Internet of Things as a Communication Tool for Efficient Management and Operation of Buildings

Jozef Švajlenka[1*], Terézia Pošiváková[2)], Denis Konovalov[3)]

[1*)] Department of Construction Technology, Economy and Management, Faculty of Civil Engineering, Technical University of Košice, Slovakia, e-mail: jozef.svajlenka@tuke.sk; ORCID: https://orcid.org/0000-0002-9273-9755
[2)] Department of Breeding and Diseases of Game, Fish and Bees, Ecology and Cynology, University of Veterinary Medicine and Pharmacy of Košice, Slovakia, ORCID: https://orcid.org/0000-0001-8185-0936
[3)] Institute of Architectural Engineering, Faculty of Civil Engineering, Technical University of Kosice, Slovakia, ORCID: https://orcid.org/0009-0008-9084-929X

http://doi.org/10.29227/IM-2024-02-15

Submission date: *03.06.2024.* | Review date: *21.06.2024*

Abstract

The trend of using the Internet of Things (IoT) can be considered a so-called new technological revolution. This fact is confirmed by the ever-increasing number of connected devices around the world in all areas of life. The Internet of Things is defined as the interconnectedness of things, services and users. It is an interplay of intelligent devices and intelligent communication technologies. The flow of information and events generated by the device can be used to simplify management, monitoring and coordination processes. Communication with devices, users and services is key to the Internet of Things. Communication technologies affect the usability of the device. New communication networks are currently emerging for the Internet of Things. These include, in particular, networks for the transmission of a smaller data stream, which is typical for sensors and transducers, to the respective device. The success of these networks depends on availability, low cost, low power consumption, long range and ease of use. The mentioned technological solutions ultimately enable a higher degree of interoperability of users with the internal environment thanks to higher information and evaluation of the internal environment in real time. Thanks to these technologies, it is possible to increase user comfort and efficiency of using buildings as such. The aim of this article is to define the basic principles and connections within the IoT issue in connection with the effective management and operation of buildings as one of the prerequisites for sustainability in the field of construction.

Keywords: *Buildings; Internet of Things; Management; Sensors*

1. Introduction

Technological progress in the field of construction and monitoring of the internal environment of buildings brings the possibility of implementing the Internet of Things (IoT) in combination with various measuring sensors for more sustainable and better quality buildings in terms of use. IoT generally refers to a network of interconnected devices that can communicate with each other, exchange data and enable automation in various sectors. IoT includes physical objects with software, sensors, and processing capabilities that are connected to the Internet, allowing them to interact and perform tasks [1],[2]. This technology has a significant impact on everyday life, from communication to data transmission, monitoring and a number of other functionalities not only in fencing but in all branches of industry, which leads to the development of new products and services.

IoT devices are programmed to execute specific functions and can revolutionize business operations, offering enhanced value to customers [3]. This technology finds extensive applications in transportation, manufacturing, public services, agriculture, infrastructure, and home automation [4]. For instance, farmers can utilize IoT-supported sensors to monitor soil conditions, while healthcare professionals can remotely track patients' health status for timely interventions [5],[6]. In the construction industry, these are, for example, communication technologies between construction participants, monitoring of the internal environment of buildings through various sensors [7], and the like.

The data generated by IoT devices is invaluable to companies, enabling better predictive maintenance, minimizing operational disruptions, and facilitating research [8]. With the increasing popularity of IoT in both residential and commercial settings, individuals can remotely monitor various assets, from cars to household appliances, enhancing convenience and efficiency [9]. IoT technology has a rich history, dating back to the concept of interconnected devices in the 19th century, with notable advancements in the 20th century, such as the integration of a toaster and a webcam into the internet. Today, IoT is driving digital transformation across industries, making activities easier, faster, and more enjoyable [10]. In summary, the Internet of Things represents a transformative technology that is reshaping how devices interact, communicate, and automate tasks, offering a wide array of benefits across different sectors and enhancing connectivity in our increasingly digital world.

The aim of this article is to define the basic principles and connections within the IoT issue in connection with the effective management and operation of buildings as one of the prerequisites for sustainability in the field of construction.

2. IoT in the Context of Construction

IoT in civil engineering involves the integration of sensors and smart devices to collect data for automation purposes. This technology is gaining significant interest due to its potential to enhance quality and productivity across various domains. In civil engineering, IoT applications are transforming infrastructure towards smart and sustainable solutions by improving efficiency throughout the construction value chain, from material production to maintenance [11]. IoT is utilized in buildings, roads, bridges, dams, railways, and sewerage systems to enhance occupant comfort, energy efficiency, security, and operational costs reduction.

Smart buildings, enabled by IoT, control operations like HVAC, lighting, security, and energy optimization through automation. IoT also plays a crucial role in intelligent transportation systems, smart irrigation facilities, smart parking systems, non-destructive testing, damage detection of structures, and real-time construction management solutions in civil engineering [12],[13]. These applications leverage IoT sensors to improve traffic efficiency, optimize irrigation, enhance parking systems, predict maintenance needs, and ensure safety in construction projects. Moreover, academic efforts are underway to integrate IoT methodologies in civil engineering classrooms using mobile devices, sensors, microcontrollers, and app development [14]. This educational approach aims to expose students to the practical applications of IoT in civil engineering, fostering hands-on learning experiences and preparing them for the evolving technological landscape in the industry.

IoT is a term for connecting devices / objects / people to the Internet. Wi-Fi and / or Bluetooth are often used with this type of device. In particular, interconnected equipment should be wireless and should bring new possibilities for interaction not only between systems, but also for new possibilities to control, monitor and provide advanced services [15]. The Internet of Things allows devices to determine whether they are remotely controlled using existing infrastructure (computer network, Internet, mobile network, ...) that allows better integration of physical devices into computer-controlled systems, and thus higher efficiency, accuracy and economy as well as lower demands. per user [16],[17]. When sensors or actuators are installed in a facility, the technology becomes part of a more general category of various systems and subsystems. Logistics systems, integrated logistics chains and cycles in a global structure also play a role.

2.1. Background context of IoT

In the recent past, the concept of IoT has evolved into a combined digital form, intersecting different sectors, not excluding construction, as a result of global demand. The current IoT implements the following aspects [18],[19]. Sensor networks can be, for example: for active airflow control; underwater acoustic; for smart grids.

The development of IoT was largely determined by the following milestones:

- 1982 Coca Cola production machine at Carnegie Mellon University,
 becoming the first device connected to the Internet to report its inventory and
- 1991 Mark Weiser's key article on the ubiquitous computer (Computer of the 21st Century),
- 1994, Reza Raji described the concept in IEEE Spectrum,
- 1993-1996 solutions several companies (for example Microsoft, Novell's NEST), - 1999 Bill Joy introduced inter-device communication (D2D) at the WEF Davos [20],[21],[22].

Since 1999, the term or the IoT tool has become popular through the Auto-ID Center at MIT (founder Kevin Ashton). The result was the knowledge and application of so-called radio frequency identifiers (RFID) for inventory and labeling of products: RFID, radio frequency identification; NFC, short distance communication; barcode; QR code; digital watermark.

2.2. Smart home

In the field of construction, IoT is currently applied as part of systems for monitoring and control of mechanical and digital platforms of buildings and their infrastructure [23]. The interaction of the various elements is controlled either automatically or physically by manual input into the device or, for example, by voice commands. Another key moment is the capture of the internal environment of buildings for additional modification aimed at increasing the living comfort of building users [24]. Subsequent applications in construction are mainly related to the regulation of energy and other media as part of the infrastructure of construction as such to increase their efficiency [25]-[28]. In addition to home energy management, IoT is particularly important to Smart Grid, as it provides systems for the automated collection and processing of energy information to improve the efficiency, reliability, economy and sustainability of electricity generation and distribution.

2.3. Monitoring of the internal environment of buildings

Regulation of ventilation according to air quality or carbon dioxide content in the interior has been a popular function in recent years, promoted by suppliers of air handling units and control and regulation systems. However, in order to fulfill its purpose of reducing operating costs (meaning not only payments for energy consumption but also, for example, service and maintenance costs) and maintaining user comfort [29], it must be installed and set up taking into account a few basic rules.

When measuring, we encounter two groups of sensors - carbon dioxide sensors and gas mixture (VOC - volatile organic compounds) sensors [30]. For safety reasons, carbon monoxide sensors are used in areas with a potential load of combustion products.

2.4. Gas mixture sensors

The HMOS (heated metal oxide semiconductor) gas mixture sensor works on the following principle: gases are ionized on the glowing grid and the working area of the sensor changes its electrical resistance, which is transformed into an output signal [31]. The sensor reacts to organic gases such as ammonia, methane, organic solvents, etc. Gas mixtures are used for calibration - from simple ones (for example CO, H_2S and methane, supplemented with oxygen and nitrogen) to mixtures that contain up to 65 components (Linde Gas SPECTRA VOC). The sensor is not selective - we are not even interested in the concentrations of individual gases, the total load of the room is measured. The specific concentration of the gases in the measured space is thus not known, only a signal indicating a value of 0 to 100% is obtained, which corresponds to the degree of air pollution. It is therefore necessary to empirically set an acceptable limit for the residence of persons and subsequently regulate the system with regard to it. Setting the required air quality has a significant impact on the energy consumption of the air conditioner, so it must be given due attention in the long-term tuning of the measurement and control system [32]. It should also be noted that VOC sensors do not measure CO_2 concentration.

2.5. Carbon dioxide sensors

CO_2 sensors currently work on the principle of NDIR (nondispersive infrared sensor) and achieve excellent long-term stability of ± 1% of the range per year. As the table suggests, they are used in rooms where, in addition to persons, there are no other significant sources of pollution [33]. In CO_2 regulation, we see a massive potential for energy savings in large buildings and family houses with recuperation units. The measured values range from 0 to 2,000 or 0 to 5,000 ppm CO_2, the minimum achievable concentration corresponding to pure outdoor air is about 300 ppm.

At the same time, however, in addition to CO_2 concentration, other factors such as temperature, light intensity, noise, predominant color shades in the room and others affect the overall well-being of indoor users, not to mention subjective feelings given by clothing, health, stress, etc.. However, the measured CO_2 value is at least a relative indicator of the room load and one of the few quantities in relation to which the air handling unit can be regulated.

2.6. Carbon monoxide sensors

Carbon monoxide is a poisonous gas that is produced by incomplete combustion. The detectors use a glowing semiconductor sensor to measure the gas concentration, the active substance of which changes its conductivity in the presence of CO_2, i.e. they are selective sensors [34]. CO_2 sensors are used as safety sensors in homes and public spaces (garages). When used in households, their task is to activate the alarm, so the sensor includes the evaluation circuit itself and the alarm siren. In garages, the analog signal is transformed from the sensor to the control panel, where limits are set to about 80 to 90 ppm CO_2 in the first stage, in which ventilation is switched on, and 120 to 200 ppm in the second stage, which switches on emergency ventilation and signaling panels. Alarms are usually routed to the building management system.

3. Conclusion

IoT technology is revolutionizing various aspects of not only civil engineering by enabling real-time infrastructure monitoring, improving construction site management, improving resource utilization and optimizing energy efficiency, and much more. Some of the key benefits of IoT in the construction industry include a number of benefits especially from the perspective of the following aspects. In the field of efficiency, IoT applications in construction increase efficiency by enabling real-time data monitoring and analysis, predictive maintenance and improved decision-making. In the area of safety, IoT increases safety by identifying potential hazards before they lead to accidents, thereby improving overall safety measures in construction projects. In the area of sustainability, IoT contributes to sustainability in the construction industry by offering benefits in terms of efficiency, safety and sustainability, leading to smarter and more sustainable infrastructure development and management. In the area of resource utilization, IoT devices and sensors help in the efficient use of resources by providing real-time progress data, identifying potential delays and optimizing project completion schedules. In the area of cost savings, the integration of IoT sensors in civil engineering projects streamlines operations, leading to cost savings through better insight into asset utilization, efficient maintenance, and accurate planning of construction tasks. Essentially, IoT plays a key role in transforming civil engineering projects, making them smarter, more efficient and better equipped to meet the challenges of the modern world by improving monitoring, safety, sustainability and resource management.

Acknowledgments

KEGA 017TUKE-4/2024, VEGA 1/0228/24, VEGA 1/0336/22

References

1. Navulur, Sridevi, and MN Giri Prasad. "Agricultural management through wireless sensors and internet of things." International Journal of Electrical and Computer Engineering 7.6 (2017): 3492. DOI: 10.11591/ijece.v7i6.pp3492-3499
2. Kim, Wan-Soo, Won-Suk Lee, and Yong-Joo Kim. "A review of the applications of the internet of things (IoT) for agricultural automation." Journal of Biosystems Engineering 45 (2020): 385-400. https://doi.org/10.1007/s42853-020-00078-3
3. Paiola, Marco, and Heiko Gebauer. "Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms." Industrial Marketing Management 89 (2020): 245-264. https://doi.org/10.1016/j.indmarman.2020.03.009
4. Nižetić, Sandro, et al. "Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future." Journal of cleaner production 274 (2020): 122877. https://doi.org/10.1016/j.jclepro.2020.122877
5. Rahmani, Amir Masoud, Suleyman Bayramov, and Behnam Kiani Kalejahi. "Internet of things applications: opportunities and threats." Wireless Personal Communications 122.1 (2022): 451-476. https://doi.org/10.1007/s11277-021-08907-0
6. Sunyaev, Ali, and Ali Sunyaev. "The internet of things." Internet Computing: Principles of Distributed Systems and Emerging Internet-Based Technologies (2020): 301-337. https://doi.org/10.1007/978-3-030-34957-8_10
7. Mishra, Mayank, Paulo B. Lourenço, and Gunturi Venkata Ramana. "Structural health monitoring of civil engineering structures by using the internet of things: A review." Journal of Building Engineering 48 (2022): 103954. https://doi.org/10.1016/j.jobe.2021.103954
8. Passlick, Jens, et al. "Predictive maintenance as an internet of things enabled business model: A taxonomy." Electronic Markets 31 (2021): 67-87. https://doi.org/10.1007/s12525-020-00440-5
9. Mannino, A., Dejaco, M. C., & Re Cecconi, F. (2021). Building information modelling and internet of things integration for facility management—Literature review and future needs. Applied Sciences, 11(7), 3062. https://doi.org/10.3390/app11073062
10. Wang, Jianxin, et al. "The evolution of the Internet of Things (IoT) over the past 20 years." Computers & Industrial Engineering 155 (2021): 107174. https://doi.org/10.1016/j.cie.2021.107174
11. Gunturi, M. "A review on the internet of things in civil engineering: enabling technologies, applications and challenges." E3S Web of Conferences. Vol. 309. EDP Sciences, 2021. https://doi.org/10.1051/e3sconf/202130901209

12. Carli, Raffaele, et al. "IoT based architecture for model predictive control of HVAC systems in smart buildings." Sensors 20.3 (2020): 781. DOI:10.3390/s20030781

13. Gholamzadehmir, Maryam, et al. "Adaptive-predictive control strategy for HVAC systems in smart buildings–A review." Sustainable Cities and Society 63 (2020): 102480. https://doi.org/10.1016/j.scs.2020.102480

14. Chacón, R., Posada, H., Toledo, Á., & Gouveia, M. "Development of IoT applications in civil engineering classrooms using mobile devices." Computer Applications in Engineering Education 26.5 (2018): 1769-1781. DOI: 10.1002/cae.21985

15. Wortmann, F., Flüchter, K.: Internet of things. Business & Information Systems Engineering, 57(3), 221-224, (2015). DOI 10.1007/s12599-015-0383-3

16. Xia, F., Yang, L. T., Wang, L., Vinel, A.: Internet of things. International journal of communication systems, 25(9), 1101, (2012). DOI: 10.1002/dac.2417

17. Atzori, L., Iera, A., Morabito, G.: The internet of things: A survey. Computer networks, 54(15), 2787-2805, (2010). https://doi.org/10.1016/j.comnet.2010.05.010

18. Weber, R. H., Weber, R.: Internet of things (Vol. 12). Heidelberg: Springer, (2010). DOI 10.1007/978-3-642-11710-7

19. Wu, M., Lu, T. J., Ling, F. Y., Sun, J., Du, H. Y.: Research on the architecture of Internet of Things. In 2010 3rd international conference on advanced computer theory and engineering (ICACTE) (Vol. 5, pp. V5-484). IEEE, (2010).

20. Greengard, S.: The internet of things. MIT press, (2015).

21. Cui, X.: The internet of things. In Ethical ripples of creativity and innovation (pp. 61-68). Palgrave Macmillan, London, (2016).

22. Lake, V., Lake, V., Lake, V.: Internet of Things (IoT): A literature review. Journal of Computer and Communications, 3(05), 164, (2015). DOI: 10.4236/jcc.2015.35021

23. Chong, G., Zhihao, L., Yifeng, Y.: The research and implement of smart home system based on internet of things. In 2011 International Conference on Electronics, Communications and Control (ICECC) (pp. 2944-2947). IEEE, (2011).

24. Zemrane, H., Baddi, Y., Hasbi, A.: Internet of things smart home ecosystem. In Emerging Technologies for Connected Internet of Vehicles and Intelligent Transportation System Networks (pp. 101-125). Springer, Cham, (2020).https://doi.org/10.1007/978-3-030-22773-9_8

25. Alaa, M., Zaidan, A. A., Zaidan, B. B., Talal, M., Kiah, M. L. M.: A review of smart home applications based on Internet of Things. Journal of Network and Computer Applications, 97, 48-65, (2017). https://doi.org/10.1016/j.jnca.2017.08.017

26. Tao, F., Wang, Y., Zuo, Y., Yang, H., Zhang, M.: Internet of Things in product life-cycle energy management. Journal of Industrial Information Integration, 1, 26-39, (2016). https://doi.org/10.1016/j.jii.2016.03.001

27. Almeida-De Araujo, Victor, et al. "Sustainability in the brazilian timber housing virtual market." Hábitat Sustentable (2023): 20-29. https://doi.org/10.22320/07190700.2023.13.01.02

28. De Araujo, Victor. "Timber construction as a multiple valuable sustainable alternative: main characteristics, challenge remarks and affirmative actions." International Journal of Construction Management 23.8 (2023): 1334-1343. https://doi.org/10.1080/15623599.2021.1969742

29. Antošová, Naďa, et al. "Application of additional insulation to ETICS on surfaces with biocorrosion." Acta Polytechnica 61.5 (2021): 590-600. DOI: https://doi.org/10.14311/AP.2021.61.0590

30. Ongwandee, M., Moonrinta, R., Panyametheekul, S., Tangbanluekal, C., Morrison, G.: Investigation of volatile organic compounds in office buildings in Bangkok, Thailand: concentrations, sources, and occupant symptoms. Building and Environment, 46(7), 1512-1522, (2011). https://doi.org/10.1016/j.buildenv.2011.01.026

31. Ghazanfarian, J., Shomali, Z.: Investigation of dual-phase-lag heat conduction model in a nanoscale metal-oxide-semiconductor field-effect transistor. International Journal of Heat and Mass Transfer, 55(21-22), 6231-6237, (2012). https://doi.org/10.1016/j.ijheatmasstransfer.2012.06.052

32. Leidinger, M., Sauerwald, T., Conrad, T., Reimringer, W., Ventura, G., Schütze, A.: Selective detection of hazardous indoor VOCs using metal oxide gas sensors. Procedia Engineering, 87, 1449-1452, (2014). https://doi.org/10.1016/j.proeng.2014.11.722

33. Mendes, L. B., Ogink, N. W., Edouard, N., Van Dooren, H. J. C., Tinôco, I. D. F. F., Mosquera, J.: NDIR gas sensor for spatial monitoring of carbon dioxide concentrations in naturally ventilated livestock buildings. Sensors, 15(5), 11239-11257, (2015). doi:10.3390/s150511239

34. Kumar, P., Skouloudis, A. N., Bell, M., Viana, M., Carotta, M. C., Biskos, G., Morawska, L.: Real-time sensors for indoor air monitoring and challenges ahead in deploying them to urban buildings. Science of the Total Environment, 560, 150-159, (2016). https://doi.org/10.1016/j.scitotenv.2016.04.032