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Editorial

Special Issue Cognitive Buildings

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1. Introduction

Cognitive building is a pioneering topic to envision the future of our built environment. The concept of "cognitive" steps towards a paradigm shift, from the static concept of the building as a container of human activities, is nearer to the modernist vision of "machine à habiter" of Le Corbusier, where the technological content adds the capability of learning from users' behavior and environmental variables to adapt itself to achieve main goals such as users' comfort, energy-saving, flexible functionality, high durability, and good maintainability. The concept is based on digital frameworks and IoT networks towards the smart city concept. A BIM-based approach to cognitive buildings and assets is widely represented in the evolving research, oriented to different fields of application throughout the buildings' lifecycle that will shape the future of the built environment, where the users could extend and improve their daily experience towards a better life.

So far, 11 papers have been published in the Special Issue. The next sections provide a brief summary of each of the papers published.

2. Explainable Post-Occupancy Evaluation Using a Humanoid Robot

Bonomolo et al. [1] propose a new methodological approach for evaluating the comfort condition using the concept of explainable post-occupancy to make the user aware of the environmental state in which (s)he works. Such an approach was implemented on a humanoid robot with social capabilities that aims to enforce human engagement to follow recommendations. The humanoid robot helps the user to position the sensors correctly to acquire environmental measures corresponding to the temperature, humidity, noise level, and illuminance. The distribution of the last parameter due to its high variability is also retrieved by the simulation software Dialux. Using the post-occupancy evaluation method, the robot also proposes a questionnaire to the user for collecting his/her preferences and sensations. In the end, the robot explains to the user the difference between the suggested values by the technical standards and the real measures, comparing the results with his/her preferences and perceptions. Finally, it provides a new classification into four clusters: true positive, true negative, false positive, and false negative. This study shows that the user is able to improve her/his condition based on the explanation given by the robot.

3. An openBIM Approach to IoT Integration with Incomplete As-Built Data

Moretti et al. [2] discuss how Digital Twins (DT) are powerful tools to support asset managers in the operation and maintenance of cognitive buildings. Building Information Models (BIM) are critical for Asset Management (AM), especially when used in conjunction with Internet of Things (IoT) and other asset data collected throughout a building's lifecycle. However, information contained within BIM models is usually outdated, inaccurate, and incomplete as a result of unclear geometric and semantic data modeling procedures during the building life cycle. The aim of this paper is to develop an openBIM methodology to support dynamic AM applications with limited as-built information availability. The

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workflow is based on the use of the IfcSharedFacilitiesElements schema for processing the geometric and semantic information of both existing and newly created Industry Foundation Classes (IFC) objects, supporting real-time data integration. The methodology is validated using the West Cambridge DT Research Facility data, demonstrating good potential in supporting an asset anomaly detection application. The proposed workflow increases the automation of the digital AM processes, thanks to the adoption of BIM-IoT integration tools and methods within the context of the development of a building DT.

4. Building Information Modeling and Energy Simulation for Architecture Design

Bonomolo et al. [3] deal with Building Information Modeling (BIM) that, over the years, has undergone a significant increase, both in terms of functions and use. This tool can almost completely manage the entire process of the design, construction, and management of a building internally. However, it is not able to fully integrate the functions and especially the information needed to conduct a complex energy analysis. Indeed, even if the energy analysis has been integrated into the BIM environment, it still fails to make the most of all of the potential offered by building information modeling. The main goals of this study are the analysis of the interaction between BIM and energy simulation through a review of the main existing commercial tools (available and user-friendly), and the identification and application of a methodology in a BIM environment by using Graphisoft's BIM software Archicad and the plug-in for dynamic energy simulation EcoDesigner STAR. The application on a case study gave the possibility to explore the advantages and the limits of these commercial tools and, consequently, to provide some possible improvements. The results of the analysis, satisfactory from a quantitative and qualitative point of view, validated the methodology proposed in this study and highlighted some limitations of the tools used; in particular, for the aspects concerning the personalization of heating systems.

5. Building Information Modeling and Internet of Things Integration for Facility Management—Literature Review and Future Needs

Mannino et al. [4] show how the digitization of the built environment is seen as a significant factor for innovation in the architecture, engineering, construction and operation sector. However, a lack of data and information in as-built digital models considerably limits the potential of building information modeling in facility management. Therefore, the optimization of data collection and management is needed, all the more so now that Industry 4.0 has widened the use of sensors into buildings and infrastructures. A literature review on the two main pillars of digitalization in construction, building information modeling and Internet of things, is presented, along with a bibliographic analysis of two citations and abstracts databases focusing on the operations stage. The bibliographic research has been carried out using Web of Science and Scopus databases. The article is aimed at providing a detailed analysis of BIM–IoT integration for Facility Management (FM) process improvements. Issues, opportunities, and areas where further research efforts are required are outlined. Finally, four key areas of further research development in FM management have been proposed, focusing on optimizing data collection and management.

6. Towards an Occupancy-Oriented Digital Twin for Facility Management: Test Campaign and Sensors Assessment

Seghezzi et al. [5] focus on calibration and test campaigns of an IoT camera-based sensor system to monitor occupancy as part of an ongoing research project aiming at defining a Building Management System (BMS) for facility management based on an occupancy-oriented Digital Twin (DT). The research project aims to facilitate the optimization of the building operational stage through advanced monitoring techniques and data analytics. The quality of the collected data, which are the input for analyses and simulations on the DT virtual entity, is critical in order to ensure the quality of the results. Therefore, calibration and test campaigns are essential to ensure the data quality and efficiency of the IoT sensor system. The paper describes the general methodology for the BMS definition, and the method and results of the first stages of the research. The preliminary analyses includes In-

dicative Post-Occupancy Evaluations (POEs) supported by Building Information Modeling (BIM) to optimize sensor system planning. Test campaigns are then performed to evaluate the collected data quality and system efficiency. The method was applied on a Department of Politecnico di Milano. The period of the year in which tests are performed was critical for lighting conditions. In addition, spaces' geometric features and user behavior caused major issues and faults in the system. Incorrect boundary definition: areas that are not covered by boundaries; thus, they are not monitored.

7. An Adapted Model of Cognitive Digital Twins for Building Lifecycle Management

Yitmen et al. [6] present the digital transformation era in the Architecture, Engineering, and Construction (AEC) industry, where Cognitive Digital Twins (CDT) are introduced as part of the next level of process automation and control towards Construction 4.0. CDT incorporates cognitive abilities in order to detect complex and unpredictable actions, and reasons about dynamic process optimization strategies to support decision-making in Building Lifecycle Management (BLM) are provided. Nevertheless, there is a lack of understanding of the real impact of CDT integration, Machine Learning (ML), Cyber–Physical Systems (CPS), Big Data, Artificial Intelligence (AI), and Internet of Things (IoT), all connected to self-learning hybrid models with proactive cognitive capabilities for different phases of the building asset lifecycle. This study investigates the applicability, interoperability, and integrability of an adapted model of CDT for BLM to identify and close this gap. Surveys of industry experts were performed, focusing on life cycle-centric applicability, interoperability, and the CDT model's integration in practice, besides decision support capabilities and AEC industry insights. The evaluation of the adapted model of the CDT model supports approaching the development of CDT for process optimization and decision-making purposes, as well as integrability enablers confirm a progression towards Construction 4.0.

8. The Implementation of Visual Comfort Evaluation in the Evidence-Based Design Process Using Lighting Simulation

Davoodi et al. [7] work on a validation of the EBD-SIM (evidence-based design simulation) framework, a conceptual framework developed to integrate the use of a lighting simulation in the EBD process, which suggested that EBD's Post-Occupancy Evaluation (POE) should be conducted more frequently. A follow-up field study was designed for a subjective–objective results implementation in the EBD process using lighting simulation tools. In this real-time case study, the visual comfort of the occupants was evaluated. The visual comfort analysis data were collected via simulations and questionnaires for subjective visual comfort perceptions. The follow-up study, conducted in June, confirmed the results of the original study, conducted in October, but additionally found correlations with annual performance metrics. This study shows that, at least for the variables related to daylight, a POE needs to be conducted at different times of the year to obtain a more comprehensive insight into the users' perception of the lit environment.

9. IoT Open-Source Architecture for the Maintenance of Building Facilities

Villa et al. [8] debate about the introduction of the Internet of Things (IoT) in the construction industry, which is evolving Facility Maintenance (FM) towards predictive maintenance development. The predictive maintenance of building facilities requires continuously updated data on construction components to be acquired through integrated sensors. The main challenges in developing predictive maintenance tools for building facilities is IoT integration, IoT data visualization on the building 3D model, and the implementation of a maintenance management system on the IoT and Building Information Modeling (BIM). The current 3D building models do not fully interact with IoT building facilities data. Data integration in BIM is challenging. The research aims to integrate IoT alert systems with BIM models to monitor building facilities during the operational phase and to visualize building facilities' conditions virtually. To provide efficient maintenance services

for building facilities, this research proposes an integration of a digital framework based on IoT and BIM platforms. Sensors applied in the building systems and IoT technology on a cloud platform with open source tools and standards enable the monitoring of a real-time operation and the detection of different kinds of faults in the case of malfunction or failure, therefore sending alerts to facility managers and operators. The proposed preventive maintenance methodology applied on a proof-of-concept Heating, Ventilation, and Air Conditioning (HVAC) plant adopts open source IoT sensor networks. The results show that the integrated IoT and BIM dashboard framework and implemented building structures preventive maintenance methodology are applicable and promising. The automated system architecture of building facilities is intended to provide a reliable and practical tool for real-time data acquisition. An analysis and 3D visualization to support the intelligent monitoring of the indoor condition in buildings will enable the facility managers to make faster and better decisions and to improve building facilities' real time monitoring with fallouts on the maintenance timeliness.

10. BIM-Based Research Framework for Sustainable Building Projects: A Strategy for Mitigating BIM Implementation Barriers

Manzoor et al. [9] underline that although Building Information Modeling (BIM) can enhance the efficiency of sustainable building projects, its adoption is still plagued with barriers. In order to incorporate BIM more efficiently, it is important to consider and mitigate these barriers. The aim of this study is to explore and develop strategies to alleviate barriers in developing countries, such as Malaysia, in order to broaden the implementation of BIM with the aid of quantitative and qualitative approaches. To achieve this aim, a comprehensive literature review was carried out to identify the barriers, and a questionnaire survey was conducted with construction projects' stakeholders. The ranking analysis results revealed the top five critical barriers to be the "unavailability of standards and guidelines", "lack of BIM training", "lack of expertise", "high cost", and "lack of research and BIM implementation". Comparative study findings showed that the "lack of research and BIM implementation" is the least important barrier in other countries, such as China, United Kingdom, Nigeria, and Pakistan. Furthermore, a qualitative analysis revealed the strategies to mitigate the BIM implementation barriers to enhance sustainable goals. The final outcome of this study is the establishment of a framework incorporated with BIM implementation barriers and strategies, namely, the "BIM-based research framework", which can assist project managers and policymakers towards effective sustainable construction.

11. Transforming Building Criteria to Evidence Index

Fischl and Johansson [10] emphasize how there is increasing pressure from developers toward architects and engineers to deliver scientifically sound proposals for often complex and cost-intensive construction products. An increase in digitalization within the construction industry, and the availability of intelligently built assets and overall sustainability, make it possible to customize a construction product. This servitization of construction products is assumed to perform much more preferably in satisfying stakeholders' physical, psychological, and social needs. The degree to which these products are performing can be evaluated through an evidence index. This article aims to introduce a conceptual model of an evidence index and to test it in the programming stage of a case study. The investigation follows the evidence-based design approach and renders evidence through key performance indicators in the programming stage of the building process. For testing the concept, a case study investigation was performed by simulating a novice research assistant, and the amount of evidence was collected and appraised for the evidence index. The case study showed that key performance indicators of a servitized project could be evaluated on a four-point scale. The quality of the evidence index generation depended on the level of expertise the evaluator has in the research and the skillful use of scientific databases.

12. Heuristic and Numerical Geometrical Methods for Estimating the Elevation and Slope at Points Using Level Curves—Application for Embankments

Deaconu and Deaconu [11] highlight that both the calculation of ground slopes at points on the map and the elevation estimation for these points bear significant importance and also have applications in various domains, such as civil engineering and road and railway design. The paper presents two methods that use level curves: one that is fast and approximate, and another that is slower but more precise. The running speed of the two proposed methods and their results are compared by performing 100 million experiments. The paper also presents how these methods can be applied to optimize embankments. An accurate method to calculate the horizontal plane of the excavation/filling when building a new house is also presented.

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