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# Application of Integrated Building Information Modeling, IoT and Blockchain Technologies in System Design of a Smart Building

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**Abstract**

The Architecture, Engineering and Construction (AEC) industry has not adopted digital transformation enthusiastically like other industries, for instance, manufacturing, aerospace or finance. Building Information Modeling (BIM) is an innovative technology that is considered as an opportunity for the AEC industry to move to the digital era and improve the collaboration among stakeholders by applying Information and Communication Technologies (ICT). BIM provides all required tools and automations to achieve end-to-end communication, data exchange and information sharing among collaborators. Accordingly, virtual 3D models, created by the BIM process, delivered as physical assets, monitored in real-time and managed using Building Management Systems (BMS), can adopt the Internet of Things (IoT) designs and services. However, the implementation of IoT in a highly modular environment with various moving parts and inter-dependencies between stakeholders leads to security concerns. Therefore, this paper proposes system design that employs the blockchain technology as a measure to secure and control the framework that involves integrated IoT and BIM technologies. Although this paper considers system design applied in a smart museum, the authors assume that design is generic and applicable in other building categories. For instance, this design can be implemented in the ongoing Alumni Hall renovation project at State University of New York College at Oneonta.



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## 1. Introduction

The expansion of Information and Communication Technologies (ICT) has been proved generating powerful, intelligent and smart industrial systems and applications. The Internet of Things (IoT) aims to provide interconnection of smart devices, collect and process data from different environments and provide products and services to end users, application groups and sectors, for instance, government, transportation, health, manufacture, farms, cultural management, etc. [1]. Implementation of IoT and digital technologies in a smart city environment has been increased, providing new challenges in a new digital ecosystem [2]. Smart cities have been equipped with IoT platforms and various electronic devices, applying machine learning and Artificial Intelligence (AI) algorithms and, therefore, becoming smarter and more efficient than before [3], [4]. However, buildings are the key elements of cities, and, therefore, buildings remain the key elements in a smart city ecosystem [2]. Therefore, beyond the smart devices and services that have been deployed in smart cities, the building information obtained through Building Information Modeling (BIM), combined with collected data and developed intelligent applications, can be a basis for IoT platforms and provided services in the integrated digital ecosystem. Although the communication infrastructure provides a desirable Quality of Service (QoS) through developments in modern communication technologies [2], the use of blockchain technology can help to address security issues in the framework that involves integrated BIM and IoT technologies. In the construction sector, the Architecture, Engineering and Construction (AEC) industry contains a high number of stakeholders who operated in the same way for decades and did not adopt digital transformation enthusiastically like other industries, for instance, manufacturing, aerospace or finance [5]. In fact, AEC is one of the least digitalized sectors and for many economic analysts this relates to flat or falling productivity rates. However, the construction sector is strategically important to economies in terms of output and job creation. For instance, the U.S. construction sector output is approximately $10 trillion in goods and services and it employs over 10 million workers [6]. The European construction sector output is approximately €1.3 trillion in goods and services and it employs over 18 million workers [7]. The failure to recognize the transformation need eventually can put at risk the sustainability of “change resistant” construction companies. To address this challenge, recently, the construction industry tries to transform by using emerging technologies with a great potential for the ICT development, enabling new stakeholders to adapt and take advantage of opportunities that emerge. Building Information Modeling (BIM) is an innovative technology that makes AEC to move to the new digital era, with reduced costs and project delivery time, and increased productivity, as far as BIM provides automation capabilities for more integrated communications, data exchange and sharing among stakeholders within a virtual 3D environment [8]. Virtual 3D models, created by the BIM process, delivered as physical assets, monitored in real-time and managed using Building Management Systems (BMS), can adopt IoT framework, which consists of a data model for the network of equipment, sensors, and wearables. This integration can improve data-driven asset management by enriching building information in operation and providing better services to users. However, this requires ensuring predefined conditions to reduce probability of fraudulent activities throughout the supply chain. Therefore, this paper focuses on both applying modern, digital technologies in the construction sector and examining their interconnection and interoperability. It is destined to enable new opportunities to new stakeholders in AEC by allowing them to adapt and benefit from all that construction sector can offer. The authors propose system design that utilizes the blockchain technology in the framework that involves integrated BIM and IoT technologies. The authors consider application of the proposed design in a smart museum building and evaluate integrated digital technologies and overall performance of the proposed framework. Consistent with increasing trend to adopt BIM worldwide that leads to so-called City Information Modeling (CIM) [9], the authors explain how this design implemented in a smart building can serve to model smart city and its ecosystem.

## 2. Combined Intelligence of IoT and Blockchain Technologies

The Internet of Things (IoT) technology enables a network of physical objects, empowered by sensing, processing and communication units, to sense physical events, exchange data and interact with the environment to make decisions or monitor some processes and events without human interventions [10]. IoT systems facilitate a real-time data collection and provide automatic and remote-control mechanisms replacing conventional monitoring and control systems across different industries. IoT systems generate massive volumes of data that require network connectivity and power, processing and storage resources to transform these data into meaningful information or services. Beside reliable connectivity and network scalability, cybersecurity and data privacy are of critical importance in using IoT networks. IoT data reliability can be achieved by using distributed signal processing methods which execute a verification process between all its physical objects to ensure that data remain immutable and untampered. Accordingly, the blockchain technology introduces a distributed ledger that is recorded, transparent, and decentralized. Blockchain represents a way to record transactions or any digital interactions that is secure, transparent, highly resistant to outages, auditable, and efficient. These features encourage IoT companies to enhance their IoT networks with the blockchain technology. Combined intelligence of IoT and blockchain technologies provides a verifiable, secure and robust mechanism to store and manage data generated or processed by connected smart devices. This network of interconnected devices can interact with their environment and make decisions without human interventions [2], [3].

## 3. Evaluation of Integrated Building Information Modeling, IoT and Blockchain Technologies

BIM is defined as "a process or method of managing information related to facilities and projects in order to coordinate multiple inputs and outputs, using shared digital representations of physical and functional characteristics of any built object" [11]. Therefore, BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" [12]. In practice, the building information modeling technology has rapidly grown from being a 3D model with three primary spatial dimensions, such as width, height, and depth; to a 4D model, where time, for instance, construction scheduling information, is added; and even to a 5D model, where cost is also considered [13]. Additionally, the BIM model contains some non-geometric information, including material for building components, weight, price, procedures, scale and size. It offers real-time data sharing and collaborative decision-making among various stakeholders and improves visualizations and simulations, as, for instance, in early virtual prototyping, etc. It also reduces material and time waste and reduces costs due to better construction outcomes and higher probability of performance [14]. The BIM model, created according to several uses upon-agreed and various phases of the construction process, can lead to the life-long monitoring system of a building, the Building Management System (BMS) [15]. The BMS design includes such system components as energy management, access control, environment protection, building control and mobile applications, developed for users, which are integrated in a 3D model of a building [16].

The building information modeling technology enriches data and information collection of a building in operation through Building Management Systems (BMS) providing real-time monitoring and improved services to users; this becomes feasible due to implementation of ICT in the BIM process [9], [17], [18]. The integration of IoT framework and BIM/BMS model can provide such functionality as real-time access to on-demand data and better interoperability; collection of data about the current state of a building; numerous uses of this data by different users; collaboration; speeding-up decision processes; and warning, detecting critical issues, predicting behaviors and/or failures [18]. The application of integrated building information modeling and IoT technologies can increase and become a formal licensing procedure in the future, intended to enable and control digital models of all buildings and provide accountability regarding the errors and inaccuracies, since assuming responsibility for retrieving, storing, distributing and updating data and information as well as ensuring their accuracy entails a great deal of risk [9], [17], [18]. While a proposed building information modeling development can become the City Information Modeling (CIM) technology that includes the entire city; the IoT framework providing storage and processing of the upcoming big volume of BIM-related data and information also can become an important concern to be addressed [9], [17], [18]. Cloud-based solutions may well be the answer; however, questions arise about this service, whether it must be governmental or private cloud. The BIM and CIM tools are connected directly with the vision of smart cities planning and management, since these models contain various systems and stakeholders. Additionally, these models enable simulations that help monitor water consumption, energy consumption, utilities, traffic, congestions, impact of natural disasters, including earthquakes, hurricanes, floods, etc., with the use of data collected from IoT devices [9], [17], [18].

The authors believe the blockchain technology provides exceptional benefits for the construction sector. For instance, when integrated Cloud computing, IoT and BIM technologies could lead to security problems [9], [17], [18], blockchain serves either as an immutable way to store data and information and utilize them as a log, or as an origin system [10]. Therefore, the integrated BIM and blockchain technologies promise an increasingly secure and private environment to conduct business with a full governance over processes. Blockchain enables such features as proof-of-ownership, for instance, rights issues; proof-of-provenance, for instance, record keeping through a traceable immutable ledger; and reduction in human errors and deviations [10]. Moreover, the BIM-related data are expected to be stored over cloud storage for maintenance purposes in an accessible repository during the life cycle of a facility in the smart city contents. By integrating multiple BIM models in a BMS, several security concerns arise. Since the BIM model contains data about the building design and its digital character, for instance, the deployed communication, and, also, about computer networks and devices at the edge, for instance, sensors and actuators; it is critical to maintain control and governance over data and information sharing. Therefore, appropriate security measures must be implemented, involving authorization and authentication mechanisms; end-to-end monitoring of communication between the sensors and backbone infrastructure; and perimeter defense systems on the back-end-generated infrastructure [10]. Additionally, due to heterogeneity of network design and complexity of communication protocols, the security measures are not compatible continuously between themselves. Therefore, the blockchain technology addresses concerns related to heterogeneity [10]. Besides, when utilizing BIM and BMS models in the construction sector, emerges the requirement for data classification, partitioning and risk management exclusively among the right-privileged stakeholders because the AEC companies and the City Urban Services should not have access to data and information, as well as to assets management of a private property or a governmental institution during its life cycle. Therefore, the blockchain technology can help to ensure that the privileges are properly assigned and properly enforced [10]. Blockchain adds a complementary layer of security enabling both control over security processes and immediate response in an event of security breach. Moreover, the key characteristic of the blockchain paradigm is that tampering with its data is not possible. Therefore, transparency and verifiability are enabled to further improve security level [10]. Additionally, blockchain can serve as real-time monitoring mechanism that collects data and information about all activities of sensors and systems [10]. It monitors all events occurring in the system, for instance, accessing the system or processing collected data and information.

## 4. Evaluation of Integrated Building Information Modeling, IoT and Blockchain Technologies in System Design of a Smart Building

The authors propose system design that integrates the BIM, IoT and blockchain technologies and underlines evolving role of smart buildings in the IoT environment, as shown in Fig. 1.

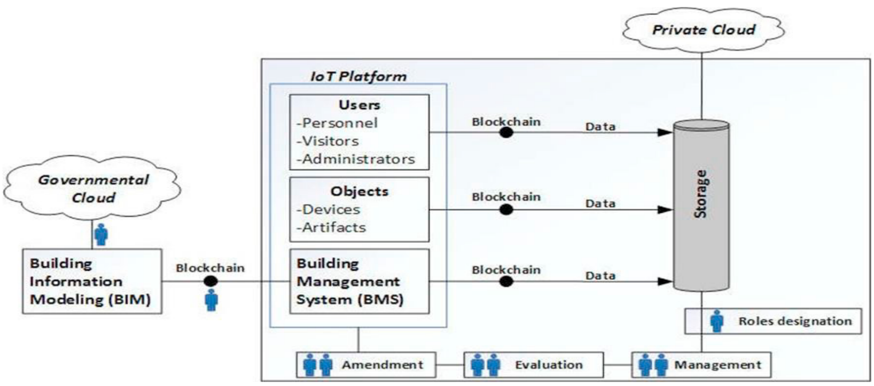


Fig. 1. Integrated BIM, IoT and Blockchain technologies in the proposed system design.

It allows efficient management of data and information related to building components, for instance, the structure; and user behavior, for instance, access, movement, reaction, etc. The use of blockchain provides an additional layer of data and information security. Although the design is used in a smart museum, the authors assume that proposed design is generic and can be implemented in various building categories, public and private. For instance, the design can be adopted in hospitals, museums, headquarters, industrial buildings, commercial buildings, offices, campus buildings, etc. The authors assume that proposed design potentially can be implemented in the ongoing Alumni Hall renovation project at State University of New York College at Oneonta. The nature of a museum building is very sensitive from its construction up to its daily operation. This happens due to the contents of a museum and its exhibits. The operation and maintenance of a museum are of high importance due to exhibitions of tangible and intangible evidence of humans and the history. The exhibition environment is a building, where storage, documentation and preservation of monumental objects take place [19]. Currently, museums play various administrative roles relating such functions as exhibition spaces; objects displayed; security and safety; financial management, for instance, admission fees and profits from museum shops; workshops, laboratories and storage spaces that usually contain numerous artifacts of high cultural value, comparable with those displayed to public; and museum employees, who play a critical role in providing a smooth and seamless operation of the museum. The security and safety function of exhibit collections is the top priority for museums [20]. However, unfortunately, sometimes that is not fulfilled. Failure of the top priority function can occur, for instance, because of theft as it happened during the notorious robbery of paintings valued at $500 million at Isabella Stewart Gardner Museum in 1990, or because of natural disasters as it happened during the devastating fire that destroyed the Brazilian National Museum in 2018. Preventive maintenance must consider such threats as natural factors, including earthquakes, fire, floods, etc.; environmental factors, including humidity, temperature, infrared radiation, atmospheric pollution, internal wind, level of sound, etc.; biological factors, including action of microorganisms, plants, animals, insects, etc.; human activity, including unauthorized access, false or inefficient documentation, vandalism, bad cleaning processes, theft, warfare, etc.; and factors of the building deterioration, including damages and defective construction materials. As far as it concerns documentation of the collection [21], data and information can relate to information on acquisition, for instance, a valid title of ownership; identification catalogue of collection items, for instance, a full identification, description, provenance, condition, treatment; location tracking of all items inside the museum, for instance, between the spaces of exhibition, laboratories and storage spaces; monitoring of access to all items; and procedures of loan to other museums.

In a smart museum, a correlation between content, time, space and human interactions is extremely important; therefore, a real-time monitoring of all interactions and fast response in case of a breach, can guarantee the security and safety of museum exhibits collection. The virtual models of buildings during the construction process can be a useful management tool also during their life cycle operating period. Moreover, BIM models can enable public services with access to the city's building structural models in order to effectively respond to natural disasters, for instance, fire, earthquakes, floods, etc., or to efficiently control the energy consumption and environmental footprint of its built stock. These models must be stored in a governmental cloud and be accessible only by authorized administrators. Between BIM and BMS models, blockchain can control access to data and information related to a building. The proposed system design allows to amend and update data and information, for instance, in cases of renovations or reconstruction; but prevents unauthorized users from retrieving data and information about the operation of a building, for instance, the position of sensors and cameras, etc. The IoT system can collect data and information concerning behavior of museum users, including the visitors, personnel, and administrators; all activities concerning museum objects, for instance, devices, artifacts, etc.; and performance of all building components. This data and information can be retrieved from the IoT systems and recorded in Blockchain before it is stored in a private cloud. Additionally, this data and information can be accessible only by authorized museum administrators in order to make required amendments, systems adjustments, and artifacts and personnel reorganization. Therefore, this continuous cycle of evaluation and feedback can help administrators of a smart museum to automatically identify anomalies in the processes, as well as improve security and safety of exhibits collection and services provided to users. Nowadays, smart devices and smart services are part of a smart city environment. However, buildings as key elements of a smart city and its digital ecosystem are totally overlooked. Therefore, BIM- and CIM-related data must improve the IoT services. Additionally, the blockchain technology must assure data integrity and information security by preventing access by unauthorized users to data and information about the building operation.

## 5. Conclusion

In this paper, the authors examined the use of integrated BIM, IoT and blockchain technologies in system design of a smart building. The authors consider these technologies as complementary developments that can work together enabling secure storage and management of data and information related to the building operation and improving provided IoT services. The authors assume the proposed design can be adopted in many categories of public and private buildings where the efficiency of construction, safety of humans and assets, and security of data and information are highly important. Finally, the authors believe that integrated BIM, IoT and blockchain technologies create an innovative framework supporting digital transformation in the construction industry.

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