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INCORPORATING INTERNET OF THINGS (IOT) AND BIG DATA ANALYTICS IN THE DEVELOPMENT OF SMART BUILDINGS IN THE ROMANIAN CONTEXT

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Abstract: The creation of optimal solutions for smart buildings (or intelligent buildings) is underpinned by information technologies that integrate the Internet of Things (IoT) and utilize Big Data Analytics to decrease costs, improve energy efficiency and reliability, and offer personalized experiences based on the preferences of the occupants. Smart building management systems (BMS) integrate an array of sensors, actuators, and specialized networks, all controlled through a centralized system, to monitor room conditions and implement automated protocols aimed at maintaining or enhancing comfort while optimizing energy usage. Big Data Analytics for smart buildings involves the use of advanced analytical techniques and tools to process, analyze, and derive meaningful insights from the vast amounts of data generated within smart building systems. The integration of Big Data Analytics in smart buildings allows for informed decision–making, predictive maintenance, and the implementation of data–driven strategies to optimize building performance and create more sustainable and responsive building ecosystems. This article will explore the applications of the Internet of Things (IoT) and Big Data Analytics within academic and industry contexts for smart buildings, covering both the construction and operational phases. It will emphasize the priorities, applications, and benefits of these technologies in the realm of smart building systems in the Romanian context.

Keywords: Big Data Analytics, Internet of Things (IoT), IoT challenges, smart buildings

INTRODUCTION

Buildings constitute fundamental and essential components of the human living environment. The inception of smart buildings can be traced back to the 1970s, marked by the introduction of the first building automation systems designed to monitor and control various building systems like lighting, heating, and air conditioning.

The concept of smart buildings has emerged from the growing integration of advanced technologies into building systems and plays a pivotal role in the enhancement of cities and infrastructures, primarily focusing on improving the comfort of residents. This integration allows for the remote control and management of a building's entire life cycle, aiming to enhance comfort, convenience, and energy efficiency while optimizing costs.

On the other hand, they contribute to superior energy efficiency, oversee safety aspects, and establish an improved framework for comfort, quality of life, and services tailored to the preferences of both residents and businesses [1].

The convergence of smart buildings and advancing technologies has unlocked a lot of opportunities to improve different facets of building management and security. Deploying applications like energy optimization, streamlining building management, enhancing resident comfort, managing reactive alarms, ensuring personal and asset protection, and handling intrusion events signifies a significant stride toward establishing more intelligent and secure living and working environments [2,3]. Intelligent management systems contribute to the smart building paradigm by enhancing features such as automation, optimization, and security protocols.

The evolution of smart buildings has experienced a notable acceleration, particularly with the introduction of Internet of Things (IoT) technology [4–8]. Also, Big Data Analytics plays a pivotal role in the design and functioning of smart buildings, providing a lot of advantages in optimizing efficiency, bolstering sustainability, fortifying security, and delivering personalized experiences. Nevertheless, storing and searching massive data in real–time is a complex and laborious task for smart buildings. This advancement has resulted in the development of more sophisticated and interconnected building management systems.

By focusing on IoT and Big Data Analytics, the study seeks to provide insights into how these technologies are intertwined and contribute synergistically to the development, management, and optimization of smart buildings. The review will encompass key findings, challenges, and emerging trends in the intersection of IoT and Big Data Analytics within the realm of smart buildings in the Romanian context.

THE INTEGRATION OF IoT IN SMART BUILDING TECHNOLOGIES

In the contemporary landscape, the IoT ecosystem transformed traditional buildings and has evolved into a comprehensive network comprising a diverse array of devices, sensors, and systems meticulously designed to seamlessly collect and exchange data. This intricate interconnectivity empowers smart buildings by fostering automation, facilitating data–driven decision–making processes, and ushering in unprecedented levels of operational efficiency. The integration of these technologies not only enhances the functionality of individual components but also converges them into a cohesive framework, allowing smart buildings to adapt dynamically to changing conditions, optimize resource utilization, and prioritize sustainability. This holistic approach to IoT in smart buildings signifies a transformative shift towards intelligent, and responsive environments, optimizing resource utilization and fostering sustainability [9–11].

In the realm of smart buildings, an intelligent system typically functions through three hierarchical levels:

- data infrastructure level (this encompasses the myriad data sources within the building that serve as the foundation for the intelligent system's operations);
- system infrastructure level (that serves as the central component of the intelligent system and enables leveraging the collected data for various purposes);
- service level (that encapsulates the array of services provided by the intelligent system to various stakeholders, including building managers, residents, energy suppliers, and others, enhancing overall operational efficiency).

The Heating, Ventilation, and Air Conditioning (HVAC) system plays a vital role in ensuring that an intelligent building maintains optimal conditions for occupants by providing sufficient heating, effective ventilation, and improved air conditioning [12–14].

The IoT architecture is designed to equip all objects with identification, detection, networking, and processing capabilities to achieve integrated ambient intelligence. This enables objects to interact, share information, and develop advanced services over the Internet facilitating several key capabilities:

- comprehensive understanding;
- context–sensitive decision–making; and
- intelligence autonomy.

Furthermore, the implications of IoT encompass two key aspects:

- integration into everyday objects, and
- formation of interconnected networks.

The architecture of the Internet of Things (IoT) facilitates the smooth transition of data from the physical realm to the digital domain, being commonly depicted as a four–stage process, known as the IoT data flow:

- sensing/perception stage;
- communication/network stage;
- data processing and analysis stage;
- cloud/storage stage. This orchestrated flow of data enables the extraction of valuable insights and empowers stakeholders to take informed actions based on analysis outcomes.

The integration of IoT in smart buildings revolutionizes how they are designed, operated, and experienced by occupants, yielding a multitude of applications, such as:

- Energy Management: IoT–enabled sensors can monitor energy consumption in real–time, allowing for optimized usage patterns, predictive maintenance of HVAC systems, and efficient allocation of resources to minimize waste;
- Occupant Comfort and Safety: Smart sensors can adjust lighting, temperature, and ventilation based on occupancy levels and preferences, ensuring a comfortable and safe environment for building occupants. Additionally, IoT devices can detect potential hazards such as gas leaks or fire outbreaks and trigger timely alerts or automated responses;
- Facility Management and Maintenance: IoT sensors can track equipment performance, predict maintenance needs, and schedule repairs proactively to minimize downtime and prolong the lifespan of building assets. Remote monitoring capabilities also enable facility managers to oversee operations from anywhere, improving overall efficiency;
- Security and Access Control: IoT–enabled surveillance cameras, motion sensors, and access control systems enhance security by monitoring building perimeters, detecting unauthorized access, and issuing alerts in case of suspicious activities. Integration with smart locks and biometric authentication further strengthens access control measures;

- Space Utilization Optimization: By analyzing data on occupancy patterns and space usage, IoT solutions can optimize office layouts, meeting room allocations, and resource utilization to maximize efficiency and productivity;
- Environmental Monitoring and Sustainability: IoT sensors can monitor air quality, humidity levels, and environmental conditions to ensure compliance with health and safety standards. Additionally, real–time data analytics enable building managers to identify opportunities for energy conservation and implement sustainable practices;
- Predictive Analytics and Decision Support: By leveraging IoT–generated data, machine learning algorithms can forecast future trends, anticipate maintenance needs, and provide actionable insights for informed decision–making, thereby improving operational performance and cost–effectiveness.

BIG DATA INTEGRATION IN SMART BUILDING TECHNOLOGIES

The integration of big data in smart building technologies represents a pivotal advancement in the realm of modern architecture and infrastructure management. This synergy harnesses the power of large–scale data analytics and intelligent systems to optimize various aspects of building operations, enhance occupant comfort, and improve overall efficiency. At its core, big data integration in smart buildings involves the collection, storage, analysis, and utilization of vast amounts of data generated by sensors, devices, and systems embedded within the building environment. These sensors capture real–time information on factors such as occupancy patterns, energy consumption, environmental conditions, and equipment performance.

Through sophisticated data analytics techniques, this wealth of information is processed and analyzed to derive actionable insights and inform decision–making processes. Moreover, big data integration facilitates the implementation of advanced management strategies such as demand response and predictive maintenance. By analyzing historical data and trends, building managers can anticipate peak energy demand periods and adjust operations accordingly to reduce costs and minimize strain on the grid. Predictive maintenance algorithms identify potential equipment failures before they occur, enabling proactive repairs and minimizing downtime. Additionally, big data integration enables enhanced security and safety measures within smart buildings. By aggregating data from surveillance cameras, access control systems, and environmental sensors, potential security threats and safety hazards can be quickly identified and addressed.

For instance, anomalous behavior patterns can trigger alerts for security personnel, while environmental sensors can detect fire or gas leaks and initiate appropriate emergency responses.

By harnessing the power of data analytics and intelligent systems, smart buildings can achieve unprecedented levels of efficiency, sustainability, and occupant satisfaction, shaping the future of urban living and infrastructure management [15–17].

RESEARCH METHODOLOGY

In this research, the principal approach to data gathering involved administering a questionnaire survey to capture information on the attitudes, perceptions, experiences, and practices of construction practitioners. By delving into these variables, the study aimed to elucidate the perspectives of industry stakeholders, prevailing challenges, and potential areas for enhancement concerning the incorporation of the Internet of Things (IoT) and Big Data Analytics in the development of smart buildings in the Romanian context.

Through the method of random sampling, the study selected 50 participants from diverse backgrounds within the civil engineering sector in Romania. This sample included CEOs, managers, and experts from various technical and economic levels, comprising 34 men and 16 women in senior positions. The data gathered from these participants can provide valuable, data–driven insights that have the potential to inform policy decisions, shape industry practices, and guide future research efforts within the Romanian construction sector. It's essential to note that all participation in the study was voluntary, and participants were fully informed about the study's objectives and the confidentiality of their responses.

The use of semi–structured interviews allowed for a balanced approach, offering some predetermined questions while also granting participants the freedom to elaborate on their responses and provide additional insights. This methodology ensured a comprehensive exploration of the participants' perspectives, experiences, and challenges within the civil engineering industry, contributing to a robust and nuanced understanding of the sector's dynamics.

The following questions focusing on smart buildings were addressed to the participants:

Q1) General understanding:

- How would you define a "smart building" within the context of the civil engineering industry?
- What are the key components or features that distinguish a smart building from a traditional one?
- How familiar are you with the current trends and advancements in smart building technologies?

Q2) Implementation and integration:

- Have you been involved in any projects related to the design, construction, or retrofitting of smart buildings?
- What challenges have you encountered during the implementation of smart building technologies?
- How do you ensure seamless integration of various smart systems within the building infrastructure?

Q3) Technology and innovation:

- Which smart building technologies do you consider most promising or impactful in the Romanian market?
- How do you prioritize the selection of smart technologies for a specific project?
- What role do you see emerging technologies like IoT, AI, and data analytics playing in the future of smart buildings?

Q4) Regulations and standards:

- Are there specific regulations or standards governing the implementation of smart building solutions in Romania?
- How do you ensure compliance with these regulations while incorporating innovative technologies?
- What changes or improvements would you suggest to existing regulatory frameworks to better support smart building initiatives?

Q5) Operational efficiency and maintenance:

- How do smart building technologies contribute to improving operational efficiency and reducing maintenance costs?
- What strategies do you employ to optimize the performance of smart building systems over their lifecycle?
- How do you address security and privacy concerns related to the data generated by smart building systems?

Q6) Market dynamics and future outlook:

- How do you perceive the current market demand for smart building solutions in Romania?
- What factors influence the decision–making process for clients considering smart building investments?
- What opportunities and challenges do you anticipate for the future growth of the smart building industry in Romania?

Q7) Collaboration and knowledge sharing:

- How do you collaborate with other stakeholders (architects, contractors, technology providers, etc.) to deliver successful smart building projects?
- Are there any industry networks or platforms you engage with to stay updated on the latest smart building developments?
- What initiatives do you support for knowledge sharing and capacity building within the civil engineering community regarding smart buildings?

The majority of participants in the study possessed a background in civil engineering, comprising 80% of the sample. Among the participants, 90% hold a diploma, while 10% have advanced degrees such as master's or PhDs. Notably, 60% of the participants have less than eight years of experience in the field, indicating a significant proportion of relatively early–career professionals.

Furthermore, 30% of participants have less than 15 years of experience, while 10% have less than 35 years of experience, suggesting a diverse range of expertise levels within the sample. Data analysis was conducted using SPSS Software version 22.0, enabling thorough examination and interpretation of the collected data.

Additionally, the rigor and validity of the semi–structured interviews were ensured through a meticulous assessment of the credibility of the obtained results. This process involved verifying the consistency and coherence of participants' responses, thereby enhancing the reliability of the qualitative findings.

RESULTS

Between May 1st and June 30th, 2024, a total of 50 semi–structured interviews were conducted as part of the research study. Importantly, all interviews were deemed valid, indicating a high level of quality and reliability in the data collection process.

This comprehensive approach ensured that a diverse range of perspectives and insights were captured from participants within the civil engineering sector, contributing to the richness and depth of the study's findings.

Question Q1, based on the general understanding, and revealed that participants demonstrated varying levels of understanding of the subjects discussed. Specifically:

- 40% of participants indicated a very high level of understanding;
- 30% of participants expressed a high level of understanding;
- 26% of participants stated they had an adequate understanding; and
- 4% of participants admitted to having a limited understanding.

Moreover, the overall average certainty level among respondents was calculated to be 90% on a scale from 0 to 100. This indicates a relatively high level of certainty among the participants regarding the subjects discussed during the interviews. Such high certainty levels suggest a robust comprehension and confidence in the knowledge shared by the respondents, thereby enhancing the reliability of the study's findings.

The responses to question Q2 about the implementation and integration of smart building components revealed the following levels of knowledge among participants:

- 46% of participants indicated a very high level of understanding;
- 26% of participants expressed a high level of understanding;
- 22% of participants stated they had an adequate understanding; and
- 6% of participants admitted to having a limited understanding.

These findings suggest that a significant proportion of participants possess a solid grasp of this knowledge. However, there are still some participants who have insufficient knowledge in this regard. Overall, these insights contribute to a nuanced understanding of the level of awareness and comprehension among industry professionals regarding the implementation and integration of smart building technologies.

The responses to question Q3, focusing on technology and innovation revealed the following levels of knowledge among participants:

- 52% of participants indicated a very high level of understanding;
- 24% of participants expressed a high level of understanding;
- 20% of participants stated they had an adequate understanding; and
- 4% of participants admitted to having a limited understanding.

These findings indicate a notable level of awareness among participants regarding technological advancements and innovative solutions. The majority of respondents exhibit a solid grasp of this information, with only a small percentage feeling less confident in their knowledge. Overall, these insights contribute to understanding the degree of familiarity and comprehension among industry professionals regarding technology and innovation in the context of smart building implementation.

For question Q4, which focused on regulations and standards, the survey recorded the following responses from participants regarding their level of understanding:

- 48% of participants indicated a very high level of understanding;
- 32% of participants expressed a high level of understanding;
- 16% of participants stated they had an adequate understanding;
- 4% of participants admitted to having a limited understanding.

These results suggest that a significant majority of participants possess a strong understanding of regulations and standards relevant to the smart building industry. However, there is still a portion of respondents who feel they have insufficient knowledge in this area. Overall, these findings highlight the importance of adhering to regulatory requirements and industry standards in the implementation and operation of smart building technologies.

For question Q5, which delved into operational efficiency and maintenance in smart buildings, the survey yielded the following responses regarding participants' level of understanding:

- 44% of participants indicated a very high level of understanding;
- 36% of participants expressed a high level of understanding;
- 18% of participants stated they had an adequate understanding;
- 2% of participants admitted to having a limited understanding.

These results indicate a strong overall comprehension among participants regarding operational efficiency and maintenance in smart buildings. The majority of respondents demonstrate a solid grasp of these concepts, with only a small percentage feeling less confident in their understanding. This suggests a promising level of expertise among industry professionals in optimizing operational performance and maintenance practices within smart building environments.

For question Q6, which explored market dynamics and the future outlook in smart buildings, the survey revealed the following distribution of responses regarding participants' level of understanding:

- 42% of participants indicated a very high level of understanding;
- 28% of participants expressed a high level of understanding;
- 26% of participants stated they had an adequate understanding;
- 4% of participants admitted to having a limited understanding.

These findings suggest that a majority of participants possess a strong understanding of market dynamics and future trends in the realm of smart buildings. Their high level of comprehension indicates a keen awareness of the evolving landscape and potential opportunities within the industry. However, there is still a small portion of respondents who feel they have room for improvement in their understanding of these aspects. Overall, these insights provide valuable context for decision–making and strategic planning within the smart building sector.

For question Q7, which focused on collaboration and knowledge sharing in smart buildings, the survey results indicate the following distribution of responses regarding participants' level of understanding:

- 54% of participants indicated a very high level of understanding;
- 26% of participants expressed a high level of understanding;
- 16% of participants stated they had an adequate understanding;
- 4% of participants admitted to having a limited understanding.

These findings highlight a strong overall comprehension among participants regarding collaboration and knowledge sharing within the smart building domain.

The majority of respondents demonstrate a robust understanding of these aspects, indicating a culture of collaboration and information exchange within the industry. However, there is still a small percentage of participants who feel they have room for improvement in their understanding of these dynamics. Overall, these insights underscore the importance of fostering collaboration and knowledge–sharing initiatives to drive innovation and progress in the smart building sector.

CONCLUSIONS

An extensive review of the literature concerning the integration of the Internet of Things (IoT) and Big Data Analytics in the advancement of smart buildings within the Romanian civil engineering context can offer invaluable insights into the prevailing research landscape, emerging trends, existing challenges, and prospective solutions within this domain.

Such a thorough examination of existing scholarly works holds the potential to illuminate the current status quo, identify patterns in technological adoption, pinpoint areas of concern, and propose innovative strategies to address them. Moreover, the exhaustive analysis of IoT's and Big Data Analytics roles in Romanian civil engineering enriches the collective knowledge base and provides practical insights for a diverse array of stakeholders, including businesses, researchers, policymakers, and more.

This study holds significant potential to shape decision–making processes, foster industry growth, and catalyze positive advancements in the Romanian IoT and Big Data Analytics landscape.

These insights hold significant implications for various stakeholders, as outlined below:

- Enhancing understanding and perception (by revealing how these technologies are perceived and utilized, the study facilitates the identification of both opportunities and challenges in their implementation);
- Recognizing barriers and risks (through highlighting associated barriers and risks, the study furnishes crucial information necessary for crafting strategies aimed at overcoming challenges and mitigating potential risks);
- Industry and supports services emphasis (targeting specific sectors refines the focus, rendering findings more pertinent and actionable for businesses operating within these fields);
- Providing insights for development (the study offers valuable guidance for policymakers, industry stakeholders, and academia);
- Bridging the business–academia divide (addressing real–world challenges serves to bridge the gap between academia and businesses, refining educational curricula and fostering collaborative efforts);
- Guiding policy and strategy (study findings can inform the formulation of policies that encourage innovation, infrastructure

enhancement, and the establishment of actual regulatory frameworks);

— Stimulating innovation (insight into the current landscape can ignite inspiration for innovations, new product offerings, and service developments aimed at addressing identified needs);

— Facilitating collaboration (serving as a catalyst for collaboration, the study encourages stakeholders to pool resources, share knowledge, and collectively drive the development of smart buildings solutions in Romania).

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