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A Review on the prospects and challenges of integrating IoT technologies in circular business models

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Abstract

In recent times, there has been an increasing imperative to embrace Circular Business Models (CBM) as an indispensable means for enhancing businesses. Nevertheless, existing academic discourse rarely investigates the complex relationship between the Internet of Things (IoT) and CBM. This research paper initiates its investigation by identifying four pivotal IoT capabilities, namely monitoring, tracking, optimisation, and design evolution, all of which are instrumental in enhancing the performance of CBM, as grounded in the ReSOLVE framework. Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines were employed for systematic literature review in order to scrutinise how these identified IoT capabilities contribute to the core concepts of the 6R-CBM and CBM-IoT cross-section heatmaps and relationship frameworks. Finally, a comprehensive examination of the challenges impeding the realisation of IoT-enabled CBM is presented. The findings of this study reveal that Loop and Optimise business models are the predominant subjects of current research endeavours. IoT emerges as a pivotal player in these business models, primarily through its tracking, monitoring, and optimisation capabilities. In contrast, there is a noticeable absence of (quantitative) case studies pertaining to Virtualize, Exchange, and Regenerate CBM. Notably, IoT exhibits the potential to limit energy consumption significantly. However, it is essential to acknowledge that impediments associated with IoT hardware, software, protocol energy consumption, interoperability, security, and financial investments may pose substantial challenges to the broader adoption of IoT within the CBM.

Keywords: Circular business model; PRISMA; Internet of Things; ReSOLVE framework

1. Introduction

1.1. Brief Historical Background of IoT

The term "Internet of Things" (IoT) originated from one of the executive directors associated with the Auto-ID Center [1]. The concept of networking devices has fostered the idea that machines can function seamlessly as an integrated system, minimising potential disruptions caused by human interfaces, which may lead to errors or time inefficiencies. It facilitates robust communication between the physical and digital realms across diverse domains, augmenting the sophistication of products, operations, and services within the value chain by offering innovative solutions to enhance their performance. IoT harnesses internet-based wireless technology to connect all devices, enabling interactions that enhance functionality. Furthermore, through the deployment of sensors, devices can acquire an awareness of their surroundings, transmitting substantial volumes of real-time data. IoT has the potential to exert a considerable influence on the supply chain by optimising resource utilisation, improving transparency and visibility throughout the entirety of the supply chain, enabling real-time supply chain management, streamlining supply chain operations, and bolstering the adaptability of the supply chain [2].

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In 2005, the International Telecommunication Union (ITU) characterised the IoT as the third phase in the transformation of the global information industry. Subsequently, in 2008, the Federal Communications Commission approved the utilisation of the "white space spectrum," as documented by Suresh et al. in [3]. Following this, prominent technology leaders such as Cisco, IBM, and Ericsson embarked on numerous educational and commercial ventures involving the IoT. Furthermore, certain nations, including China, incorporated the IoT into their long-term strategic plans as a pivotal emerging technology, as indicated by the Ministry of Industry and Information Technology (MIIT) in 2012 [4].

The Internet of Things (IoT) technology can be briefly described as establishing connections among humans, computers, and objects. It relies on an array of information-sensing equipment, including RFID, infrared sensors, global positioning systems, and laser scanners, among others, to link any object within an Internet Protocol (IP) framework, assigning each a unique IP address for information exchange and communication. This framework enables the realisation of intelligent functionalities such as positioning, tracking, monitoring, and management of objects. The system architecture can be tailored to real-time operational contexts and processes. For instance, within a smart home environment, every electrical switch box may be linked to a smartphone, allowing for remote operation.

An example of such technological advancement is evident in Huawei's recent development, the HarmonyOS system, which employs a full-stack decoupling architecture. This innovation addresses constraints at the interface of software and hardware, facilitating the integration of additional collaborators into the system [5]. Consequently, the scope of IoT applications has significantly expanded. In such scenarios, there is no need for a processor and storage device in each switch box; a sensor is sufficient to capture signals and process them, primarily for tasks like switching ON/OFF of a machine.

1.2. Prospects of IoT technologies in CE

The Circular Economy stands to gain advantages from the integration of IoT technologies, enhancing process innovation, minimising material consumption, and facilitating the execution of CE strategies. For example, a study in [6] contends that blockchain and IoT technologies foster sustainability and CE by encouraging eco-friendly practices, enhancing product life cycle transparency, boosting system efficiency, trimming development and operational expenses, and aiding in corporate performance reporting as well as sustainability monitoring capabilities.

The 4th industrial revolution, also known as the Industry 4.0 era, IoT presents prospects for advancing the principles of CE within value chains by enabling real-time monitoring of resource inventories, as articulated in [7]. IoT also has the potential to facilitate the reduction of waste through the detection of product lifecycles, thereby enhancing the optimisation of material reuse and recycling processes. To summarise, IoT promotes an exact, efficient, and sustainable resource utilisation approach, aligning with the transition from a disposable resource paradigm to a renewable one. Furthermore, it plays a pivotal role in the inception and progression of CBM, as elucidated in [8] study.

Hence, the advancement of IoT-enabled Circular Business Models has garnered significant attention in academic research circles. Recent studies have evaluated the influence of Industry 4.0 technologies, such as IoT, on CBM, yielding varying conclusions [9,10]. These studies have investigated the economic, social, and environmental facets of CBM and IoT, offering comprehensive insights [11,12] and, in a separate survey conducted by Rejeb et al. [13], assessed the contributions and challenges posed by IoT in the CBM purview. They identified key driving factors and presented a structured framework that explored CE strategies with a focus on business and management, leveraging IoT technologies.

Nonetheless, a substantial disparity persists between theoretical concepts and practical implementation [14]. Notably, a significant proportion of Small and Medium-sized Enterprises (SMEs) find themselves under considerable pressure to enhance their environmental performance. The potentially substantial cost associated with adopting IoT technologies may deter them from embracing opportunities for emissions reduction that IoT offers, especially considering their unique circumstances, as observed in [12] study. Addressing this challenge necessitates a thorough comprehension of the capabilities of IoT and the distinguishing features of various CBMs to identify the most advantageous convergence point. Given the existence of these gaps in the existing research, this paper seeks to address the following research questions:

- What are the collaborative benefits of IoT capabilities within various CBMs?
- What is the potential for reducing carbon emissions through IoT within various CBMs?
- What are the barriers that impede SMEs from embracing IoT for advancing circular strategies?

1.2.1. Contributions

This paper's contributions can be outlined as follows: We employed a predefined circular business framework, ReSOLVE, established by the Ellen MacArthur Foundation, to analyse the CBM-IoT context. We then connected this framework with the principles of the 6Rs to precisely map IoT capabilities within each business practice. This visual representation elucidates the varying contributions of IoT within different business models and facilitates our exploration of the relationship between IoT capabilities, the 6Rs, and CBM. Furthermore, we conducted a quantitative review of existing literature to assess how IoT can play a role in reducing environmental impacts within CBM and to identify the obstacles associated with its implementation.

2. PRISMA Review System and Applications

We conducted a literature search following the checklist framework outlined in the PRISMA-P guidelines, initially developed for use in the medical field [15]. While there are a number of alternative approaches available for conducting literature reviews and meta-analyses [16], PRISMA guidelines have gained widespread acceptance as a transparent approach for conducting literature reviews. Notably, these guidelines have been increasingly applied in the field of sustainability and CE research [17-20]. The most recent PRISMA Abstract 2020 guidelines [21] recommend addressing five main items in conjunction with ten subcategories within a review. In this study, we refer to the checklist items presented in Table 1 below.

Table 1 Key stages in PRISMA Abstract 2020 [21]

Item	Section and Issue	Items Checklist
1	Title BACKGROUND	Classifying the article as a systematic review
2	Objective METHODS	Providing a clear statement of the primary objectives
3	Eligibility criteria	Specifying the criteria for inclusion and exclusion of a review
4	Sources information	Specifying source of information (e.g., searching techniques, databases) used for identifying relevant studies
5	Bias risks	Specifying the approaches used to evaluate the risk of bias in the reports incorporated
6	Results' synthesis RESULTS	Identifying the techniques adopted for presenting and synthesising results
7	Included studies	Giving a total number of studies included and participants, as well as summarising applicable characteristics of the studies.
8	Synthesis of results	Presenting critical outcomes of the results, preferably showing the number of studies included and participants. If a meta-analysis was conducted, state the summary evaluation and confidence/credible interval. If comparing sets, indicate the direction of the result.
9	DISCUSSION Limitations of Evidence	Provide a summary of the limitations of the proof included in the review (e.g., study risk of bias, inconsistency and imprecision).
10	Interpretation	Providing a broad clarification of the results and essential implications.

These categories describe the search objectives and eligibility requirements, as well as the procedures and justifications used to include and exclude particular records (e.g., some papers do not contain the keywords searched for but do contain keywords with similar meanings, while other reports do contain the keywords but do not explain them in detail). Second, it outlines the quantitative analysis's stages, which involve gathering information from particular publications and balancing their values. This review of the literature was done using this framework.

2.1. Categorisation of papers included

We have utilised the 6R concept, initially introduced by Joshi et al. in [22], as the foundational framework to categorise circularity strategies and their associated business models, as illustrated in Figure 1. The 6 R concept delineates the following principles: Reuse, Recycle, Reduce, Repair, Remanufacture, and Redesign. In [23], the framework has been recognised for encompassing the operational approaches and fundamental tenets of CE. Furthermore, the Ellen MacArthur Foundation (EMF), in their 2013 report [24], emphasised the increasing importance of exploring new avenues to advance CE within the guiding principles of the 6Rs. This "industrial system is restorative or regenerative by intention and design." This is particularly significant in the context of the Industry 4.0 era. From a systemic perspective, the amalgamation of these six operational approaches gives rise to novel macro-level business models within the realm of CE, as expounded [25].

Drawing upon these characteristics, the ReSOLVE framework further elaborates on the concept of CE, emphasising the preservation and augmentation of natural capital, the optimisation of resource yields, and the enhancement of system efficiency. This framework categorises circular models based on the economic and resource implications across major sectors, as outlined by the EMF [26]. It serves as a valuable tool for formulating circular strategies and promoting growth initiatives. Subsequently, Jabbour et al. [27] established a connection between Industry 4.0 technologies and the six CBM proposed by the ReSOLVE framework, which include *Regenerating, Share, Optimize, Loop, Virtualize, and Exchange*. This connection was designed to guide organisations in the implementation of CE principles, as initially expressed in [26] as presented in Table 2 below.

Table 2 Description of 6 BM in the ReSOLVE framework

Business Model	Description of Model
Regenerate	The use of renewable resources and energy is the foundation of this business strategy. Organic waste is transformed into sources of energy and raw materials for other chains through the utilisation of biological cycles, which also allow the transit of materials and energy.
Share	In this model, Individuals exchange assets with one another (either privately held product sharing amongst peers or publicly owned product sharing). As a result, manufacturers should build their products to survive longer and provide maintenance to enable product reuse and life extension.
Optimise	In order to eliminate waste in production systems throughout supply chains, this model necessitates that firms embrace digital manufacturing technologies, such as IoT, automation, and big data. Organisations will gain from improved performance as a result.
Loop	The model strives to advance the circularity of energy and raw resources. Therefore, the design, manufacture, and supply chain must be modified in light of the complete life cycle.
Virtualize	This service-oriented business model substitutes virtual and dematerialised goods for tangible ones.
Exchange	This model entails switching out outdated, non-renewable items for modern, renewable ones.

It is noteworthy that while most technologies present opportunities in specific domains, the IoT emerges as a significant enabler capable of rendering such business models feasible [27].

The vocabulary used to describe IoT-related capabilities differs depending on the situation, so we compiled the technology's fundamental capabilities from published research. Using features like tracking, monitoring, control, optimisation, and design evolution, a study in [28] contends that IoTs can aid in the development of circular business models. They also note that optimisation frequently requires the usage of control capability. In order to limit the number of pertinent IoT capabilities to four, as indicated in Table 3, we added the control capability into optimisation.

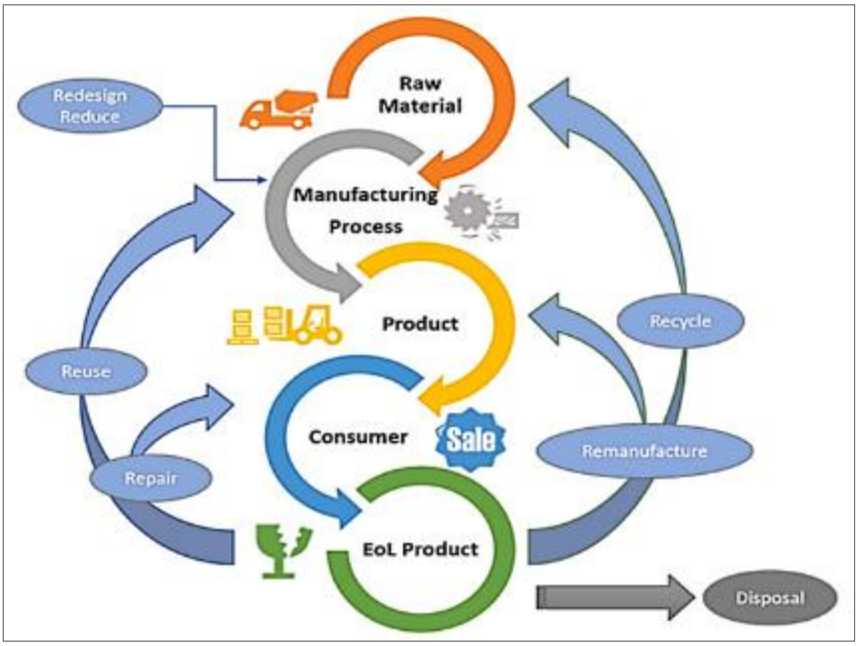

Figure 1 6R for achieving CE objectives. Adapted from [29]

Table 3 IoT traits that support ReSOLVE framework implementation

Capabilities of IoT	Functions Description
Monitoring	Availability of information used for products' environment or real-time condition, comprising any form of notifications.
Tracking	Availability of information used for products' identity, location, or exclusive structure
Optimisation	Information obtainable about a product's name, location, or distinctive composition
Design Evaluation	Based on evidence from other lifespan phases, a product's design can be improved. Upgrades to functionality or routing are included.

2.2. Selection and deselection of Articles

We used the following terms as a basis for the literature search in a Boolean operation: Title→Abstract→Keyword = ["internet of things" AND ("circular economy" OR "circular business model" OR "sustainable supply chain")]. This was done in order to systematically review the contribution of the IoT to circular economy business models. There were a total of 182 papers available on Web of Science (WoS) and 492 papers available on Scopus. Through perusing abstracts, we eliminated duplicate entries and studies that had no connection to any of the 6Rs. After browsing the entire text, we further destroyed papers that contained non-CBM descriptions that were found in the ReSOLVE framework.

In this manner, 59 publications were kept in order to research how the IoT contributes to CBM; for example, see Fig. 2. Then, a quantitative investigation of the IoT's impact on CBM's environmental implications was carried out. For this, we obtained 23 findings from the included publications that a) assessed effects on energy-related indicators in the circular economy (such as energy use or CO2 emissions) and b) compared these impacts before and after utilising IoT technology.

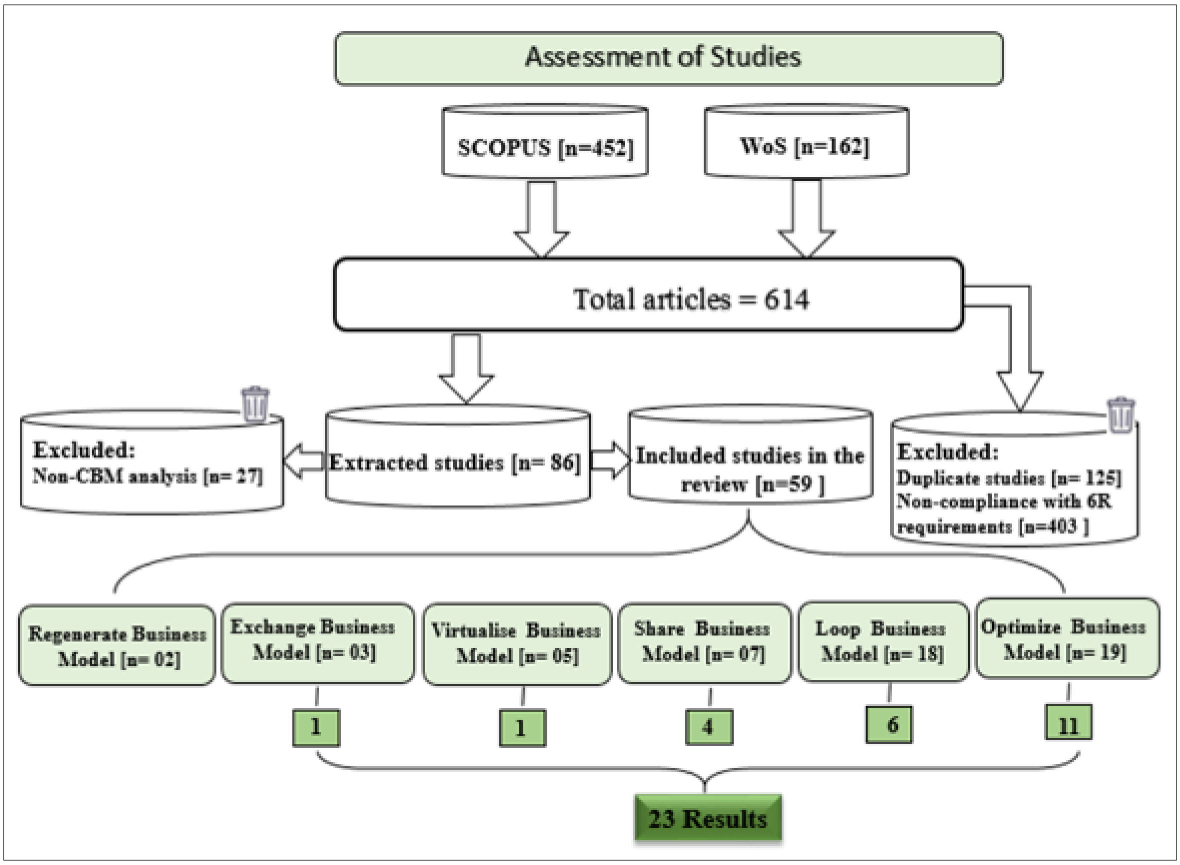

Figure 2 A flowchart illustrating the review's chosen studies

3. Descriptive finding of IoTs Effects on CBM

The 59 publications that were collected were used to clarify how IoT affects CBM. The annual number of articles published is seen in Fig. 4. These publications mainly cover the fields of engineering, environmental science, and computer science. Notably, as shown in Figure 4, there was a significant increase in the number of papers published from 2019 to 2021, followed by a decrease afterwards.

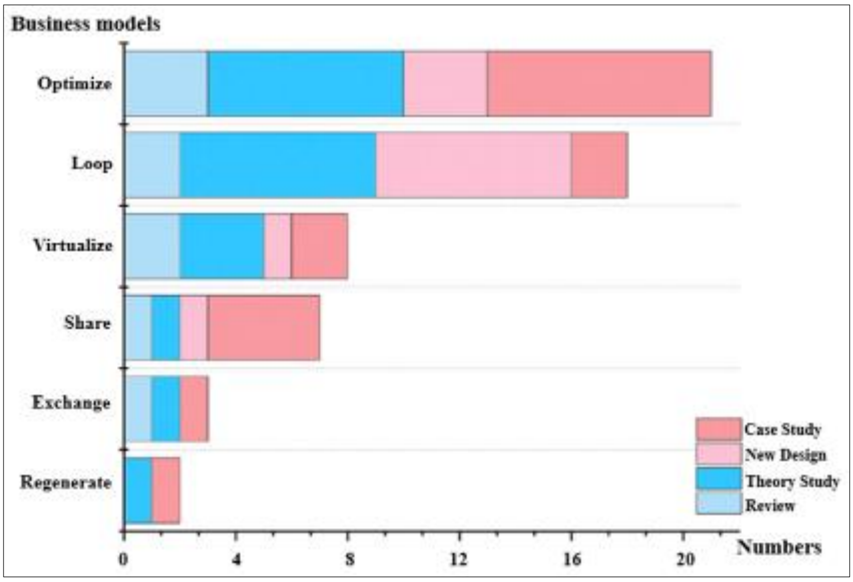

Figure 3 Categorisation of publications in the 6 R CE business model sets

The 59 papers are divided into four main categories using the model developed by Maroli et al. in [30]: literature reviews, theoretical analyses, new designs, and case studies. Reviews of the literature include papers that list and categorise earlier studies. A freshly proposed framework for a particular topic is often examined and discussed in theoretical analyses, which are typically based on expert surveys (Delphi) or questionnaires. With no empirical validation through real-world situations, novel designs refer to the creation of new mathematical models or protocol designs for IoT solutions. When compared to innovative designs, case studies produce reference results based on either real-world examples or established situations through the following calculation or simulation of a specific case.

To provide a synopsis of each study category, a brief additional summary of each paper is also provided in the table. As shown in Figure 3, these publications are further divided into six business models suggested by the ReSOLVE framework [31]. It's important to note that more than 60% of the publications explain how the Internet of Things fits into the Loop and Optimise frameworks. These two models have the potential to have a significant impact on the industrial, transportation, and storage sectors. IoT, therefore, holds the potential to enable substantial revolutionary changes within these sectors [31].

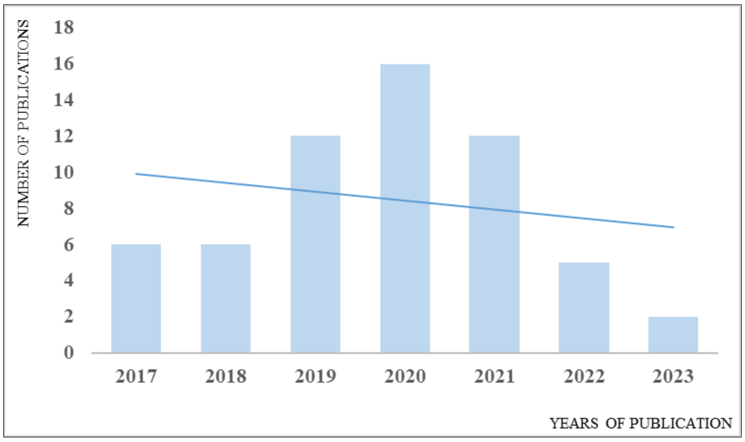

Figure 4 Numbers of IoT publications by year

In terms of the Optimize model, the IoT enhances decision-making procedures targeted at lowering energy and resource consumption, which is a crucial component of intelligent manufacturing and Sustainable Supply Chain Management (SSCM). Most theoretical research in this area focuses on investigating and developing frameworks for reducing carbon footprints across various industries. These frameworks [32-35] take advantage of IoT capabilities to gather and process information more effectively. The few case studies and unique designs, on the other hand, frequently concentrate on process optimisation within businesses. In these situations, IoT is used to create intelligent logistics delivery and production scheduling models that support sustainable and environmentally friendly growth in the field of smart manufacturing [36].

The majority of studies have focused on waste management in the context of the Loop business model. IoT is primarily used in this field to improve waste collection and decision support systems for recycling end-of-life products [37-39]. By creating CE-IoT-enabled ecosystems that make use of essential IoT technologies, several theoretical studies have taken things a step further [40]. Others have combined IoT and Life Cycle Assessment (LCA) models to help with the process of creating new products with minimal adverse effects on the environment [41,42]. IoT-enabled solutions that are based on items with varied technical characteristics, including instances like plastic garbage and abandoned cars, among others, have been validated by new design projects and case studies [43,44].

The articles only cover a small percentage of the four remaining business models. The sharing model is one of them that mainly relies on IoT-enabled online platforms or applications to support the exchange of goods or information among various stakeholders [45]. In contrast, the implementation of the Virtualize and Exchange models frequently necessitates the use of additional technologies, such as 3D printers, Digital Twin (DT) systems, and virtual world tools [46,47].

4. ReSOLVE framework integration with 6R and IoTs technologies

In this part, we divided the articles into groups using different matrices, taking into account section 2's discussion of the 6 R principles, IoT capabilities, and CBM categories. This produced a graphic showing the occurrences of cross-sections between CBM and IoT as well as CBM and 6R within the sample of 59 publications, which is referred to as a "heat map" (see Figure 5). It's important to note that numerous articles discuss cross-sections between CBM and 6R as well as IoT on multiple occasions. Notably, while having different meanings, these groups do not overlap. We examine the trends found for each of the CBM categories in the sections that follow.

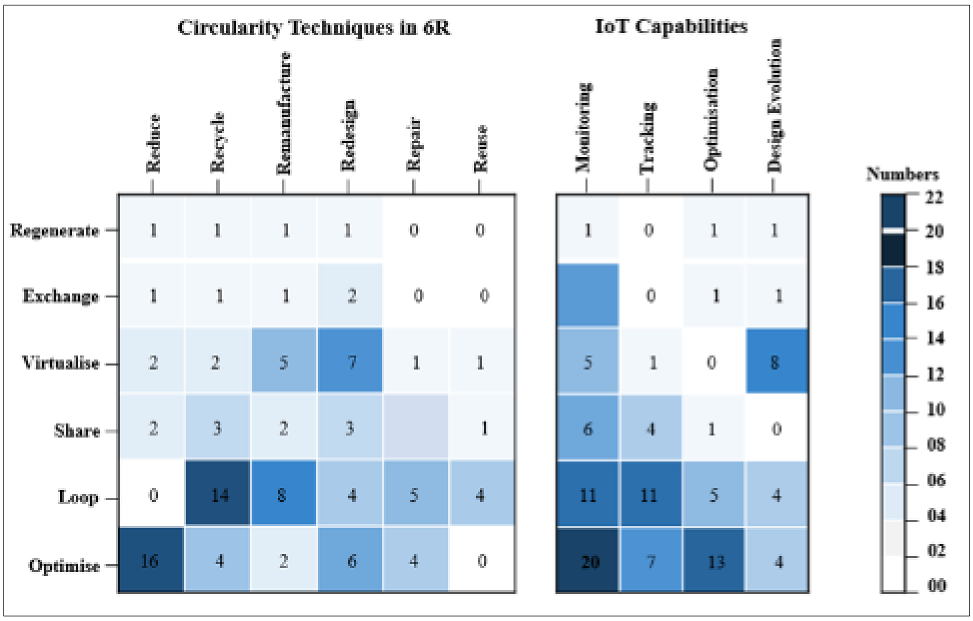

Figure 5 Heat MAP cross-sectionexistence of the CBM-6R and CBM- IoT

4.1. Optimise Business Model

The majority of studies that explore the Optimize model are strongly related to "Reduce," which is supported by IoT. As shown in Fig 5, monitoring and optimisation skills are generally used to achieve this alignment. By continuously monitoring processes and agents like machines, IoT technology increases the possibility of seeing possible faults and enables predictive maintenance to reduce the loss of underperforming items [48]. Additionally, managers can monitor and optimise production rates by utilising IoT data in conjunction with resource production and consumption demands. They are able to automatically intervene in processes thanks to the use of sensors and algorithms [34,49]. It is possible to develop sophisticated and integrated data-driven process manufacturing models with improved resilience and accuracy by combining IoT, cloud computing, and machine learning [50].

4.1.1. Applicability of IoT Capabilities in the optimise model

- *Monitoring*: If the state of the ideal ball mill is carefully examined and applied to the other ball mills, IoT sensors will enable energy and cost savings [51].
- *Tracking*: Utilising RFID technology for the tagging and monitoring of fresh milk has the potential to diminish product loss or shrinkage [52]
- *Optimisation*: Using RFID tags and wireless sensor networks, each node (including suppliers, wholesalers, and retailers) might manage and optimise its performance in terms of production, deliveries, and environmental compliance [53].

4.2. Optimise Business Model

According to the study's findings, "Recycle"-related IoT-enabled solutions are the most common, followed by "Remanufacture" and "Repair." 'Loop' concept papers frequently rely on tracking and monitoring tools, with no attention paid to optimisation and design evolution. The adoption of creative internet-based transactions has the potential to make use of information for more effective and sustainable post-consumer product collection in the context of recycling, remanufacturing, and mending. As mentioned in [39], these products can be tracked utilising a variety of technologies such as sensors, RFID tags, and barcodes. As a result, businesses are able to remanufacture or recycle product and packaging components [54,55]. However, according to the 'Redesign' perspective, product designers need to take the surroundings into account when making design choices. They can use data from an IoT-based product life cycle management system to help them in their efforts to develop and build more sustainable products. The research in [33,42,56] serves as an example of this strategy.

4.2.1. Applicability of IoT Capabilities in the Loop Model

- Monitoring: The uncertainty of a product's residual value based on the life cycle tracked by IoT sensors is addressed by an IoT-enabled decision support system for a CE model [57].
- Tracking: According to De Fazio et al. in [58], the POIROT research project uses IoT technologies to create a platform for the traceability of organic waste and convert it into inert, odourless, and sterilised material.
- Optimisation: A system that integrates intelligent transportation systems comprising RFIDs, sensors, cameras, actuators, and surveillance systems. This system is complemented by an advanced decision-making system that facilitates real-time data sharing among truck drivers, enabling dynamic route optimisation to enhance the efficiency of waste collection [38].

4.3. Virtualise Business Model

Virtualize places a high priority on customer service; therefore, using real-time data to track supply activities is crucial to improving the client experience. Through the power of design evolution, this strategy also opens up the possibility of IoT-enabled "Redesign" of both products and services. It is possible to accomplish system reconfigurability by virtually developing, simulating, and optimising systems and then putting these modifications into practice in the real world. As demonstrated by Sassanelli et al. research [59], this entails adjustments to specific hardware components (such as changing robot tools for disassembly tasks) as well as alterations to software resources (such as coding for robot programs). A study in [60] emphasised the idea that IoT technology allows the formation of links between businesses, suppliers, and customers, with a trend towards selling services rather than tangible things. The IoT can also collect essential data on consumer behaviour and historical design traits, which designers may use to improve service quality.

4.3.1. Applicability of IoT Capabilities in the virtualise model

- Monitoring: In order to determine whether knowledge sharing and learning across a horizontal supply chain was efficient and decreased greenhouse gas emissions associated with business travel, a study in [46] examined 3D Virtual World tools with multiple sources of 'streamed' data supplied by IoT.
- Design evolution: A Study in [61] unveiled a platform that combines hybrid IoT and blockchain technologies to encourage stakeholder innovation in prefabricated housing buildings. Through online platforms like mobile apps, these stakeholders actively contribute to the co-design of the project's lifespan value. Likewise, a study in [62] created a platform that allows IoT devices to be installed in smart buildings to track energy usage. Additionally, it provides building managers and end users with consulting services for energy optimisation. By allowing customers to virtually try out things through a mirror image, a study in [63] investigated how IoT may alter the shopping experience. This strategy tries to alleviate the drawbacks of conventional Internet shopping methods. Through a connection protocol, research in [47] connected the IoT to the Manufacturing Execution System (MES). Through this connectivity, CE procedures can be digitalised within the system, and orders from outside sources can be sent to the MES.

4.4. Share Business Model

Key IoT features that are essential to the sharing business model include monitoring and tracking. These capabilities also aid in product "Redesign" and "Recycle," which aim to increase product lifespan. Websites and mobile applications are used to gather data on consumer behaviour, enabling businesses to concurrently improve product design and provide digital services to increase equipment use or ease replacements. As seen in Rymaszewska et al. and Ingemarsdotter et al.'s tests [64,28], this method increases customer satisfaction. Additionally, adding sensors to products makes it easier to track maintenance needs and monitor performance. Organisations may provide clients with high-quality services thanks to this proactive strategy. Organisations can invest in initiatives that follow the 3Rs' (repair, reuse, and recycle) tenets by constantly reviewing the items they utilise. As a result, this helps to increase the longevity of things.

4.4.1. Applicability of IoT Capabilities in the Share Model

- Monitoring:According to cost, demand, and other factors, an automated negotiation ecosystem between scrap metal producers and garbage collection businesses might be provided via an inter-company IoT communication protocol [45].

- Tracking: An intelligent component was designed for Cranfield University's shoe recycling project, which tracks the state of the shoes and determines when they need to be upgraded or replaced. The shoes' modular construction makes it simple to deconstruct them for recycling or refurbishing [65].
- Optimisation: IoT enables business-to-business e-commerce systems to achieve a mutually visible inventory in real-time where average food inventory, amount of food waste, frequency of lateral inventory share, and ordering from the main depot are optimised along with customer service level in the network [66].

4.5. Exchange Business Model

According to the suggestion in the study [67], this model could be improved by including additive manufacturing and IoT devices with monitoring capabilities. The use of 3D printers could help with the development of sustainable and renewable production methods. Some businesses can create customised items by utilising databases that include 3D printers and fostering relationships between companies and customers. IoT technology is essential in this situation for saving both time and resources during additive manufacturing. These features increase the viability of adopting IoT to adhere to circular economy concepts.

4.5.1. Applicability of IoT Capabilities in the Exchange Model

- Monitoring: IoT-enabled 3D printers allow for the recycling of small amounts of trash, and additive manufacturing results in a decreased consumption of materials [67].
- Optimisation: The seed swarm optimisation technique builds effective multi-target production planning in real-time using IoTs for the detection of engineered disassemblers and the real-time status of replicable resources [29].

4.6. Regenerate Business Model

The model might profit from the IoT in the form of sensors and networks, and the design, production, and supply decisions of CE could be adjusted based on the data provided by IoT [68]. This would make it possible to reduce unnecessary resource consumption, improve harvest productivity, and lengthen the life cycle of land use.

IoT technology as a whole is gradually supporting the 6R concept. It encourages the integration of the six Rs into various circular business models, which differ significantly from growth in the linear economy and are made possible by the IoT technology [69]. So, using the 'heat map' data to identify the primary contributors of 6R and CBM, we built a relationship structure that included the conceptualisation of 4 IoT capabilities, 6R, and the ReSOLVE framework, as illustrated in Fig. 6 below.

4.6.1. Applicability of IoT Capabilities in the Regenerate Model

- Monitoring: monitoring and managing aspects of land management, such as crop rotation, automating irrigation systems depending on current weather conditions, and controlling the application of pesticides in accordance with the well-being of plantings [68].
- By enabling the capacity to change the composition of the ceramic bodies and the transport mix to maximise the use of local raw materials, IoT allows real-time measurement of the manufacture of ceramic tiles. This reduces the distances between mines and factories and favours rail transport. [70].

5. Challenges associated with the adoption of IoT in CBM

As mentioned above, we found various ways that IoT could support the deployment of circular CBMs while reading the literature. However, some of these sources also emphasised IoT's potential environmental dangers or other barriers to its adoption and use.

5.1. Negative effects of using IoTs

According to research in [71], one of the drawbacks of IoT-driven business models is the energy consumption and subsequent carbon emissions linked to IoT components, including IoT hardware, node software, and protocol energy utilisation. IoT networks are built on hardware, so it's critical to optimise hardware and software components to minimise environmental effects jointly. For specialised digital signal processing tasks like compression, feature extraction, or machine learning training, this improvement becomes more critical. Additionally, the effectiveness of IoT relies on protocols that facilitate communication among various nodes and routing devices within an IoT network.

Regarding software implementation, these protocols must prioritise energy efficiency and minimise the utilisation of communication interfaces.

The IoT devices may also add to the production of electronic garbage, which presents problems for recycling and disposal. As noted in [72], RFID tags are a prime example because they not only provide environmental risks but also present difficulties in recycling. According to a study in [73], another critical issue is that IoT promotes bulk customisation, making it harder for subsequent users to reuse or recycle products.

The current body of literature is notable for the scant attention paid to the adverse environmental effects of IoT adoption, including issues like the ecological cost of developing and deploying IoT devices. The results of several preliminary analyses addressing this issue have been published. For instance, a study in [74] revealed the annual energy usage of IoT devices (particularly LoRa) in the context of energy management systems, suggesting a usage rate of 5.20 kWh when installed in small buildings with an area of 16–40 m2. A study [52] evaluated the environmental performance and burdens related to the usage of RFID tags in a fresh milk supply chain in a different research. According to their analysis, which was based on Life Cycle Assessment (LCA), the environmental costs associated with the use of 1 million RFID tags included 32,900 kg CO2-eq in terms of the potential for climate change, 23.9 kg P-eq in terms of the potential for freshwater eutrophication, and 156 molc H+-eq in terms of the potential for acidification. There are surprisingly few academic works that explore the effects of IoT on CBM through empirical case studies or simulations compared to the amount of existing research.

Additionally, the security and confidentiality of data may also be challenging to maintain [75] because Botnets can target end users as weak firewall nodes and intermediary nodes in the manufacturing and remanufacturing cycle [76]. The IoT botnet Mirai serves as a typical illustration. It may target consumer electronics and home routers and transform them into zombie remote-control bots that can be used in large-scale network attacks [77].

However, concerns should be raised about the need for standardised processes and explicit guidelines for the deployment of IoT across various businesses. It is significant that, as observed by Astill et al. study in [78], there needs to be more existing policies that adequately address the issue of data ownership among various parties. The resolution of these issues relating to data ownership is essential for the effective and broad adoption of CE policies.

Similarly, a study in [79] noted that there is frequently a need for more clearly defined data management methods intended to ensure the acquisition of high-quality data for industrial analysis. It can be challenging to evaluate and confirm the quality of models representing real-world systems because of the limited accessibility and diversity of industrial data. This includes figuring out when enough data has been gathered to guarantee the accuracy of a simulation framework, as stated in [50].

IoT activities supported by the European Union's Horizon 2020 research program may address these issues. According to Calisti's study in [80], these programs include the European Cloud Initiative, the GAIA-X initiative, and public-private partnerships like the Smart Networks and Services JU and the AI, Big Data, and Robotics projects [81]. These initiatives will likely make use of distributed artificial intelligence, proactively address security, privacy, and trust requirements, and support the creation of novel decentralised structures and governance models.

6. Conclusion

The state-of-the-art relationship between IoT and CBM has been evaluated in this review from a number of angles. This paper evaluates the literature on the IoT and CBMs, which has been considerably growing in recent years, based on the PRISMA approach. It presents the current research status of IoT-assisted CBMs. It discusses their value for businesses from the standpoint of 6R with illustrative cases through the classification of their techniques and contents. The IoT has significantly improved industrial efficiency, promoted recycling, and reduced wasteful material and energy consumption by supporting seamless interoperability to optimise systems and real-time monitoring and tracking. These IoT capabilities are essential for helping CBMs, particularly when Loop and Optimise CBMs are involved.

In addition, the IoT's capacity for dynamic feedback makes it an excellent tool for reevaluating and reworking product or service concepts, particularly in the context of virtualise, share, and exchange models. We have suggested potential directions for these topics based on our preliminary study. In the Share model, for instance, IoT can build platforms that let users share things, enabling consumers to receive the same level of service from a smaller selection of physical goods. Additionally, the IoT can complement the Redesign Circular Economy concept through the integration of diverse technologies by providing virtual and dematerialised service alternatives instead of physical products with comparable functionality.

However, IoT can improve resource use efficiency and lower waste generation. However, widespread IoT adoption and the associated data processing activities may unintentionally increase energy use and lead to the production of electronic garbage (e-waste), which is frequently difficult to recycle. IoT also poses a number of challenges for its widespread adoption across various industries, such as difficulties in creating global standards for data processing, worries about cybersecurity risk, and relatively expensive initial investment costs. Small and medium-sized firm investors who are interested in cutting-edge technology and sustainable development can learn a lot from these assessments of the benefits and challenges associated with IoT.

Limitations and future research direction

Just like other studies, this one has limitations as well. This work has a number of rules, most of which result from the fact that research into the interplay between the IoT and CE is still in its infancy. Only a few case examples are accessible, and the vast bulk of references are focused on conceptual frameworks, theoretical models, and theoretical evaluations. The efficacy of meta-analyses, as tried in this work, is constrained by the absence of case studies. Few case studies specifically address the Circular Economy methods of Virtualize, Exchange, and Regenerate.

Determining how IoT might contribute to CBM and environmental improvements calls for a more systematic and quantitative review of case studies. Additionally, the body of extant studies provides scant information about IoT's adverse ecological effects. While some research suggests that its manufacture and use have only a minor environmental impact, a thorough analysis of the ecological advantages and disadvantages of IoT calls for more study. Specific IoT application scenarios, material selections, and the possibility for upcoming advancements that may result from scalability and learning effects should all be considered in this research. In the forthcoming stages of IoT research, these factors become the primary topics of concentration.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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