketing dictionary of Monash University, it is defined as a bridge between the digital world and the physical world with the purpose of providing a unique interactive experience for the user [3]. It was firstly coined in 2007 by Chris Weil, the Chairman-CEO of Momentum Worldwide, in order to highlight the significance of inextricable connection between tangible and virtual realities. In 2013 Momentum Worldwide, understanding the power of phygital, laid claim to the copyright and even integrated it into their motto: “An agency for the Phygital World” [4].

The phygital experience is widely implemented by companies in order to provide qualitative customer experience and keep them interested in buying more. According to Frost & Sullivan [5], making customer the center of attention through the omnichannel strategy focused on phygital concept helps to provide high-quality engagement. Moreover, the use of smartphones, QR Codes, and artificial intelligence can amplify phygital experience even further. Thus, it helps companies to win over loyal and engaged customers.

The most widespread example of phygital concept is Near Field Communication (NFC) technology. According to Samsung, NFC allows users to make secure transactions, exchange digital content, and connect electronic devices with a touch. An NFC tag sends radio waves to activate the antenna in a receiving device. The recipient validates the information to complete the information exchange. Thus, NFC plays pivotal role in connecting two worlds. For instance, NFC embedded in clothing or accessories like wrist-band can unlock features for its users by scanning or entering particular area. It improves immersive experience of both tangible and virtual realities. Another famous example of the concept being implemented is the Pokémon go [6]. It is an app where people need to catch Pokémons using their smartphone’s camera and GPS aiming to grow their collection. The game, created in 2016, still has about 90 million active users in 2024. There are further examples demonstrating the power of merging physical and digital experiences to promote active engagement. It is worth mentioning the Active Parks project, implemented in the UK in 2014 [7]. It is based on a phygital game that allows older and sedentary park users to spend time surrounded by nature, which is beneficial to their health. Digital element – mobile phones with GPS/NFC technologies – is combined with exploring the real physical world in a fun and engaging gamified manner.

There are different types of disabilities, which calls for different solutions on how to enhance accessibility in cities. One dimension is intellectual disability (or ID) – certain limitations in cognitive functioning and skills, including conceptual, social and practical skills, such as language, social and self-care skills. It has been proven that interactive technology has benefits for improving the above-mentioned conditions, thus, phygital interfaces are to be applied. To prove the point, M. Gelsomini, M. Spitale and F. Garzotto conducted a study in 2020 [8] on how people with intellectual disabilities perform using phygital interfaces, the findings indicated that phygital materials do better than just digital, being able to engage and motivate users effectively, and proven that integration of machine learning approaches has potential in real life settings.

Another type of disability is the blind and visually impaired people, who face obstacles all around them and could greatly benefit from phygital solutions. We would like to address some of the leading examples from various countries to analyze the implementation and their potential to benefit the community.

One of the challenges in implementing the phygital experience is working with old buildings that require refurbishment to meet the needs of the disabled. A case worth noting in implementing the phygital experience in an old infrastructure of the New York subway system, first operated in 1904. In 2020 the Transit Tech Lab launched a startup competition, where they chose 9 companies to improve accessibility. Among them was Okeenea Digital with its audio-based indoor navigation app Evelity. It is adapted for all type of disabilities and can easily build the best route regarding person`s special needs. Later, the underground was equipped with beacons to advance the accessibility even more. Evelity cooperated with Régie des Transports Métropolitains (RTM), the Marseille metro operator, to improve the physical accessibility of its 2 lines and 29 stations [9]. Evelity configured the geolocation infrastructure and the Evelity back office installed Bluetooth beacons at the proper places and set up the app. Thus, the features enabled a user, even a blind one, to navigate through an unknown station, discovering the services available and reaching them. The problems they solved included making the underground inclusive for everyone, independent of type of disabilities, reducing cost of disability management, finding alternative to the quickly obsolete and non-dynamic signage and making travel safer. The field of interests of Okeenea Digital covers not only underground and public transport, but also includes workplaces, universities, museums and hotels. In spite of having so many advantages, the app isn’t popular worldwide. It has about 1000 downloads and no reviews on Play Market. On Apple store there are 20 mostly positive reviews, as a result average rate of the app is 4.3.

Another example worth mentioning is Tactile Studio, specializing in designing educational solutions enhanced by sensory experiences – touch, sound, smell. The Tactile studio promotes the phygital concept through the idea of the interactive hybrid between physical (gestures) and digital (screens). It requires programming, modern electronics, 3D modeling and involving the leading experts. One of their greatest projects was visualizing 16 stations, creating a tactile trail at the Pavilion de I’Horloge at Louvre [10]. On the path the visitors can find the archaeological sites and identify the specific period to which it belongs, as well as the explanation of the decorative elements with the ability to touch the reproductions. In this case, the sensitive consoles with infrared sensors are placed in every room, allowing interaction by passing the hand over it to light up the corresponding room and get the information about it. The Tactile studio provides a comprehensive experience with audio devices and Braille text. Furthermore, Louvre is equipped with video materials with sign language specifically for the hearing-impaired people. The actors in the videos wear historical costumes to make the experience more immersive and entertaining.

Another point we would like to cover is the significant progress in creating application for the visually impaired people. TUAT corp. – a South Korean company that introduced artificial intelligence in their application Sullivan+ in order to recognize and vocalize objects from photos. It helps blind and low-vision individuals experience the phygital concept and understand what is around them. Implementation of the artificial intelligence makes this app accessible all around the world, irrespective of a particular city or country. Furthermore, Sullivan+ makes it easier to get acquainted with a new person because of the built-in Face recognition that can identify the age and gender. Color recognition supports single-color mode, that describes what color is in the center of the photo, and full-color mode, that indicates what color covers a large part of the entire screen. Alongside that, the Light brightness function helps the visually impaired people facing problems with understanding how bright it is around them. It can also describe the surroundings and thus help to navigate the unfamiliar spaces [11].

Sullivan+ is a highly popular app among users with disabilities. It has more than 100 000 downloads on Play Market and the average rate of app is 4.6. However, reviews include a lot of complaints that AI doesn’t work properly, making the proposed solution ineffective. It is stated that AI cannot recognize faces properly, generating different answers to the same photo. Moreover, it has problems with processing prompts creating poor phygital experience.

Similarly, an application Lazarillo aims to make commuting easier and more efficient for the disabled people. It offers audio navigation with real time updates and multiple layers of information with the concept of the smart city in mind. As a person walks, Lazarillo will announce places of interests, streets, intersections, restaurants, shops and transit areas. In addition, it can create routes within the map and guide the users on their way to the destination. The developers offer specific personalized services to particular businesses, which include not only mapping and creating the digital plan of the facilities, but also can add accessible and interactive digital information to their physical space. [12] Applications like Lazarillo are easily-applicable in smart cities as they do not require major refurbishment, but rather work with the existing environment and Big Data.

On Play market the average rate of Lazarillo is 4.2 and on Apple store it is 3.8. Working as an extension to existing maps as Google maps, Apple Maps, Moovit, Waze, or others, Lazarillo is dependent on the quality of the map in that region or country. Thus, it causes some problems with accessibility for people from less developed regions. According to Perkins school for the Blind [13], navigating tutorial through the app is difficult, especially for the impaired people without previous experience. The major drawbacks of the app are outdated information about locations and inability to eliminate certain locations from announcement list.

Microsoft has been creating phygital solutions for many years. Microsoft Seeing AI and Microsoft Soundscape are among them. Both apps are for the visually impaired people, helping them navigate the city`s landscape using their phone. Seeing AI combines the artificial intelligence`s developments and smartphone`s capabilities, determining the surroundings, including people, documents. money and different signs and labels. Barcode reader is quite a unique feature, giving the detailed information about a product, its ingredients after scanning its barcode. This app was first introduced on iOS in 2017 and got an Android version in 2023, having received an overwhelmingly positive feedback from the users. What enabled the success of the app was two inventions made at Microsoft – a vision-to-language technology and an image classification system with only 3,57% error rate, that were both applied [14].

Microsoft Soundscape follows a similar concept, though it uses 3D audio features in real time, helping the blind and low-vision people navigate the world as they are getting to their destination. The project, started in 2014, has since undergone a list of improvements, is now available on iOS and iPhone in the US and UK. The fascinating concept works with headphones, where the sounds are perceived as coming from a direction where the place of interest is located relative to the user, so they can create a mental image of the space around them – a soundscape is created. The app features three main options: My location (information about the current location and what is near; Around me (information on what is ahead, right, left and behind the user`s current location); Ahead of me (five pieces of information on what is in front of the user) [15].

“Be my eyes” is an innovative company that has been developing their own solutions since 2012 and has become the biggest online community for blind and low-vision people [16]. The idea takes its origin from Hans Jorgen Wiberg, a Danish furniture craftsman, who is visually impaired himself. His friend helped him with this app by saying that he used video calls to connect with family and friends in order to ask what is around him. Understanding the fact that visually impaired people needed a little assistance to solve everyday tasks, he decided to implement the similar mechanism with video calls so that blind and low-vision people became more independent from their friends and families.

The Be my eyes app was launched on IOS in 2015 and within 24 hours the app had more than 10 000 users. The app enables the phygital concept through relationship between a visually impaired person and a volunteer. A person with disabilities submits requests through the app, waiting for an available volunteer to respond. Be my eyes users are able to ask for help in over 180 languages, making it accessible all over the world. There was high demand for making app cross-platform, as a result Be my eyes was launched on Android in 2017. This step led to even higher popularity with 1.5 million signed people as volunteers. This year Microsoft decided to support this project and helped to expand Specialized Help opening hours to 24/7. Nowadays, the app has 6.7 million active volunteers and 500 000 blind and low-vision people. In 2023 Be my eyes app in collaboration with Open AI introduced Be my AI, powered by GPT-4. This technology is powerful in proving blind or low vision people with better navigation and independence. Being integrated into existing app, the technology allows users to upload images from their smartphones without any additional plugins or extensions. Having received an image from a user, GPT-4 tries to process the photo and vocalize it. However, if GPT-4 encounters any problems, the app will automatically offer users to be connected to a volunteer.

The Be My Eyes Work app creates an accessible workspace for blind or low-vision people. AI software automatically connects to colleagues or even a fully outsourced service of support creating a phygital experience that enables to use the Be My Eyes Work app for daily work-related tasks, downloading software and developing skills. Besides, it helps the employment rate to increase among the impaired people and makes smart cities inclusive for everybody.

Many people take reliable transportation for granted, as it is a significant part of smart cities. However, the impaired people, especially those with severe disabilities, confront the challenges with obtaining access to transportation all the time. People with disabilities are often conditioned to social isolation due to inability to fully function in the outside world, which can then lead to depression and other mental issues. Moreover, that can cause problems with employment, education and income.

Impaired people are dependent on others when it comes to driving a car. According to the Bureau of Transportation Statistics of the USA [17], more than one third of individuals with a disability report that they are not active drivers, which is significantly more than among people without disabilities. For those using wheelchair, for example, it is required to retrofit a car in order to be mobile. According to Gilani Engineering, an agency from Australia, cost of modifying a vehicle starts at around $200 and can reach up to $80 000 [18]. Besides the financial burden, it is required to have a personalized medical report to meet the needs and to find expert technicians, able to implement the required modifications.

There has been a drastic improvement in technology in the recent years that has significantly alleviated problems of impaired people. Significant impact on developments is made by transnational corporations such as Uber and Lyft. Uber creates phygital experience through offering autonomous vehicles (AVs) to their customers so that they have an option of going with or without a driver [19]. Thus, impaired people get an opportunity to reach their destination on their own. Autonomous vehicles are an example of the phygital technology as they combine physical – the car itself, some sensors and the transportation environment – with digital – AI algorithms and software, mapping, autonomous control systems. According to California Department of Motor Vehicles [20], autonomous technology includes a combination of hardware and software, remote and/or on-board, that has the capability to drive a vehicle without active physical control or monitoring by a human operator. Another American company that has been developing their own solution in this field since 2013, is Aptiv. They offer a self-driven taxi that operates using information about the environment from the imaging radars that are located on the car, in this case – Hyundai Ioniq 5. Ever since, they have provided 100 000 public self-driven passenger rides. The idea behind their approach is smart mobility, which aims to help elderly and disabled people to move independently [21]. Josie Archer, one of the employees, says that disabled people often have to schedule their daily activities around a driver or someone to take them to their destination, thus autonomous driving vehicles would drastically improve their lifestyle – they would download an app and the car would go where they need it to go.

Autonomous vehicle on its own is not enough to assist a disabled person, it involves machine learning, artificial intelligence, features that allow to understand spoken instructions, communicate with a person and actively analyze surroundings in real time. For instance, Texas A&M [22] has been working on developing protocols and algorithms to enable people and AVs to communicate effectively. The project involved creating a self-driving car that can store information about the user, their disability, requirements and preferences as well as commonly visited places. When the shuttle arrives to pick up the rider, it could scan the area with lasers, cameras and radar to create a 3-D map of the area in addition to using open-source information. The AV can then send a notification to the user`s smartphone with its location and use facial recognition to make sure it is picking up the right person. It can communicate using audio or written text on the screen to inform the passenger about all the details of the trip. It is aimed to ensure the user`s safety and comfort, while also reducing stress and making the experience as human-like as possible.

The deployment of autonomous vehicles could face stark reality due to limited technological development and inflexible, restrictive policies. AVs must meet all the requirements of every individual in order to be fully accessible. For instance, the blind and the visually impaired may require refreshable braille and an auditory system, including beacons to inform about the position of a car. On the contrary, people with ambulatory and physical disability, who use a wheelchair, need a ramp or a lift system integrated into the body of a car. Deaf people, being fully capable of driving vehicles even now, need a visual representation of any audible information displayed in AVs [23].

In Ukraine, Uklon, a taxi company, creates phygital experience through implementing inclusive class taxi for physically impaired people who use wheelchair [24]. Uklon utilizes special retrofitted cars featured with hydraulic lift, ramp, special safety belts and wheelchair tie-downs. Nowadays, this project works only in Lviv and Kyiv and their districts, however, Uklon is planning to expand it to other cities. User-friendly app enables impaired person to order a car by entering a starting point and a destination. A disabled person may be accompanied by one to three individuals, depending on the car’s modification. Inclusive taxi is supported by big companies like MacPaw, Mastercard and OKKO.

Another group of people that have issues with transportation is those with intellectual and developmental disabilities. They often rely on care givers in such mundane travels, so AVs could help them get around more independently – both by eliminating the need to navigate on their own and by allowing their care providers to monitor their way through GPS and cameras inside the car. People with mental disabilities might suffer from anxiety and fear before boarding a car or any other means of transportation, alongside with anxiety caused by unfamiliar devices and appliances, so it has to be simplified, and aim to reduce the amount of stress for the users. They can also suffer from motor disorders, which significantly limits their ability to drive [25]. A key study worth mentioning is ‘Willingness of people with mental health disabilities to travel in driverless vehicles’ by R. Bennett, R. Vijaygopal and R. Kottasz, published in 2019 [26]. The researchers analyzed 177 answers of mentally disabled people to open-ended questions on their attitude towards AVs and defined three main approaches: freedom, fear and curiosity. People with intellectual impairments talked about freedom as the main association with AVs if they had prior knowledge about it, and if the respondents value the possible autonomy and independence it can offer. They were more willing to give it a try if they believed their condition hindered their everyday life. Fear was found closely linked to anxiety, in this case it can be strengthened by lack of control in a self-driven car. Women are often more anxious about trying new technologies and spatial anxiety (navigating the environment), and the study proves the point. Overall, it is crucial to address and work with the concerns of the potential users of such cars, reducing their fears. Curiosity depends on locus of control, which refers to how much a person believes he can control his life and the results of different events happening. However, curiosity did not have a significant direct impact on the willingness to travel in AVs. Therefore, we believe that autonomous vehicles have a significant potential to facilitate mentally disabled people commuting on an everyday basis, but it requires further technical advancements as well as increased awareness and trust in the technology.

It is of utmost importance for Ukraine to implement the advancements focused on supporting people with disabilities, particularly in light of the full-scale Russian invasion. Furthermore, constant technological developments are to be considered, as they enable to combine innovations with the existing surroundings. Ukraine promotes the phygital concept in smart cities too. For instance, in Lviv there is a project that allows the impaired people to do sightseeing and manage daily tasks. The extension to the Google maps is developing constantly and is available on any device with the access to the Internet. It was introduced in February 2024. It includes more than 100 places for visitors with different types of disabilities, providing a more inclusive environment for tourists and citizens. Restaurants, hotels, museums, administrative buildings, libraries, hospitals, parks and places for entertainment are listed, while the convenient search by category improves the user experience [27]. The Accessible City map is supported by the city council, making this project a state-endorsed one.

To sum up, smart city is about improving quality of life for every citizen using leading edge technologies and data collection. Phygital concept is the cornerstone of the smart city. It allows to implement features for the impaired people through interacting with city using different devices. The examples covered in the paper allow to trace the latest developments in the field. The first group studied is people with intellectual disability and how they benefited from the phygital interfaces when learning. The second point of focus is the visually impaired and blind people, for whom the phygital experience is often implemented in the form of apps or features for smartphones using audio guidance. Okeenea Digital developed Evelity app that helps disabled people to find their way indoors, for example in New York’s and Marseille underground systems. Tactile Studio has been cooperating with the Louvre Museum for 11 years, having visualized 16 stations with tactile path. TUAT corp. enriched the market by creating Sullivan+ that uses AI to process photos in real time, describes them using audio to facilitate commuting. Lazarillo creates the best route for its users and announces places of interests during a walk. Microsoft has also been active in developing phygital technologies such as Microsoft Seeing AI and Microsoft Soundscape that help to navigate the city and mundane task using smartphone`s features.

Autonomous vehicles as a concept is vital for smart cities as transportation has always been one of the challenges for the disabled. Autonomous vehicles are implemented by the Uber taxi service and have proven to be successful, while Aptiv provides self-driven taxis allowing the disabled to become more independent in getting to their destinations. Transportation is no less an issue for people with intellectual and developmental disabilities, who are both optimistic and fearful of the autonomous transportation options.

A modern example of such technologies being implemented in Ukraine is the Accessible City map in Lviv. It provides the list of more than 100 accessible places. It is also worth mentioning Uklon, a taxi service that provides inclusive taxis for the physically impaired. Projects like these create phygital experience and have a significant impact on life of disabled people, making the reality of smart cities closer. Thus, it is necessary to support and invest in projects to alleviate everyday life of the impaired people.

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