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INTERNET OF THINGS (IOT)-ENABLED INDUSTRIAL SYMBIOSIS MODEL FOR CONSTRUCTION MATERIAL SHARING: BIBLIOMETRIC ANALYSIS

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ABSTRACT

Under the umbrella of Circular Economy (CE), the concept of Industrial Symbiosis (IS) offers a heuristic solution for enhancing resource efficiency through reusing and exchanging of resources. Indeed, IS integrates the complexity of industries encouraging the use of materials and by-products as feedstock sources instead of being wasted. Digital technologies in CE transition have obtained significant attentiveness in academic research in last decade. However, while studies on the concepts of IoT, CE and IS have increased, there is a deficiency in research that systematises the literature for refining the importance of the intersection of IoT and IS in building construction. Thus, the purpose of this research is to conceptualise a IoT-enabled IS model for construction material sharing through Scopus-based systematic review of key literature. The journal articles published in Scopus database related to the fields of CE, IoT and IS were reviewed to understand their intersection towards construction material sharing. Systematic review outcomes were analysed using bibliometric analysis technique. The evolution of the publications, leading journals and authors who published the most papers on the intersection of CE, IoT and IS were mainly reviewed and a IoT-enabled IS model for construction material sharing in construction industry was conceptualised as the key implication of this research. The next stage of the research is to develop a generic symbiotic prototype for IoT-enabled construction material sharing between building construction projects, which can be applied in any context subjected to context specific enhancements.

Keywords: *Circular Economy (CE); Construction Industry; Construction Material Sharing; Conceptual Model; Industrial Symbiosis (IS); Internet of Things (IoT).*

1. INTRODUCTION

The construction industry consumes more and more materials compared to other industries. Thus, resource depletion and construction waste have been identified as a key issue in the construction industry nowadays. Further, construction industry is a key contributor of global Greenhouse Gas (GHG) emissions.

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The concept of Industrial Symbiosis (IS) offers a heuristic solution for enhancing material usage efficiency of construction through reusing and resharing of building materials between construction projects that are geographically proximate. IS has emerged to integrate the complexity of industries encouraging the use of materials' by-products, water and energy as feedstock sources instead of these resources being wasted (Frosch & Gallopoulos, 1989). Indeed, the IS networks have impacted significantly on environmental and economic growth of countries through diminution of virgin materials extraction and GHG emissions (Domenech et al., 2019). Further to the authors, the excessive materials, reusable materials and/or the material waste can be reshared as a resource with other co-located building construction projects without disposing directly for landfilling.

At present, the Circular Economy (CE) transition in construction industry has been enabled with digital technologies for improved resource management (Kristoffersen et al., 2020). Digital technologies including Internet of Things (IoT) have obtained world concern towards circular economy transition of construction industry (Yu et al., 2022). IoT is defined as *"a dynamic information network with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network"* (Van Kranenburg, 2008). IoT can be used leveraging the sharing of materials among the construction projects under the concept of industrial symbiosis through a real-time data driven platform. IoT can be used as a smart platform enabling real-time tracking and monitoring of the processes (Godinho et al., 2022). However, adopting digital technologies, specifically IoT is still modest in IS network formulation. While studies on both concepts have increased, a few of research have been focused on the importance of intersection of IoT and IS in building construction. Even though many studies are focusing on material sharing between industries under the IS umbrella (Desrochers & Leppala, 2010; Massard et al., 2014; Shi & Li, 2019; Van Beers et al., 2007;), a less or no studies were found related to IoT-enabled IS in construction industry for construction material sharing. Thus, this research aims to conceptualise a IoT-enabled IS model for construction material sharing through Scopus-based systematic review of key literature.

As the key insinuation of the research, two (02) research objectives were formulated to achieve through the systematic review;

1. To understand the intersection between digital technologies, IS and CE concepts in construction industry specifying IoT.
2. To conceptualise a IoT-enabled IS model for construction material sharing.

2. THE CONCEPT OF INDUSTRIAL SYMBIOSIS FOR CONSTRUCTION MATERIAL SHARING IN CIRCULAR CONSTRUCTION

The construction industry consumes materials in large scale showing a high resource intensity (Yu et al., 2021). For example, annual raw material consumption in the United Kingdom (UK) construction industry is around 1.8 million tons (World Economic Forum - WEF, 2015 as cited in Yu et al., 2021). The importance of material efficiency and sustainable resource management can be highlighted a vital and timely need in countries assuring the reduction of environmental impacts of construction industry (Mastos et al.,

2020). Material efficiency is about *"sparing use of natural material resources, effective management of side-streams, reduction of waste, and recycling"* (Ruuska & Häkkinen, 2014).

The concept of CE has become an alternative to linear economic model in construction industry in which extending the product lifetime and close material flows is targeted to be achieved (Alcayaga et al., 2019). As stated by Ginga et al. (2020), CE is a way to optimise the use of resources through regeneration of waste in construction industry. Under the umbrella of CE, IS has become a priority action in achieving resource optimisation through exchanging resources among the geographically proximate industrial entities (Ventura et al., 2023). IS is a concept that engage traditionally separated and geographically proximate three or more different industrial entities to attain collective advantages though the physical exchange of resources including materials, energy, water, by-products, services and infrastructure (Chertow, 2007; Mallawaarachchi et al., 2021). In the traditional industrial setting, the linear industries usually approach the model of take-make-use-disposal of waste directly into the environment (Mallwaarachchi et al., 2020). IS can be used an ideal strategy for exchanging materials among the construction projects which ensures connecting waste and by-product as inputs to another process while avoiding waste and loss of valuable resources (Järvenpää et al., 2021). Further, it is an important CE practice that contributes to close the material loop through reduction of the dependency on primary or virgin materials in construction (Yu et al., 2021). IS practices includes both direct exchanges between resource providers and consumers within the construction industry and intermediaries and coordinators who provide services, such as recycling treatments and business relationship management (Chertow & Ehrenfeld, 2012).

The implementation of IS has been recognised as an effective strategy towards the optimisation of resource management and the improvement of co-operation in the context of Industry 4.0 (Scafà et al., 2020). IoT can be used leveraging the sharing of materials among the construction projects under the concept of industrial symbiosis through a real-time data driven platform. However, consideration given on such intersection between IoT, CE and IS concepts is lack in extent of literature.

The methodology adopted in this study is described subsequently.

3. RESEARCH METHODOLOGY

To complete the present study, a systematic review of literature was used as the methodological basis. Hence, key literature published showing the intersection of the fields of Internet of Things (IoT), Industrial Symbiosis (IS) and Circular Economy (CE) were first recognised through a systematic review in Scopus database. This Scopus-based review paper provides first insights into the development of IoT-enabled IS model for construction material sharing in the 08-year period from 2016 to 2023. As the initial step of the review, the literature search was conducted in Scopus database using the key words of "Internet of Things", "Industrial Symbiosis" and "Circular Economy" to search titles, abstracts and documents keywords published from 2016 to 2023 [TITLE-ABS-KEY ("Internet of Things" AND "Industrial Symbiosis" OR "Circular Economy"]. Initially there were 258 articles that were further refined by using the filters available on Scopus's search tool: (i) DOCUMENT TYPES=(Articles) AND (ii) SOURCE

TYPE=(Journals) to identify the quality literature. Accordingly, 74 journal articles were selected as the basis for bibliometric analysis.

Bibliometric analysis was used to recognise the papers relevant for the review. As stated by Grag and Sharma (2017), bibliometric analysis technique has been highly used to evaluate the contribution of the research scholars in various different fields of research, patterns of publications and, the relationship between research findings.

Hence, the analysis of literature was conducted by adopting two (02) selected bibliometric indicators of the co-occurrence of words and number of articles showing the intersection of the fields of IoT, IS and CE. As stated by Mallawaarachchi et al. (2020), number of articles reflects the scientific output, which provides a count of the quantity of works produced by a researcher where co-occurrence facilitates a basis to recognise the specific network of a given type of a research based on its development over the years. Hence, the evolution of the number of journal articles published over the years, leading journals published on the intersection of IoT, IS and CE and the leading authors who have published a high number of articles combining the field of IoT, IS and CE were distinguished. The selected bibliometric indicators were used as a basis to choose the literature for understanding the intersection between IoT, IS and CE concepts in construction industry in order to conceptualise a IoT-enabled IS model for construction material sharing.

4. RESULTS AND DISCUSSION

This section presents the key research findings related to two major areas; (i) Outcomes of bibliometric analysis, and (ii) IoT-enabled IS for construction material sharing.

4.1 OUTCOMES OF BIBLIOMETRIC ANALYSIS

As the initial step, the data derived through Scopus-based systematic review were analysed by using bibliometric analysis to track the evolution of the IoT-enabled IS concept in construction industry. The results which were analysed for the period from 2016 to 2023 are organised under three (03) key headings as: (i) Evolution of the number of journal articles published on IoT-enabled IS, (ii) Leading journals published on IoT-enabled IS, and (iii) Analysis of the leading authors in the field.

4.1.1 Evolution of the Number of Journal Articles Published on IoT-Enabled IS

In the systematic review, 78 journal articles published from 2016 to 2023 (first two months only) were chosen for analysis. During the period considered, the evolution of the number of journal articles published on IoT-enabled IS in Scopus database is presented in Figure 1.

As derived through analysis, the total number of journal articles published on the intersection of IoT, IS and CE in Scopus was 74 in which one articles has been published in year 2016. The number has been escalated to 7, 12 and 14 in years 2019, 2020 and 2021 respectively. As Figure 1 further illustrates, the number has been drastically increased to the peak of 28 in year 2022 while 7 articles were found during the first two months in year 2023.

Overall, the graph indicates an escalating growth of publications on the intersection of IoT, IS and CE over the years beginning from 2016 (01 article) to 2022 (peak of 28 articles). Many of the published articles have been focus on analysing the use of digital

technologies towards a circular economy with Industry 4.0. A study conducted by Liu et al. (2023) proposes a conceptual framework of I4.0 technologies-embedded sustainable supply chain management (SSCM) as a way towards a CE.

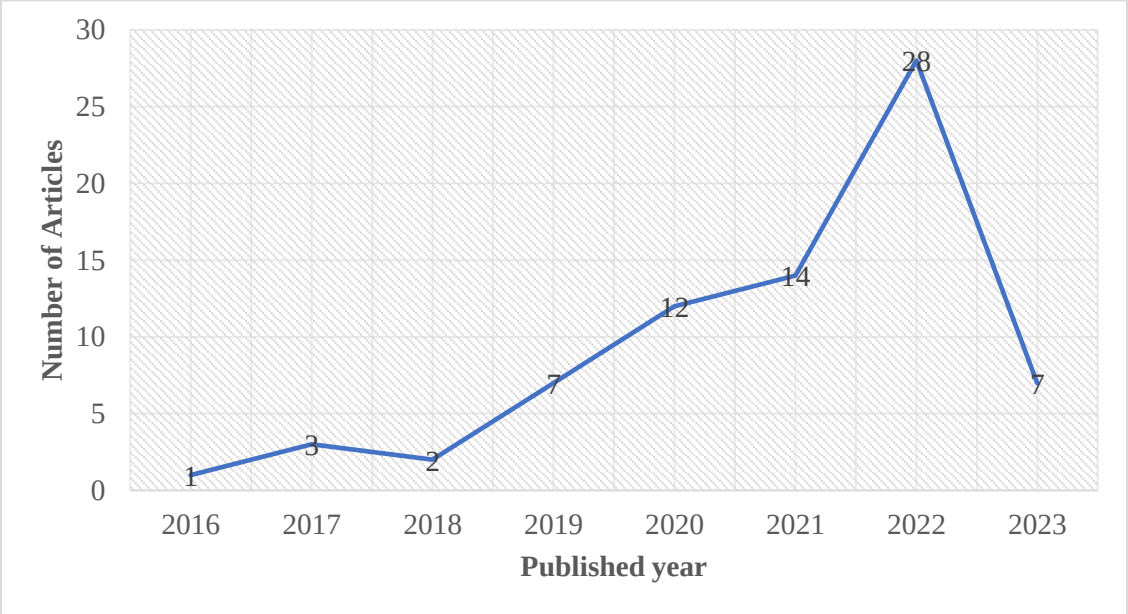

Figure 1: Evolution of the number of articles

According to a study by Akberdina et al. (2023), digital technology shows a significant contribution to sustainable CE. However, a few or no research articles were found interconnecting IOT and IS in construction industry in terms of construction material sharing thus, research gives a comprehensive underpin for conceptualising a IoT-enable IS model for construction material sharing.

4.1.2 Leading Journals Published on IoT-Enabled IS

The leading journals that have published most articles considering IoT, IS and CE intersection over the period from 2016 to 2023 are presented in Figure 2. As shown in Figure 2, 'Journal of Cleaner Production' was the leading journal that published the highest number of articles (04 articles) on the intersection of IoT, IS and CE during the period from 2016 to 2023. 'Computers and Industrial Engineering' and 'Sustainability Switzerland' are the second leading journals that published a high number of articles. Acta Agriculturae Scandinavica Section B, Soil and Plant Science, Science of the Total Environment, Resources Conservation and Recycling, Mathematics, Benchmarking and Journal of Advanced Mechanical Design Systems and Manufacturing are other journals that have given a major concern towards publishing articles on the intersection of IoT, IS and CE during the period from 2016 to 2023.

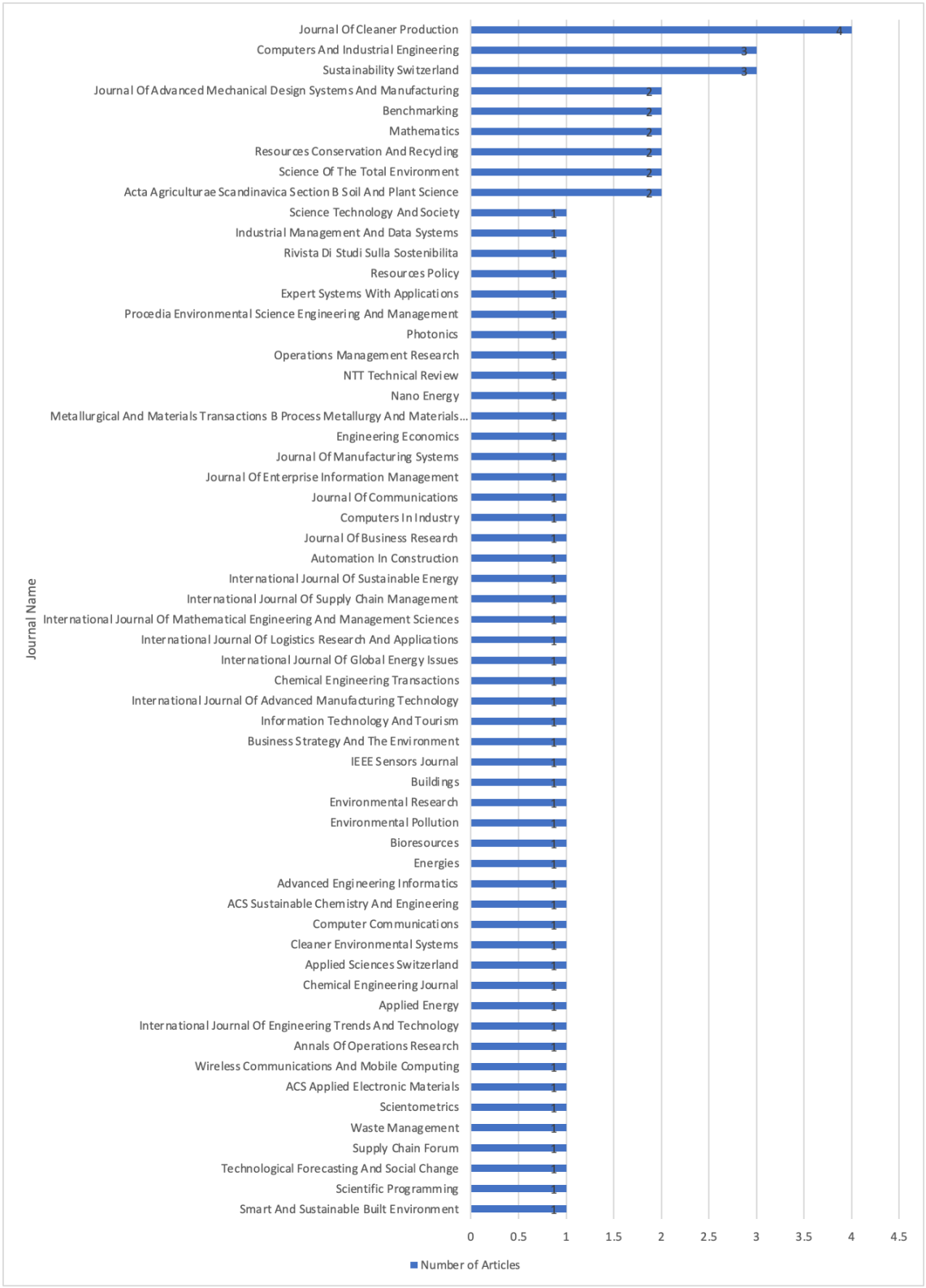

Figure 2: Leading journals that published most articles

4.1.3 Leading Authors in the Field

Various scholars have been contributed for adopting digital technology towards CE and IS. Figure 3 presents the leading authors who have published most papers on IoT, IS and CE concepts in Scopus from 2016 to 2023. As derived through analysis, the author who have published the most articles during the period from 2016 to 2023 is Chen with 3 records in Scopus. As the second highest records in Scopus, 2 articles have been published by many authors including Chen, Garrido-Hidalgo, Hsu, Olivares, Ramakrishna, Ramirez, Roda-Sanchez, Sarkis, Yamada and Yang. Since the concern given on enabling IoT in the concept of IS, number of articles published by authors is considerably less. However, Figure 3 despites a rapid growth in the number of publications over the years from 2016 to 2023.

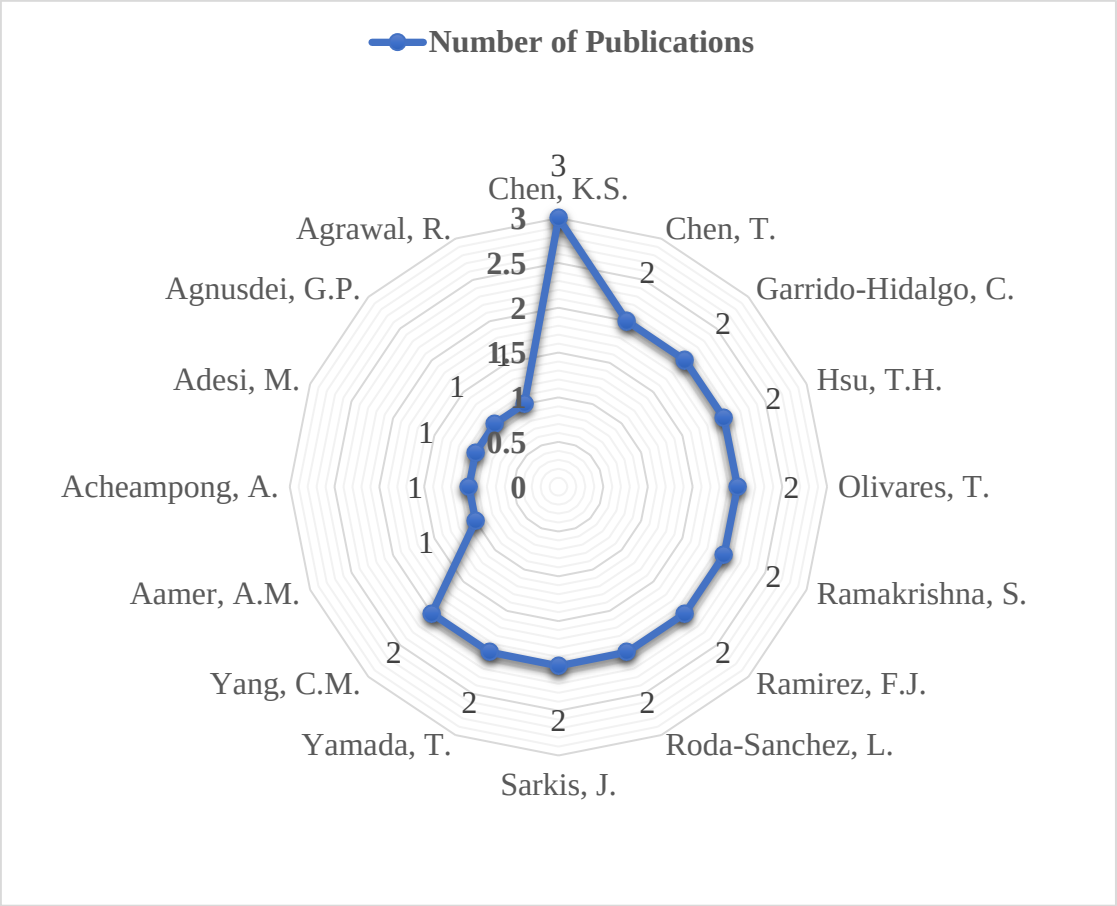

Figure 3: Leading authors in the field

As the second stage, the key literature published during the period of 2016 to 2023 in Scopus were screened and reviewed to the intersection between IoT, IS and CE concepts in construction industry in order to conceptualise a IoT-enabled IS model for construction material sharing.

4.2 IOT-ENABLED IS FOR CONSTRUCTION MATERIAL SHARING: A PROPOSED CONCEPTUAL MODEL

At present, the CE transition in construction industry has been enabled with digital technologies by tracking the flow of materials, products and components and making the data available for improved resource management (Kristoffersen et al., 2020).

Industry 4.0 is seen as a combination of digital technologies and real-time communication aiming to industrialise the manufacturing systems which includes smart sensors, IoT, big data and analytics, cloud computing, and machine learning etc (Järvenpää et al., 2021). IoT provides a valuable opportunity for the construction industry to solve its time and resource management issues and frequent defaults (Ghosh et al., 2021). The use of IoT influences the collection of large amounts of data, leading to big data, which in turn effect as data analytics tools to obtain competitive advantages (Godinho et al., 2022). As reviewed in key literature, IoT data technology can be enabled in IS for effective construction martials sharing between construction projects. IoT can be used for leveraging the sharing of materials among the construction projects under the concept of IS through a real-time data driven platform. Indeed, IoT is one of the key technologies responsible for ensuring the integration of data and communications across the industry and beyond, in constant exchange of information with the stakeholders involved (Carvalho et al., 2020). Furthermore, IoT supports to improving tracking and record keeping, improving estimation of the remaining life of used products and making decisions to improving durability of product or materials in the construction process (Rejeb et al., 2022).

Enabling digital technologies specially IoT and Big data technology into the IS network operation has been identified as an effective strategy for hindering the information and knowledge gaps between industry partners by many scholars. Information network of IS supports the exchange of symbiosis related raw data such as, types of materials available to exchange, amount to be shared, material frequency and amount required by other partners of the IS network, etc to identify the opportunities for material exchange in construction industry (Shi & Li, 2019). As stated by Järvenpää et al. (2021), information sharing through smart platform is important for successful IS as it communicates accurate and real-time information for stakeholder. According to a study by Kerdlap et al. (2019), real-time data-driven IS platform could connect waste generators, collectors, recyclers, primary and secondary consumers of the recycled materials within the construction industry, which may integrate all such industrial partners of the IS network.

Accordingly, the authors conceptualised a model to enable IoT technology in IS for construction material sharing in construction industry as presented in Figure 4.

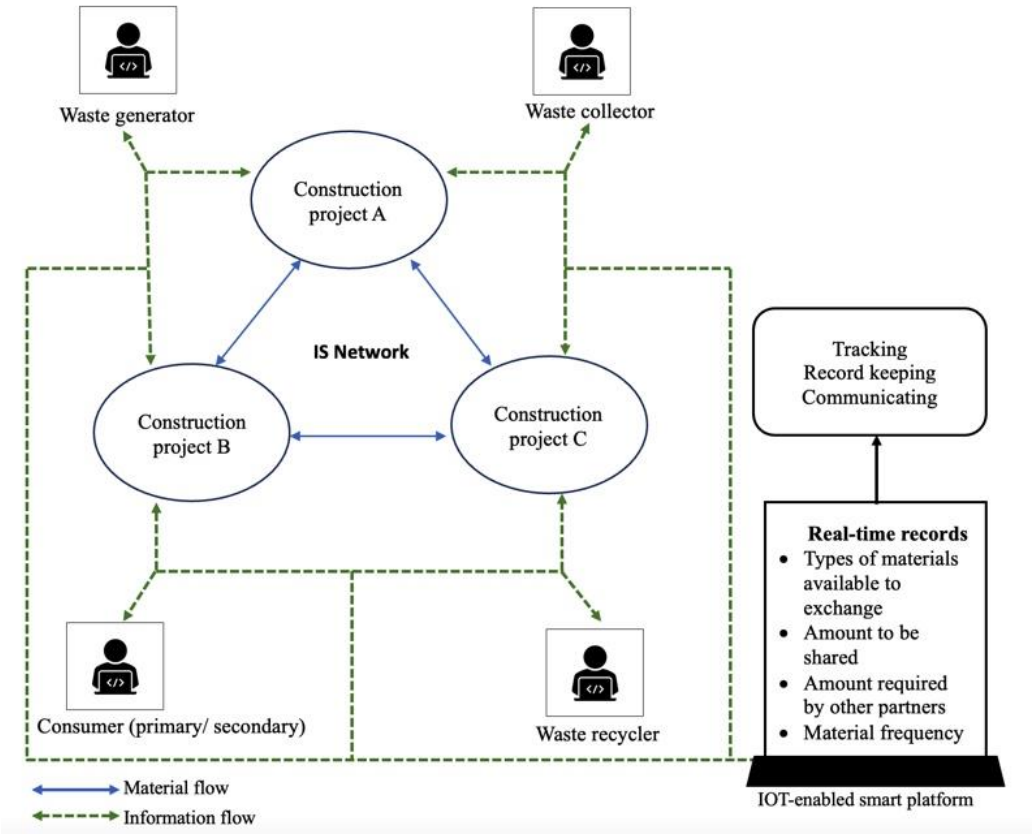

Figure 4: Proposed conceptual model for IoT-enabled IS

The proposed model was developed by clustering three construction project entities based on the theory of "at least three or more industrial entities and two material flow synergies between the entities" (Chertow, 2007). All industry partners including waste generators, collectors, recyclers, primary and secondary consumers of the recycled materials within the construction industry are connected and integrated through the IoT-enabled smart platform. Information flow, which was connected through IoT-enabled smart platform integrates all industrial entities and the stakeholders to one smarter location. This ensures real-time tracking, record keeping and communication of accurate data related to the material flow between industrial entities, such as types of materials available to exchange, amount to be shared, material frequency and amount required by other partners of the IS network.

Hence, in the proposed model, IoT has been used leveraging the sharing of materials among the geographically proximate construction projects through a real-time data driven/ smart platform.

5. CONCLUSIONS

The contribution of construction industry towards environmental degradation is a critical concern in the world, which is ever-increasing. This can be addressed through the extension of material reuse to multiple construction projects under the concept of IS. Enabling IoT could create a significant impact on the success of IS networks as it reduces knowledge and communication gaps between industry partners of the IS network.

Based on the research problem's contextualisation, this research will significantly contribute both theoretically and empirically.

This paper presents a proposed model which was developed by systematic reviewing key literature published in Scopus database during the period from 2016 to 2023. By adopting the proposed model, construction projects which are geographically proximate can be integrated to a one smart planform for timely exchanging of materials for fulfilling material needs of construction. Further, the model acclimates IoT technology by assuring real-time tracking, record keeping, and communicating material related data among the industry partners who have engaged in the IS network. Real-time data tracking and monitoring of material needs and availability of supply by each and every construction project in the network may ultimately reduce the cost of materials. Further, this research brings an innovative and heuristic opportunity to construction project owners to contribute significantly to decline the generation of GHG emissions and C&D waste for achieving sustainable development goals and climate change adaptive actions in the country. Indeed, the bibliometric analysis outcomes of the research may contribute significantly to new knowledge through the intersection of IS and IoT in the construction industry assuring the circular economy transition. The next stage of the research is to develop a symbiotic prototype for IoT-enabled construction material sharing between building construction projects, which can be applied in any context subjected to context specific enhancements and modifications.

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