An Integrated BIM-IoT approach to support energy monitoring

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Abstract

BIM, Building Information Model, is considered the 3D representation of an artifact and its characteristics such as geometry, spatial relationships, and geographical information to support integrated design. With recent developments in BIM, there has been a shift from simple 3D to interact with virtual and augmented reality. This innovation drives improvements in work productivity, home comfort, and entertainment, common goals of the Internet of Things (IoT). Therefore, 3D and sensors can integrate through data captured in a BIM model, an environment that lends itself well to the visualization of the results of Machine Learning operations. This paper proposes a methodology that allows data visualization and representation from sensors within a BIM model to support design decisions that fall under different disciplines. The research focuses on a real case study of a university classroom that includes several sensors capable of recording data that feed a database based on the predictive/decisional phase developed through Machine Learning techniques to optimize electrical consumption. The proposed methodology integrates an IoT cloud platform that allows the optimal management and monitoring of electricity consumption in a public environment through a model updated in real-time.

Keywords

Building Information Model, Internet of Things, Energy Monitoring, Data Analysis

1. Introduction

BIM (Building Information Modeling) is widely used in the construction industry, focusing mainly on building systems and components. Building applications through BIM create advantages in various applications, for example, forecasting and organizing maintenance work, energy management, sustainability assessment, and life cycle costs [1], [2], [16]. With the advancement of technological innovation, the amount of data that can be stored has grown, and this increase is partly due to the use of technology at a more affordable cost allowing the development of devices connected to the Internet continuously: this technology is called the Internet of Things, which refers to devices able to exchange information autonomously [3], [4]. Thanks to the development of this technology, the IoT has emerged from its embryonic stage as a revolutionary technology supporting a fully integrated internet designed to handle different application scenarios such as smart industries, smart cities, smart buildings, and smart healthcare [18-20]. Indeed, a crucial role of the IoT is to create a digital copy of reality, generating digital scenarios for the management of different sectors [5], [6]. During COVID-19 scenario the use of IoT devies are increased [24-26]. This study gives special attention to data visualization, which allows preliminary analysis, continuous monitoring, and final processing of the collected data using computer graphics techniques and interactive technologies. Furthermore, data

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collection methods have evolved from the traditional wired transmission to open wireless technologies such as RFID tags, embedded sensors, actuator nodes, and MEMS Micro-Electro-Mechanical Systems [7], [8]. [17] [21-23].

2. Related Works

BIM modeling technology includes information and visualization of the building but does not have the means to incorporate information about the surrounding environment into the model automatically. In fact, such modeling must be supported by a plug-in for integration between reality and the BIM model, which is the first step towards an intelligent building [9]. The digital twin can integrate the Internet of Things, artificial intelligence, machine learning, and data analysis with spatial network graphs. It can also use machine learning and artificial intelligence systems to process data and produce new knowledge or predict actionable scenarios by developing collected data, creating digital simulation models that update and change when their physical counterparts change. Therefore, a digital twin can continuously encapsulate and update its characteristics from multiple sources [10]. Several studies have attempted to integrate sensor information and BIM information, such as visualizations, and to build management systems, to find that data obtained from building structural health diagnosis could not be effectively and systematically integrated with other relevant monitoring data to support management data and proposed a dynamic parametric BIM approach using time series sensor data to support dynamic and data-driven visualization [11]. This study integrates the management of data collected from IoT-based sensors to a BIM model and the consequential 3D visualization, where all sensors are represented in the BIM model and exchange information by interacting with each other. This work describes a methodological proposal that allows the visualization and representation in a smooth way of the data acquired by the sensors within the BIM environment to support design decisions involving different skills from multiple disciplines [12]. The study is based on a real case study of a university classroom comprising multiple sensors capable of producing data that feed a database at the basis of the predictive/decision-making phase developed through Machine Learning techniques [13]. The methodological proposal includes an IoT-based cloud platform that assists the communication between sensors and Dynamo software to access the data, automatically updating the information in the BIM model [14].

3. Proposed Approach

This study enhances the ability to intelligently monitor and manage a BIM model according to precise asset steps that include a modeling technique that focuses on producing a 3D model of the case study environments and the management of the spatial information of the same. The collection of data on an IoT-based cloud platform allows easy and intuitive data management; the development of the automated exchange of sensor data between sensor data collection software, parametric design software, and the BIM modeling platform and, finally, the integration of Machine Learning techniques for the management of the architectural space from the point of view of living comfort. This approach can be considered in the more advanced stages of designing or managing an environment to find the best design solution among several alternative scenarios under different conditions. First, the basic requirements and the goal to be achieved are established. Subsequently, the designer parameterizes the coefficients to improve the characteristics of the model. The application of parametric design has been successfully adopted in several BIM applications as a design change management engine; however, parametric systems have evolved into practical design tools but are not yet considered complete BIM design applications. Dynamo is an open-source visual programming application from Autodesk that aims to be accessible to programmers and computer language novices. It gives users the ability to visually describe behavior, define custom logical elements, and execute lines of code using various textual programming languages such as Python. Visual programming is a form of coding that, unlike textual programming, does not require the compilation of code or familiarity with a textual programming language; instead, it uses a visual interface in which the designer connects nodes of predefined functionality. Together, these nodes form a more extensive network of functionality capable of achieving complex goals. This approach is easier to use and explore than programming based solely on lines of text. It makes tasks previously reserved for experienced programmers accessible to building designers. Designers can also use the power of the Revit API to use individual objects or families of objects in the program to perform parametric operations. Dynamo allows users to set up automation or calculation platforms through a visual node-based compilation interface. Designers can perform data processing and correlate structural and geometric parameter checks.

4. Case of Study

In this study, we propose to analyze a workflow involving the collection of data through light and lighting sensors, a detection system with cameras and energy consumption, and their integration through a parametric control mechanism and visualization modules to facilitate management and monitoring, with the aim of activating autonomous choice mechanisms to improve electricity consumption due to the lighting of an environment. This workflow is developed in two architectural phases: Visual Programming and Parametric Design. Visual programming allows the connection with the data collection platform, the set of values and the data display mode, and the automatic integration with the BIM work environment. On the other hand, to achieve the goal of displaying the data obtained for improving consumption, it exploits the potential of parametric design: scale-up of the real building with sensors through the development of the Digital Twin (BIM model) by introducing a 3D virtual space and positioning the sensors detected by an IoT-based platform, parameterizing, according to the decision objectives related to the different scenarios, the operating rules of the custom nodes that are implemented within the Visual Programming environment, by automatically updating the Digital Twin. The case study focuses on reproducing a digital twin of a university classroom. Firstly, the classroom understudy was furnished with sensors that monitor the different parameters of its current state interconnected to a microcontroller, Arduino. The sensors used in this study were mainly three: 1) a Light Dependent Resistor sensor placed near the external openings to collect data about the amount of light entering the classroom; 2) video cameras, to monitor the number of people inside a classroom and the spatial distribution within it; 3) sensor to monitor the energy consumption of the lighting system. The acquired data is then stored on a cloud platform, ThingsBoard [15], which allows the data to be read and visualized immediately and easily, customizing the type of data according to the type of sensor selected or the design requirements. The next step is the real-time visualization of the data from the sensors within the BIM model, and this becomes possible through the use of Dynamo. Once all the data has been collected using reinforcement machine learning, it is possible to automatically manage the intensity of the light inside the classroom, based on the amount of light coming in from outside and weighted by the amount and distribution of students inside the classroom to limit energy consumption and, therefore, protect the environment. Reinforcement learning is a machine learning technique that aims to create autonomous agents capable of choosing actions to be performed to achieve specific objectives through interaction with the environment in which they are placed. In fact, the processor uses trial and error to solve the problem. In this approach, the artificial intelligence receives rewards or penalties for the actions it performs from the programmer to maximize the rewards to be received. It is up to the model to figure out how to perform the task to maximize the reward, starting with totally random trials and ending with sophisticated tactics. Leveraging the power of search and many trials, reinforcement learning is the most effective way to suggest machine creativity. Finally, thanks to the dedicated API, the ThingsBoard platform is automatically queried to capture the actual data and then, via a display, directly to the Digital Twin in a BIM environment. The ability to use the data in real-time allows a better study of the electrical consumption and the light intensity needed by the students inside the classroom, becoming a tool to support design decisions to make appropriate changes in real-time, according to the needs, and then see the effects of these choices in a practical and fast way.

Figure 1 Proposed Architecture

5. Conclusions

This work aimed to introduce a methodology that allows data management from sensors within the BIM environment to support decisions, sometimes complex, that require interdisciplinary skills. The case study was the monitoring and controlling lighting in a public environment such as a university classroom that includes several sensors to reduce energy consumption due to lighting. The proposed methodology integrates the use of an IoT-based platform, Thingsboard, which allows communication between sensors and Dynamo software to access sensor data, automatically updating the information contained in the BIM model. The experimental results, although preliminary, yielded promising results. They have shown that the system can learn and manage specific actions autonomously, supporting users. Future developments include expanding the database with other useful sensors to refine the data, the introduction of contextual parameters that could improve the system's performance in terms of reliability, and developing an application that could help users manage the building.

6. References

[1] H. Gao, C. Koch, and Y. Wu, "Building information modelling based building energy modelling: A review," *Applied Energy*, vol. 238. 2019. doi: 10.1016/j.apenergy.2019.01.032.

[2] J. C. P. Cheng, W. Chen, K. Chen, and Q. Wang, "Data-driven predictive maintenance planning framework for MEP components based on BIM and IoT using machine learning algorithms," *Automation in Construction*, vol. 112, 2020, doi: 10.1016/j.autcon.2020.103087.

[3] S. Tang, D. R. Shelden, C. M. Eastman, P. Pishdad-Bozorgi, and X. Gao, "A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends," *Automation in Construction*, vol. 101, May 2019, doi: 10.1016/j.autcon.2019.01.020.

[4] S. A. Khowaja, P. Khuwaja, K. Dev, and G. D'Aniello, "VIRFIM: an AI and Internet of Medical Things-driven framework for healthcare using smart sensors," *Neural Computing and Applications*, 2021, doi: 10.1007/s00521-021-06434-4.

[5] F. Colace, C. Elia, C. G. Guida, A. Lorusso, F. Marongiu, and D. Santaniello, "An IoT-based Framework to Protect Cultural Heritage Buildings," 2021. doi: 10.1109/smartcomp52413.2021.00076.

[6] F. Colace, C. Elia, E. Landolfi, M. Lombardi, D. Santaniello, and A. Troiano, "An IoT-Based Framework for Smart Agriculture Managing and Product Enhancing," in *Proceedings of Sixth International Congress on Information and Communication Technology*, 2022, pp. 111–119. doi: 10.1007/978-981-16-2102-4_10.

[7] A. Castiglione, F. Colace, V. Moscato, and F. Palmieri, "CHIS: A big data infrastructure to manage digital cultural items," *Future Generation Computer Systems*, vol. 86, 2018, doi: 10.1016/j.future.2017.04.006.

[8] D. Capriglione *et al.*, "Development of a test plan and a testbed for performance analysis of MEMS-based IMUs under vibration conditions," *Measurement: Journal of the International Measurement Confederation*, vol. 158, 2020, doi: 10.1016/j.measurement.2020.107734.

[9] X. Gao and P. Pishdad-Bozorgi, “BIM-enabled facilities operation and maintenance: A review,” *Advanced Engineering Informatics*, vol. 39. 2019. doi: 10.1016/j.aei.2019.01.005.
[10] C. Boje, A. Guerriero, S. Kubicki, and Y. Rezgui, “Towards a semantic Construction Digital Twin: Directions for future research,” *Automation in Construction*, vol. 114. 2020. doi: 10.1016/j.autcon.2020.103179.
[11] S. H. Khajavi, N. H. Motlagh, A. Jaribion, L. C. Werner, and J. Holmstrom, “Digital Twin: Vision, benefits, boundaries, and creation for buildings,” *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2946515.
[12] T. Bloch and R. Sacks, “Comparing machine learning and rule-based inferencing for semantic enrichment of BIM models,” *Automation in Construction*, vol. 91, 2018, doi: 10.1016/j.autcon.2018.03.018.
[13] I. Cvitić, D. Peraković, M. Periša, and B. Gupta, “Ensemble machine learning approach for classification of IoT devices in smart home,” *International Journal of Machine Learning and Cybernetics*, 2021, doi: 10.1007/s13042-020-01241-0.
[14] A. di Filippo, M. Lombardi, F. Marongiu, A. Lorusso, and D. Santaniello, “Generative design for project optimization,” 2021. doi: 10.18293/dmsviva21-014.
[15] M. Henschke, X. Wei, and X. Zhang, “Data Visualization for Wireless Sensor Networks Using ThingsBoard,” 2020. doi: 10.1109/WOCC48579.2020.9114929.
[16] AlZu’bi, S., Hawashin, B., Mujahed, M., Jararweh, Y., & Gupta, B. B. (2019). An efficient employment of internet of multimedia things in smart and future agriculture. Multimedia Tools and Applications, 78(20), 29581-29605.
[17] Al-Ayyoub, M., Al-Mnayyis, N., Alsmirat, M. A., Alawneh, K., Jararweh, Y., & Gupta, B. B. (2018). SIFT based ROI extraction for lumbar disk herniation CAD system from MRI axial scans. Journal of Ambient Intelligence and Humanized Computing, 1-9
[18] Al-Ayyoub, M., AlZu’bi, S., Jararweh, Y., Shehab, M. A., & Gupta, B. B. (2018). Accelerating 3D medical volume segmentation using GPUs. Multimedia Tools and Applications, 77(4), 4939-4958
[19] Al-Ayyoub, M., AlZu’bi, S., Jararweh, Y., Shehab, M. A., & Gupta, B. B. (2018). Accelerating 3D medical volume segmentation using GPUs. Multimedia Tools and Applications, 77(4), 4939-4958.
[20] AlZu’bi, S., Shehab, M., Al-Ayyoub, M., Jararweh, Y., & Gupta, B. (2020). Parallel implementation for 3d medical volume fuzzy segmentation. Pattern Recognition Letters, 130, 312-318.
[21] Sandeep Kumar (2021) Artificial Intelligence and Machine learning for Smart and Secure Healthcare System, Insights2Techinfo, pp.1
[22] A. Dahiya, K. Psannis (2021), Internet-of-Medical-Things (IoMT): An Unexplored Dimension in Healthcare, Insights2Techinfo, pp.1
[23] Mamta (2021) Quick Medical Data Access Using Edge Computing, Insights2Techinfo, pp.1
[24] Ruchi Bhatnagar and Deepak Sinha (2021) Smart Adoption of IoT in Covid 19 Pandemic paves new era of sustainable future world, Insights2Techinfo, pp.1
[25] A. Dahiya, B. B. Gupta (2021) How IoT is Making DDoS Attacks More Dangerous?, Insights2Techinfo, pp.1
[26] Tripathi, S., Gupta, B., Almomani, A., Mishra, A., & Veluru, S. (2013). Hadoop based defense solution to handle distributed denial of service (ddos) attacks. Journal of Information Security. Vol. 4 No. 3 (2013) , Article ID: 34629 , 15 pages DOI:10.4236/jis.2013.43018