ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING
TOME XVI [2023] | FASCICULE 4 [OCTOBER – DECEMBER]

[1.]Ştefan ȚĂLU, [2.]Mihai ȚĂLU, [3.]Laura–Catinca LEȚIA

THE INTERNET OF THINGS IN CIVIL ENGINEERING: A REVIEW OF CHALLENGES AND SOLUTIONS IN THE ROMANIAN CONTEXT

[1.]Technical University of Cluj–Napoca, The Directorate of Research, Development and Innovation Management (DMCDI), Cluj–Napoca, ROMANIA
[2.]University of Craiova, Faculty of Mechanics, Department of Applied Mechanics and Civil Engineering, Craiova, ROMANIA
[3.]Technical University of Cluj–Napoca, Faculty of Building Services Engineering, Structures Department, Cluj–Napoca, ROMANIA

Abstract: The Internet of Things (IoT) is the network of physical objects (that contain sensors, actuators, trackers, storage, software, and other technologies) connected with computing systems via wired (for example, Ethernet) or wireless (for example, WiFi, cellular) networks to exchange data and information, merging the digital and physical universes to improve productivity, efficiency, services, etc. At the same time, civil engineering is experiencing a rapid digital transformation changing research frontiers and knowledge base structure towards intelligent tendencies and smart and sustainable infrastructure. The application of IoT in civil engineering assumes new challenges, such as data security and privacy concerns, interoperability issues, and the need for IoT professionals. However, the benefits of IoT in enhancing construction processes, infrastructure management, and sustainability make it a compelling and promising area for the civil engineering industry, making it more efficient, sustainable, and responsive to the needs of modern society. This paper aims to assess the current status of IoT implementation in civil engineering, highlighting its applications, benefits, and potential. Additionally, this article will explore the challenges and difficulties faced by the industry in fully leveraging the capabilities of IoT. By understanding the existing issues, this study intends to offer insights and recommendations to overcome obstacles and optimize the usage of IoT in civil engineering projects in the Romanian context.
Keywords: civil engineering, civil engineering projects, device communication, Internet of Things, IoT challenges, global network

INTRODUCTION

The concept of the Internet of Things (IoT) was first coined by British engineer Kevin Ashton in 1999. Kevin Ashton, while working at Procter & Gamble, used the term "Internet of Things" in a presentation to describe a revolutionary idea where everyday physical objects could be connected to the Internet and communicate with each other. At the time, Kevin Ashton was exploring ways to improve supply chain management and inventory control in retail using RFID (Radio Frequency Identification) technology. He realized that by equipping objects with RFID tags and connecting them to the internet, businesses could gain real–time visibility into their inventory, track products, and automate processes more efficiently. The term "Internet of Things" captured the essence of this vision, emphasizing the interconnectedness of physical objects and their ability to communicate over the Internet without human intervention. The concept quickly gained traction and became a cornerstone in the development of the IoT industry [1].

Following Kevin Ashton's proposal, IoT has grown exponentially, becoming a major driver of innovation in technology and transforming various industries. Today, the IoT ecosystem includes a vast array of devices, sensors, and systems that collect and exchange data, enabling automation, data–driven decision–making, and new levels of efficiency in numerous domains. From smart homes to industrial automation, from healthcare to agriculture, IoT applications have proliferated, making our lives more connected and convenient [2,3].

The Internet of Things (IoT) has a lot of applications in the field of civil engineering (such as buildings, roads, bridges, dams, railways, sewerage systems, etc.), revolutionizing the way infrastructure is designed, constructed, and managed [4]. IoT implementation in buildings aligns with the broader concept of creating smart buildings that are energy–efficient, technologically advanced, and user–centric. By focusing on these aims, IoT technology contributes to sustainable and optimized building management, leading to a positive impact on both occupants and the environment [5,6].

While converting existing buildings into smart buildings is feasible, the complexity and extent of the conversion may vary depending on the building's age, infrastructure, and desired level of smart functionality. In some cases, retrofitting may be straightforward, while in others, it might involve more extensive modifications [7].

By employing this interconnected network of sensors, actuators, and microchips, smart buildings can create an efficient, automated, and adaptive environment. By harnessing the power of IoT and automation, smart buildings offer numerous benefits, including increased energy efficiency, cost savings, improved occupant comfort, enhanced security, and reduced environmental footprint. The ongoing advancements in IoT technology continue to expand the possibilities and potential for smart buildings in creating more intelligent, sustainable, and connected spaces, to enhance energy efficiency, occupant comfort, security, and overall building performance. As technology continues to advance, smart buildings will likely become more sophisticated, offering even greater benefits and capabilities to building owners, operators, and occupants, making smart buildings an essential component of sustainable and eco–friendly urban development.

Some examples of smart infrastructure in different sectors are smart office buildings, smart transportation facilities, health care facilities and hospitals, educational facilities, smart stadiums, smart parking lots, smart waste management, smart energy grids, smart farming, smart bridges, and roads [8–10].

Modern smart buildings were initially envisioned as sensor–embedded residences with various integrated systems. The concept revolved around using a network of sensors to gather data about the building's environment, such as temperature, lighting levels, occupancy, and energy usage. The key features of such smart buildings include sensor integration, centralized control, remote operation, efficiency and sustainability, interoperability, and data analytics [11–13].

IoT SYSTEM ARCHITECTURE

The Internet of Things (IoT) integrates systems from hardware to software, encompassing numerous technologies and components. The Internet of Things (IoT) system architecture is commonly described as a four–stage process, also known as the IoT data flow, where data is collected from sensors attached to various "things" and then transmitted through a network for processing, analysis, and storage. It involves four main stages:

- Sensing/Perception stage: in this initial stage, sensors, and devices attached to physical objects, often referred to as "things," collect data from the environment. These sensors can measure various parameters, such as temperature, humidity, pressure, motion, and more. The data collected at this stage is often in the form of raw sensor data.
- Communication/Network stage: once the sensors have gathered the raw data, it needs to be transmitted or communicated to a central processing system or data center. This stage involves the use of communication protocols and networks, such as Wi–Fi, Bluetooth, Zigbee, LoRaWAN, or cellular networks, to transfer the data from the sensors to a gateway or directly to the cloud.
- Data processing and analysis stage: after the data is transmitted to the central system or cloud, it undergoes processing and analysis. This stage involves various data processing techniques, such as filtering, aggregation, normalization, and analytics. The goal is to extract meaningful information and insights from the raw data. Data processing can occur either at the edge (edge computing) or in the cloud, depending on the specific use case and requirements.
- Cloud/Storage stage: in the final stage, the processed and analyzed data is stored in a cloud–based data center or storage system. Cloud storage provides scalability, accessibility, and the ability to store vast amounts of data generated by numerous IoT devices. The data stored in the cloud can be further used for real–time monitoring, historical trend analysis, predictive analytics, and other applications.

The four–stage IoT system architecture enables the seamless flow of data from the physical world (things and sensors) to the digital world (cloud and data center), where valuable insights can be derived, and appropriate actions can be taken based on the analysis results. This process is fundamental to the functioning and effectiveness of IoT solutions in various industries and applications [14].

APPLICATIONS OF IoT IN CIVIL ENGINEERING

The Internet of Things (IoT) has a wide range of applications in civil engineering, transforming the way infrastructure is designed, built, and managed [15–23]. Some examples of IoT applications in civil engineering include:

- Structural health monitoring: IoT sensors can be integrated into buildings, bridges, and other infrastructure to monitor their structural health in real time. These sensors can detect vibrations, stresses, strains, and temperature changes, providing early warnings of potential structural issues and allowing for timely maintenance and repair. Benefits of structural health monitoring using IoT sensors:
  - Enhanced safety: Structural health monitoring using IoT sensors helps identify potential structural issues early, minimizing the risk of catastrophic failures and ensuring the safety of occupants and the public;
  - Predictive maintenance: Continuous monitoring allows for predictive maintenance, leading to cost savings and reduced downtime due to unscheduled repairs;
  - Data–Driven decision making: Real–time data from IoT sensors enables data–driven decision–making for structural maintenance and repairs;
  - Increased lifespan: Proactive maintenance and early detection of structural issues contribute to extending the lifespan of buildings and infrastructure;
  - Structural performance optimization: Continuous monitoring and analysis allow engineers to optimize

structural designs and materials for improved performance and efficiency.

- Smart construction sites: IoT–enabled devices and sensors can be deployed on construction sites to monitor equipment, materials, and workers. This enables better project management, optimized resource allocation, improved safety, and reduced downtime. Benefits of IoT in smart construction sites:

— Improved productivity: IoT–driven data insights enable optimized resource allocation and streamlined workflows, enhancing construction site productivity;

— Enhanced safety: IoT–based safety monitoring reduces risks and helps in early detection of potential hazards, ensuring a safer working environment;

— Cost savings: Predictive maintenance and efficient resource management lead to cost savings on equipment repairs and operational expenses;

— Real–Time decision making: Real–time data from IoT devices empowers project managers to make prompt and data–driven decisions;

— Environmental compliance: IoT environmental monitoring ensures construction sites comply with environmental regulations, mitigating environmental impacts;

— Better project management: IoT data provides project managers with a comprehensive view of construction site activities, enabling more effective planning and execution.

- Smart infrastructure management: IoT can be used to monitor and manage various aspects of infrastructure, such as smart lighting systems that adjust brightness based on occupancy, smart water management systems for leak detection and conservation, and intelligent traffic management systems for real–time traffic control. Benefits of IoT in smart infrastructure management:

— Improved Efficiency: IoT–driven smart infrastructure management optimizes resource usage, reduces operational costs, and enhances overall efficiency;

— Real–Time Insights: IoT sensors provide real–time data, enabling quick response to changing conditions and immediate intervention when needed;

— Enhanced Safety and Resilience: Continuous monitoring and predictive maintenance enhance the safety and resilience of critical infrastructure;

— Data–Driven Decision Making: Data analytics from IoT devices support data–driven decision–making for infrastructure planning and management;

— Sustainability: IoT–driven smart infrastructure management contributes to sustainability goals by reducing energy consumption and resource waste.

- Environmental monitoring: IoT sensors can be employed to monitor environmental conditions in and around construction sites or infrastructure. This includes monitoring air quality, water quality, noise levels, soil conditions, wildlife monitoring, and urban environmental monitoring, which helps in assessing the environmental impact and ensuring compliance with regulations. Benefits of environmental monitoring using IoT Sensors:

— Real–Time insights: IoT sensors provide real–time data on environmental parameters, allowing for immediate action or response in case of pollution or environmental risks;

— Data–Driven decision making: Environmental data collected from IoT sensors enable data–driven decision–making for environmental management and policy development;

— Early detection of environmental issues: IoT–based monitoring allows for early detection of pollution events, enabling timely interventions and minimizing environmental impacts;

— Cost–Effective solutions: IoT–based environmental monitoring systems can provide cost–effective solutions compared to traditional monitoring methods;

— Environmental conservation: Environmental monitoring using IoT sensors contributes to better conservation and protection of natural resources and ecosystems.

- Smart waste management: IoT–based smart waste management systems use sensors to monitor waste levels in bins, optimizing waste collection routes, smart collection vehicles, reducing operational costs, and promoting sustainability. Benefits of IoT–based Smart Waste Management:

— Cost savings: Optimized waste collection routes and schedules lead to reduced fuel costs and operational expenses for waste management companies and municipalities;

— Waste reduction: Efficient waste collection minimizes overflowing bins and litter, leading to a cleaner and more aesthetically pleasing environment;

— Environmental impact: Smart waste management helps reduce carbon emissions and contributes to environmental sustainability by optimizing waste collection processes;

— Real–Time insights: Real–time monitoring provides instant feedback on waste bin fill levels and collection status, allowing for immediate response to any sudden changes or emergencies;

— Improved efficiency: IoT–based smart waste management streamlines waste collection operations and improves overall efficiency, ensuring a more reliable and consistent waste collection service.

- Geotechnical monitoring: IoT devices can be installed in the ground to monitor soil conditions and slope stability, providing crucial data for geotechnical engineers to make informed decisions during construction and maintenance projects. Benefits of Geotechnical Monitoring using IoT:
  - Enhanced safety: Geotechnical monitoring helps identify potential geotechnical hazards, enabling timely interventions and ensuring the safety of structures and individuals;
  - Improved design and construction: Real–time data on soil conditions allows engineers to optimize their designs, select appropriate construction methods, and make informed decisions during construction projects;
  - Cost savings: Early detection of geotechnical issues can prevent costly damages and delays, ultimately saving resources during construction and operation;
  - Predictive maintenance: Geotechnical monitoring enables predictive maintenance, ensuring that structures and foundations are regularly inspected and maintained to prevent failures;
  - Data–Driven decision making: Geotechnical data collected from IoT sensors facilitate data–driven decision–making for construction, infrastructure planning, and risk management.
- Energy efficiency and building automation: IoT can be used to create smart buildings with automated systems that optimize energy usage. This includes smart thermostats, lighting controls, and energy management systems, leading to energy savings and reduced carbon footprint. Benefits of IoT in Energy efficiency and building automation:
  - Energy savings: IoT–enabled building automation optimizes energy usage, leading to significant energy savings and reduced operating costs;
  - Enhanced comfort: Building automation systems provide occupants with a comfortable and personalized environment, adjusting settings based on their preferences and needs;
  - Sustainability: Smart buildings contribute to environmental sustainability by reducing energy consumption and greenhouse gas emissions;
  - Improved operational efficiency: IoT–based automation streamlines building operations, leading to increased efficiency in maintenance, energy management, and facility management;
  - Data–Driven decision making: Data analytics from IoT sensors help building managers make data–driven decisions for optimizing operations and energy usage;
  - Remote control: IoT allows for remote monitoring and control of building systems, facilitating easier management of multiple properties from a centralized location.
- Asset tracking and management: IoT–based asset tracking systems allow civil engineering firms to monitor the location and condition of equipment, tools, and materials, ensuring better inventory management and reducing the risk of theft or loss. Benefits of IoT in Asset tracking and management:
  - Improved asset visibility: Real–time tracking provides businesses with comprehensive visibility into the location and status of their assets, leading to better resource management;
  - Enhanced security: IoT–based asset tracking systems deter theft and improve asset security by enabling rapid recovery and accurate identification of lost or stolen assets;
  - Increased efficiency: Automation and real–time data enable businesses to optimize asset utilization, streamline workflows, and reduce operational costs;
  - Predictive analytics: IoT–generated data allows for predictive analytics, helping organizations identify patterns and trends related to asset usage and performance;
  - Regulatory compliance: IoT–based asset tracking systems assist in meeting regulatory compliance requirements by providing accurate records of asset movement and condition;
  - Streamlined maintenance: Predictive maintenance and condition monitoring ensure that assets are well–maintained, reducing the risk of unexpected breakdowns.
- Disaster management: IoT technologies have an important role in disaster management by providing real–time data on weather conditions, water levels, and potential hazards. This data helps in early warning systems and disaster preparedness planning. Benefits of IoT in Disaster management:
  - Early detection and timely response: IoT technologies enable early detection of disasters and rapid response, saving lives and minimizing property damage.
  - Data–Driven decision making: Real–time data from IoT sensors helps disaster management authorities make informed decisions and allocate resources more effectively;
  - Resilient communication: IoT–based communication systems ensure uninterrupted communication channels during disasters when traditional networks may be compromised.
  - Improved situational awareness: IoT devices provide detailed situational awareness, helping responders assess the severity of the disaster and plan their actions accordingly.
  - Faster recovery and reconstruction: IoT data aids in efficient post–disaster recovery efforts, expediting the rebuilding process.

- Remote monitoring and maintenance: IoT enables remote monitoring and maintenance of infrastructure, reducing the need for physical inspections and facilitating predictive maintenance practices. Benefits of IoT–enabled Remote monitoring and maintenance:

— Cost savings: Remote monitoring reduces the need for frequent site visits, saving time and travel costs for maintenance personnel;
— Increased efficiency: Real–time monitoring and predictive maintenance optimize asset performance, reducing downtime and maximizing productivity;
— Improved safety: Remote monitoring minimizes the exposure of maintenance personnel to potentially hazardous environments;
— Enhanced asset lifespan: Proactive maintenance based on real–time data helps prolong the life of assets and equipment;
— Data–Driven decision making: Data analytics provide valuable insights for making informed decisions related to asset management and maintenance;
— Scalability: IoT–based remote monitoring systems are easily scalable, allowing businesses to monitor and maintain multiple assets or facilities efficiently.

The integration of IoT in civil engineering offers numerous benefits, including enhanced safety, improved efficiency, cost savings, and more sustainable infrastructure development and management. As the technology continues to evolve, the potential for IoT in civil engineering applications is expected to expand further.

RESEARCH METHODOLOGY

The primary method of data collection in this research was through a questionnaire survey. By using questionnaires, the researchers aimed to collect data on various variables of interest related to the civil engineering industry in Romania, such as attitudes, perceptions, experiences, or practices of the construction practitioners to gain a better understanding of their perspectives, challenges, and potential areas for improvement in the industry. This could include topics such as construction methods, safety practices, project management, sustainability, and more.

Using the method of random sampling, the findings from the selected 60 participants (CEOs, managers, and various experts from various levels in the technical and economic fields, 48 men and 12 women in senior positions) can offer valuable data–driven insights that may inform policy decisions, industry practices, and future research endeavors related to the Romanian construction sector.

All participation in the studies was voluntary. All participants received information about on study aims and confidentiality. Semi–structured interviews allow for a balance between having some predetermined questions while also allowing participants the freedom to elaborate on their responses and provide additional insights.

The following questions were addressed to the participants:

- Q1) Are there parts/devices/machines/installations in your company that can be operated via the Internet?
- Q2) When did you implement these parts/devices/ machines/plants in your company?
- Q3) Can you provide a list of these parts/devices/ machines/installations?
- Q4) How many types of these parts/devices/machines/ installations are there in your company?
- Q5) Do you know how to operate these parts/devices/machines/installations in your company?
- Q6) How has the integration of internet–operated parts/ devices/machines impacted your work or the company's operations?
- Q7) What is the reliability of these devices/machines/ installations in the IoT system?
- Q8) Do you receive any training or support to operate these internet–connected parts/devices/machines effectively and securely? If yes, could you provide the period of time?
- Q9) Do you know the advantages and disadvantages of using these parts/devices/machines/installations in your company?
- Q10) Are you planning to implement modern IoT solutions in your company in the future period?
- Q11) How do you ensure the security and privacy of internet–operated systems within the company?
- Q12) What do you think would be the risks and challenges in the next 5 years for implementing these IoT solutions?

Most of the participants are civil engineers (70 %), 80 % of participants obtained a diploma, and 20% held master's and PhD. It's interesting to note that 50% of the participants have less than ten years of experience in the field, 40% of participants have less than 20 years of experience, and 10% of participants have less than 40 years of experience.

SPSS Software version 22.0 has been used for the data analysis. The correct application of the semi–structured interviews was verified by analyzing the credibility of the obtained results.

RESULTS

During June 1st – July 31th, 2023, 60 semi–structured interviews were conducted, and all of them were considered valid.

Question Q1 finds that the participants in these interviews demonstrated the following level of understanding of these subjects:

- very well: 50% of participants;
- well: 30% of participants;
- enough: 15% of participants; and

- not enough: 5% of participants.

The overall average certainty level was 85% on a scale from 0 to 100 which indicates a relatively high level of certainty among the respondents about these subjects.

The answers to questions Q2 and Q3 find that the participants knew the period of implementation of these parts/devices/ machines/plants in their company as follows:

- very well: 40% of participants;
- well: 30% of participants;
- enough: 25% of participants; and
- not enough: 5% of participants.

It is noted that for questions Q4 and Q5, the following results were recorded:

- very well: 45% of participants;
- well: 35% of participants;
- enough: 15% of participants; and
- not enough: 5% of participants.

It was found that for questions Q6 and Q7, the following results were obtained:

- very well: 50% of participants;
- well: 30% of participants;
- enough: 15% of participants; and
- not enough: 5% of participants.

For question Q8 it was found that respondents confirmed the training or support to operate these internet–connected and the period of time as follows:

- very well: 50% of participants;
- well: 30% of participants;
- enough: 15% of participants; and
- not enough: 5% of participants.

Question Q9 finds that the participants knew the advantages and disadvantages of using these parts/devices/machines/installations in their company as follows:

- very well: 55% of participants;
- well: 35% of participants;
- enough: 5% of participants; and
- not enough: 5% of participants.

Furthermore, it was found that the respondents' dissatisfaction with IoT devices is not directly influencing their interest or willingness to adopt more IoT solutions in the company (this finding can have several implications: dissatisfaction with IoT devices, separation of concerns, potential for improvement, and varied factors influencing implementation).

The answers to question Q10 find that the participants planning to implement more IoT solutions in their company in the future as follows: 95% of participants, and only 5% participants are not sure.

For question Q11 it was found that respondents knew that the IoT introduces new challenges and risks for the security and privacy of data and devices and it is very important to ensure that IoT network is protected from unauthorized access, malicious attacks, and data breaches, as follows: 95% of participants knew, and only 5% participants are not sure. They agree to use the best practices to follow, such as:

- choosing reliable IoT devices;
- encrypting and authenticating your IoT data;
- implementing access control and monitoring;
- updating and backup the IoT system.

On the other hand, they specified correctly some of the common types of vulnerabilities that affect IoT devices, such as:

- the use of default or weak credentials (failing to change default passwords can leave devices vulnerable to unauthorized access);
- the insecure network protocols (IoT devices may use weak or unencrypted communication protocols, making them susceptible to eavesdropping and data interception);
- the lack of updates or patches (failure to apply these updates can leave devices exposed to known security flaws);
- the inadequate access control (weak access controls can allow unauthorized users to gain access to sensitive data or control IoT devices);
- and the poor data protection (insufficient encryption or data protection measures can expose sensitive data to unauthorized access or tampering).

Furthermore, regular security assessments, employee training, and staying informed about emerging threats can further strengthen their IoT security posture. The results for question Q12 regarding respondents' opinions about the risks and challenges in implementing IoT solutions over the next 5 years were: 90% of participants knew about the risks and challenges associated with implementing IoT solutions in the next 5 years; only 10% of participants were not sure about the risks and challenges.

It is highlighted that understanding the risks and challenges associated with IoT implementation can lead to better decision–making, risk management, and resource allocation. It enables organizations to take necessary precautions and implement measures to mitigate potential problems before they escalate.

CONCLUSIONS

A comprehensive literature review on technology adaptation in civil engineering can provide valuable insights into the current state of research, trends, challenges, and potential solutions in this field. Designing a smart civil engineering structure requires interdisciplinary collaboration among civil engineers, architects, IoT experts, and technology providers.

By analyzing existing studies and publications, researchers can identify gaps in knowledge, emerging technologies, and best practices for improving technology adoption in civil engineering.

On the other hand, the study's comprehensive examination of IoT in civil engineering from Romania contributes valuable knowledge to the field and offers actionable insights for businesses, researchers, policymakers, and other stakeholders. It has the potential to influence decision–making, promote growth, and drive positive advancements in the IoT landscape in Romania based on the following reasons:

— understanding perception and use: The study provides valuable insights into the perception of IoT technologies in Romania. Understanding how these technologies are perceived and utilized by businesses and industries can help identify opportunities and challenges for their adoption and implementation.
— identifying barriers and risks: by highlighting the barriers and risks associated with IoT adoption, the study offers essential information for businesses and decision–makers. Recognizing these obstacles allows organizations to develop strategies to overcome challenges and mitigate potential risks.
— industry and support services focus: focusing on the industry and support services sectors in Romania, the study narrows down its scope to specific domains, making the findings more relevant and actionable for businesses operating in these sectors.
— providing insights for development: the study's exploration can serve as a foundation for future planning and investment decisions; this can guide policymakers, industry stakeholders, and academia in creating supportive environments for IoT growth.
— bridging business–academia gap: research that addresses real–world industry challenges can bridge the gap between academia and the business world. The findings can be valuable for academia to refine their curricula, foster collaboration with businesses, and conduct further research in relevant areas.
— informing policy and strategy: the study's findings can inform policymakers about the current state and potential of IoT in Romania. It can influence the formulation of policies that promote innovation, infrastructure development, and regulatory frameworks to support IoT growth.
— driving innovation: understanding the existing landscape of IoT in Romania can inspire innovative ideas and solutions. The study may spark innovations, product developments, and service offerings to address the identified needs and challenges.
— fostering collaboration: the study can serve as a basis for collaboration between businesses, academia, and government agencies. It encourages stakeholders to work together to address challenges, share knowledge, and drive the development of IoT solutions in Romania.

References

[1] T. Kramp, R. van Kranenburg, and S. Lange, "Introduction to the Internet of Things". In: Bassi, A., et al. Enabling Things to Talk. Springer, Berlin, Heidelberg. 2013
[2] A. Nazarov, D. Nazarov, and Ş. Ţălu, "Information security of the Internet of Things". In: Proceedings of the International Scientific and Practical Conference on Computer and Information Security – INFSEC, SCITEPRESS – Science and Technology Publications, Lda, vol. 1, pp. 136–139, 2021. Eds.: Nazarov D. and Nazarov A. International Scientific and Practical Conference on Computer and Information Security (INFSEC 2021) Yekaterinburg, Russia, April 5th–6th, 2021.
[3] R. Dallaev, T. Pisarenko, Ş. Ţălu, D. Sobola, J. Majzner, and N. Papež, "Current applications and challenges of the Internet of Things". New Trends In Computer Sciences, vol. 1, issue 1, pp. 51–61, 2023
[4] G. Manisha, "A review on the internet of things in civil engineering: enabling technologies, applications and challenges", E3S Web of Conferences, 309, 01209, 2021
[5] M. Mishra, P.B. Lourenço, and G.V. Ramana, "Structural health monitoring of civil engineering structures by using the internet of things: A review", Journal of Building Engineering, vol. 48, 103954, 2022
[6] D. Nazarov, A. Nazarov, and Ş. Ţălu, "BIM–technologies for a smart city". AIP Conference Proceedings, vol. 2657, 020050, pp. 1–4, 2022. Eds.: Zakharova G. and Semenov A. IV International Scientific and Practical Conference "New Information Technologies In the Architecture and Construction" (NITAC 2021), Ekaterinburg, Russia, November 2–3, 2021.
[7] M. Jia, A. Komeily, Y. Wang, and R.S. Srinivasan, "Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications", Automation in Construction, vol. 101, pp. 111–126, 2019
[8] K.M. Karthick Raghunath, M.S. Koti, R. Sivakami, V.V. Vinoth Kumar, G. NagaJyothi, and V. Muthukumaran, "Utilization of IoT–assisted computational strategies in wireless sensor networks for smart infrastructure management". Int J Syst Assur Eng Manag, 2022.
[9] G. Swetha Shekarappa, M. Sheila, R. Saurav, and B. Manjulata, "Chapter Nineteen – Smart transportation based on AI and ML technology". In: Artificial Intelligence and Machine Learning in Smart City Planning, Elsevier, Eds. V. Basetti, C.K. Shiva, M.R. Ungarala, S.S. Rangarajan, 2023, pp. 281–299.
[10] A. Woll, and J. Tørresen, "What is a Smart Hospital? A Review of the Literature". In: Duffy V.G., Lehto M., Yih Y., Proctor R.W. (Eds.) Human–Automation Interaction. Automation, Collaboration, & E–Services, vol. 10, 2023. Springer, Cham.
[11] C. Pathmabandu, J. Grundy, M.B. Baruwal Chhetri, and Z. Baig, "Privacy for IoT: Informed consent management in Smart Buildings", Future Generation Computer Systems, vol. 145, pp. 367–383, 2023
[12] M. Willetts, and A.S. Atkins, "Application of data mining to support facilities management in smart buildings". In: Marques G., Saini J., Dutta M. (Eds.) IoT Enabled Computer–Aided Systems for Smart Buildings. EAI/Springer Innovations in Communication and Computing. 2023, Springer, Cham
[13] K. Gong, J. Yang, X. Wang, C. Jiang, Z. Xiong, M. Zhang, M. Guo, Lv Ran, S. Wang, and S. Zhang, "Comprehensive review of modeling, structure, and integration techniques of smart buildings in the cyber–physical–social system". Front. Energy, vol. 16, pp. 74–94, 2022
[14] M. Mansour, A. Gamal, A.I. Ahmed, L.A. Said, A. Elbaz, N. Herencsar, and A. Soltan, "Internet of Things: A comprehensive overview on protocols, architectures, technologies, simulation tools, and future directions". Energies, vol. 16, 3465, 2023

[15] R.C.Y. Lam, A. Junus, W.M.Y. Cheng, X. Li, and L.C.H. Lam, "IoT Application in Construction and Civil Engineering Works", 2017 International Conference on Computational Science and Computational Intelligence (CSCI), Las Vegas, NV, USA, pp. 1320–1325, 2017

[16] F. Lamonaca, P.F. Sciammarella, C. Scuro, D.L. Carnì, and R.S. Olivito, "Internet of Things for Structural Health Monitoring", 2018 Workshop on Metrology for Industry 4.0 and IoT, Brescia, Italy, 2018, pp. 95–100

[17] D. Abruzzese, A. Micheletti, A. Tiero, M. Cosentino, D. Forconi, G. Grizzi, G. Scarano, S. Vuth, and P. Abiuso, "IoT sensors for modern structural health monitoring. A new frontier", Procedia Structural Integrity, vol. 25, pp. 378–385, 2020

[18] S.G. Szentesi, L.D. Cuc, R. Lile, and P.N. Cuc, "Internet of things (IOT), challenges and perspectives in Romania: a qualitative research", The Amfiteatru Economic journal, Academy of Economic Studies – Bucharest, Romania, vol. 23(57), pp. 448–448, 2021.

[19] Y. Gamil, M.A. Abdullah, I.A. Rahman, and M.M. Asad, "Internet of things in construction industry revolution 4.0: Recent trends and challenges in the Malaysian context", Journal of Engineering, Design and Technology , vol. 18, no. 5

[20] M.M. Mijwil, K.K. Hiran, R. Doshi, and O.J. Unogwu, "Advancing construction with IoT and RFID technology in civil engineering: a technology review", Al–Salam Journal for Engineering and Technology, 2023

[21] L. Shuai, "Application analysis of Internet of Things technology in civil engineering construction", Proc. SPIE 12625, International Conference on Mathematics, Modeling, and Computer Science (MMCS2022), 126252Y (1 June 2023)

[22] M. Zhang, N. Ghodrati, M. Poshdar, B.C. Seet, and S. Yongchareon, "A construction accident prevention system based on the Internet of Things (IoT)", Safety Science, vol. 159, 106012, 2023

[23] D.T. Patil, and A. Bhaumik, "Efficiency of Internet of Things (IoT)–enabled systems in reducing construction cost", 2023 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE), Dubai, UAE, pp. 408–413, 2023

ACTA TECHNICA CORVINIENSIS
Bulletin of Engineering

ISSN: 2067-3809