INFORMATION MANAGEMENT IN CARBON EMISSIONS QUANTIFICATION

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ABSTRACT

Global warming is a critical problem that resulted from excessive greenhouse gas emissions and 97% of the greenhouse gases are carbon emissions. The current carbon quantification methods involved massive information and deemed to have low productivity and the accuracy of the quantified carbon emissions is debatable. Thus, the effectiveness of mitigation efforts to reduce carbon emissions is lowered due to the simplification and assumptions during the quantification process. This paper aims to review the potential of Internet of Things (IoT), Building Information Modelling (BIM), and blockchain to quantify the lifecycle carbon emissions. Literature review using synthesis method is adopted to identify the state-of-art for the application of IoT, BIM, and blockchain for carbon emissions quantification. The review concluded that IoT, BIM, and blockchain have the potential to reduce human errors and speed up the real-time carbon emissions quantification. IoT is capable to extract real-time data from the physical environment, BIM can reduce document errors, enhance the collaboration between the stakeholder, and improve the workflow across the supply chain, and Blockchain is well-known for its tamper-proof characteristic which increases the reliability and security of the data stored. These technologies are complementary to each other and able to enhance the reliability and accuracy of carbon emissions quantification. In short, the integration of the technologies can increase the credibility in quantifying the carbon emitted and facilitate the selection of the most appropriate retrofit scenarios for emissions reduction.

KEYWORDS

Carbon Emissions Quantification, Internet of Things (IoT), Building Information Modelling (BIM), Blockchain

1. INTRODUCTION

Global warming and climate change are some of the severe problems which can be resulted from greenhouse gas (GHG) emissions and the construction industry is the main contributor. The construction industry consumes 40% of the total energy consumption and emits 33% of the related global GHG (Chau et al., 2015; Li et al., 2020; Zabalza Bribián et al., 2009). According to Li et al. (2020), 97% of GHG emissions are made up of carbon emissions. The studies in reducing carbon emissions have indeed been extensively carried out and many more similar studies are still underway. Although many studies have been carried out, the results have not yet resolved some basic issues which are the accuracy of carbon footprint estimates and feasibility of methods and techniques introduced. This is because the energy consumption and carbon emissions are subject to uncertainties due to the different computational methods (Ingrao et al., 2018). Ingrao et al. (2021) reviewed and highlighted the need to have accurate life cycle assessment for quality, reliable, and reproductive inventories data.

Traditionally, carbon emissions are measured by adding all the emission output from different phases in the construction supply chain. This will cause missing data when tracking the carbon emission (Resch et al., 2019) and affect the accuracy of the data collected due to manual effort and potential human error. The accuracy of the assessment will be greatly reliant on the quality of the data collected. However, data in the existing assessment methods are collected manually and do not satisfy real-time and dynamic requirements (Tao et al., 2014). Real-time monitoring of carbon emissions is essential to governance the use of clean energy and improve environmental performance (Liu et al., 2020). Wu et al. (2014) also conclude that real-time data can ensure a more precise calculation and comparison in energy estimation and carbon emissions. Nonetheless, monitoring real-time and automation in carbon quantification is still minimal due to a scarcity of trustworthy inventories and models (Liu et al., 2020). Therefore, the accuracy of energy consumption and carbon footprint needs to be enhanced to facilitate the selection of the most appropriate retrofit scenarios for emissions reduction.

The calculation of life cycle carbon emission is complicated and thus simplification and approximation are common in LCA practice (Yang et al., 2018). Thus, these make the process of collecting and tracking reliable data for life cycle carbon emission strenuous across the building life cycle (Fenner et al., 2020; Zhang et al., 2020). Besides, the quality of the data is debatable as existing data available from different locations will be used at locations that lack local data (Anand & Amor, 2017). This is because the construction products in different countries may have different energy consumption and emissions due to many factors including the diversity of fuels and methods in generating electricity (Song et al., 2021). Typically, LCA in Malaysia is conducted by using databases from other countries as Malaysia does not have local inventory data (Moayedi et al., 2017). Thus, it reduces the reliability of the carbon emissions measured.

This research identifies the gap and review the potential of integrating relevant technologies to measure and record real-time carbon emissions to solve issues related to the accuracy and accountability of the data for carbon emission quantification. The next section of paper discussed the existing carbon emissions quantification in the construction industry followed by the background of IoT, BIM, and blockchain. Further discussions were made to explore the potential of integration IoT, BIM, and blockchain for carbon quantification.

2. CARBON EMISSIONS QUANTIFICATION

Life cycle carbon emission comprises embodied carbon and operational carbon. Embodied carbon is generated throughout the upstream material production, transportation, and construction with the downstream maintenance and demolition stage. Meanwhile, operational carbon is created from the energy consumed during the use stage for heating, cooling, lighting, air-conditioning, machinery, and plant operation, and so forth (Chau et al., 2015; Pan & Teng, 2021). Operational carbon has been found to dominate the fractions in studies related to carbon footprints due to the continuous emissions throughout the building lifecycles (Fenner et al., 2020). Operational emissions are the energy required to maintain the comfort of the indoor environment by the operation process such as air conditioning, lightings, equipment, and appliances (Biswas & Gupta, 2019; Ibn-Mohammed et al., 2013). Moreover, operational emissions are relying on the occupants (Ibn-Mohammed et al., 2013), building location, occupation type (Fenner et al., 2018, 2020), climate condition, degree of comfort demanded, and operating schedule (Yang et al., 2018). Operational emissions are accumulated over the building lifespan and will be influenced by the effective life of the building (Dixit et al., 2010; Ibn-Mohammed et al., 2013). Meanwhile, embodied carbon is the summation of the GHG emissions excluding the operational phase emissions (Opher et al., 2021). It includes the emissions from extraction of the natural resources, manufacturing of the construction materials, transportation to the construction site, construction, maintenance, and demolition at the end of life (Chau et al., 2015; Opher et al., 2021). Embodied emissions are largely affected by material selection and primary energy sources (Dixit et al., 2010; Ibn-Mohammed et al., 2013). It is important to quantify carbon emission accurately to further plan relevant actions to net-zero carbon. Technologies such as IoT, BIM, and blockchain have great potential to enhance the reliability and accuracy of carbon emissions quantification.

3. IOT, BIM, AND BLOCKCHAIN

IoT, BIM, and blockchain have great potential to improve the current practice in the built environment (Alvarez et al., 2021; Siountri et al., 2020). Blockchain is able to support BIM technology through smart contracts and integration of these technologies is able to establish clear responsibilities among stakeholders. On the other hand, the integration of blockchain and IoT is able to enhance security in the centralized database (Zhong et al., 2020). The combination of IoT, BIM, and blockchain technologies has been used for various purposes yet integration of these technologies for carbon emissions estimation is relatively novel. Brandín & Abrishami (2021) investigate the synergy between IoT and blockchain in a BIM environment for off-site manufacturing management across the supply chain. The authors concluded that the synergies between blockchain and IoT are able to improve the transparency and immutability of the system while the integration of IoT, BIM, and blockchain is able to guarantee the quality of data. Alvarez et al. (2021) highlighted the advantages and challenges of adopting distributed ledger systems, BIM, and IoT for airport pavement management. Meanwhile, Siountri et al. (2019) integrate the technologies for information management in smart building and highlight the capabilities of the integration to assure data integrity. Siountri et al. (2020) also concluded that integration of IoT, BIM, and blockchain are complimentary and the collaboration between the technologies can secure the storage and management of data while at the same time improve the IoT services.

3.1 Internet of Things (IoT)

Internet of things (IoT) is an interconnection of sensing devices that give real-time data to assist the designer to make better decisions (Carneiro et al., 2018). It connects all real-life and virtual devices and allows them to interact in the same network (Carneiro et al., 2018). It is also able to collect and analyze data automatically by using sensors, radio-frequency identification (RFID), or Near Field Communication (NFC) (Isikdag, 2015). A study by An et al. (2021) on the IoT-based LCA platform of wind turbines has proven that the accuracy of the assessment can be ensured by using a real-time collection of energy consumption and carbon emissions data spawned by the physical environment. The author also suggested the use of blockchain technology for the authenticity and credibility of data for future research directions. Tao et al. (2014) employed IoT for LCA for energy-saving and emission-reduction and highlighted the potential of IoT in the whole life cycle of a product. Ingrao et al. (2021) concluded that using sensors in IoT technology is capable to increase the effectiveness of LCA evaluation and demonstrated the difference between data calculated from mathematical models and data collected from the direct measurement from sensors. Zuo et al. (2018) developed an IoT and cloud-based method for real-time energy consumption monitoring and analysis for green and sustainable manufacturing.

3.2 Building Information Modelling (BIM)

Building information modelling (BIM) has been utilized to solve sustainability issues in recent years. BIM is a 3D modelling that provides a great amount of information including geometric and semantic information (Carneiro et al., 2018). Moreover, Crippa et al. (2018) integrates BIM and LCA for embodied carbon estimation on wall systems and concluded that the integrations improvise the building carbon footprint quantification. Kaewunruen & Lian (2019) uses 6D BIM to optimize the life cycle management for the railway turnout system. Ding et al. (2020) developed a BIM-based carbon emission measurement system for prefabricated residential buildings for a more precise measurement of carbon footprint. Lu et al. (2019) conducted research for BIM-based LCA for hospital building and summarized that carbon emitted throughout the operational stage are the highest due to geographical location and the characteristic of the hospital building. Gan et al. (2018) present a framework that uses BIM to analyze the effect of various envelope designs on building carbon emissions. Sun & Park (2020) built a BIM-based performance evaluation system to compute the carbon footprint and provide a strategy to manage the carbon emissions effectively by converting them into the cost. Asare et al. (2020) concluded that integrating BIM and LCA is able to aid the designers in selecting more eco-friendly materials and products. Yang et al. (2018) develop a BIM-enabled LCA method to facilitate low carbon design and increase the credibility of LCA data. In short, various research has proven the advantages of integrating BIM and LCA but mainly focused on embodied carbon measurements. This is because BIM is often used as a source to acquire the material properties and characteristics which can reduce the manual input of quantified materials and shorten the time for the estimation procedure (Tushar et al., 2021).

The integration of BIM and IoT is focusing on the field of facility management (Chang et al., 2018; Cheng et al., 2020; Evjen et al., 2020), safety (Chen et al., 2021; Chen et al., 2018; Cheung et al., 2018; Ding et al., 2021), and energy management (Bapat et al., 2021; Birgonul, 2020). Atazadeh et al. (2019) concluded that BIM can assist in the process to understand legal ownership of the data collected through IoT sensors.

3.3 Blockchain

Blockchain is a decentralized and distributed ledger system that stores all the transactions (Manglekar & Dinesha, 2018). It is a tamper-proof database that can ensure the security and accuracy of the data recorded by autonomous verification through a consensus algorithm (Biswas & Gupta, 2019; Rodrigo et al., 2020; Xu et al., 2018). Besides, it can perform transactions without centralized third parties (Liu et al., 2019) which makes data sharing easier across a large network (Xu et al., 2018). Blockchain technology was originally used to transfer digital money, but it was adopted widely in other applications lately including Construction Supply Chains (CSCs) (Shemov et al., 2020; Sivula et al., 2020; Tezel et al., 2020), information management (Sheng et al., 2020; Zhong et al., 2020), procurement (Tezel et al., 2020), asset management (Götz et al., 2020), transportation (López & Farooq, 2020), etc.

Blockchain has been widely employed in the construction supply chain to strengthen the traceability of the supply chain. Wang et al. (2021) concluded that blockchain can solve the transparency and provenance problems in the supply chain. Wang et al. (2021) developed a smart contract in blockchain to improve traceability and shareability in the agricultural food supply chain. Wang et al. (2021) suggested that integration of blockchain and supply chain can enhance the collaboration in the supply chain by information sharing and automation by the blockchain system. Carbon emissions are measured across the construction supply chain. Since many researchers have highlighted the advantages of incorporating blockchain system in the supply chain, optimizing blockchain system in carbon emissions calculation have the potential to increase the accuracy and credibility of the measurement. Rodrigo et al. (2020) have examined the potential of adopting blockchain systems in embodied carbon estimation in the construction supply chain and conclude that blockchain systems are able to increase the accuracy of the estimation. The automation in data collection is able to prevent data error by human factors. However, the centralized database is vulnerable to attack (Zhong et al., 2020). Arif et al. (2020) concluded that blockchain is able to enhance the data security, confidentiality, and integrity of smart homes. Cho et al. (2021) developed a blockchain network to provide transparent and reliable management of IoT data for fine dust reduction measures. Thus, an integration of IoT and decentralized blockchain systems is necessary to ensure the information in the databases is secured. Besides, the information by IoT can be recorded automatically when the condition in the smart contract by blockchain is triggered. Therefore, automation in life cycle carbon emission collection can be performed by integrating IoT and blockchain.

Integrating blockchain and BIM is able to establish clear responsibility and contractual relationships among the stakeholders (Liu et al., 2019; Zhong et al., 2020). Suliyanti & Sari (2021) and Zheng et al. (2019) integrate BIM and blockchain for information exchange and enhance information security. Xue & Lu (2020) integrates BIM and blockchain to reduce the information redundancy issues that arise due to the integration process.

3.4 Integrating IoT, BIM, and Blockchain for Carbon Quantification

The traditional manual methods in estimating the carbon emissions are exhaustive and require a mass amount of fragmented data to complete the quantification. The manual and repetitive nature of completing the estimation can result in loss of data. To overcome the issues, the carbon emitted at various construction phases can be collected by using IoT-based sensing devices in real-time. The data can then be integrated into the BIM platform for visualization and be used further for sustainability analysis and recorded in a tamper-proof blockchain system. IoT will be the source of real-time data which collects the information automatically. The data can be collected from the physical environment automatically through IoT sensor and thus reduces errors due to human factors. The carbon emissions recorded is able to fulfill the real-time requirement and increase the accuracy and reliability of the data collected. Meanwhile, BIM will act as a platform to visualizes the information from various parties and stages. Besides, BIM is a great tool to assist in the calculation of embodied carbon by multiplying the quantity of the material used with the carbon factors of the building material. Traditionally, the quantity of material used will be extracted manually from the bill of quantity (BQ). BIM can assist in extracting the precise quantity of material in the form of an excel file and reduces omission errors. Various research has been conducted and proven the use of BIM in increasing the accuracy of embodied carbon emission measured (Asare et al., 2020; Gan et al., 2018; Sun & Park, 2020; Yang et al., 2018). Whereas blockchain will act as a core to record data, which solves the information authenticity and information sharing simultaneously (Zhong et al., 2020). Beforehand, simplification and assumption are common when calculating carbon emissions. Blockchain is also able to ensure all the carbon emission across the supply chain is collected. This is because blockchain is well-known for its transparent and tamper-proof nature that is able to secure the accuracy of data collected. The decentralized system of blockchain enables it to operate without the need for third-party control. The carbon emissions can be recorded automatically once the predefined conditions in the smart contract are triggered.

In short, integrating IoT, BIM, and blockchain is able to ensure the carbon emissions quantified are of higher accuracy as compared to the traditional manual method. The integration of these technologies is able to increase the reliability of the carbon emissions quantification as these technologies are complementary to each other.

4. CONCLUSION

This paper reviews the potential of integrating IoT, BIM, and blockchain into quantifying carbon emissions. The integration has the potential to promote automation in carbon quantification and increase the accuracy and traceability of the carbon emission due to real-time data obtained from IoT, the capability to reduce manual input and potential human errors from BIM, and the tamper-proof characteristics of blockchain. The study examines the role of each technology in quantifying carbon emissions and how the technology is complementary to each other. IoT is the source of real-time data that collects the information automatically. Meanwhile, BIM is the platform that visualizes the information from various parties and stages and blockchain is the core which is to record data and solve the information authenticity and information sharing simultaneously. Integrating BIM and IoT is able to promote automation in real-time data collection which is hard across the construction supply chain. Blockchain is able to solve the information authenticity issues from BIM and the security issues that arise from IoT. The findings of the paper are expected to create a novel way to quantify carbon emissions and broaden the use of IoT, BIM, and blockchain. However, the integration of IoT, BIM, and blockchain technologies is still at an early stage and are more applicable to the carbon emissions quantifications of operational phase than of the construction phase, where many of site issues have to be considered. Also, the input mechanism of blockchain data is relatively weak despite its tamper proof structure. Thus, future research is suggested to focus to study the feasibility to integrate IoT, BIM, and blockchain.

ACKNOWLEDGEMENT

This work was funded and supported by the Ministry of Higher Education (MoHE) Malaysia under Fundamental Research Grant Scheme (FRGS/1/2020/SSI02/UTM/02/2) and Universiti Teknologi Malaysia. The authors would like to express their appreciation for the assistance of the sponsors.

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