Review

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Circular Modality in Construction: an Interdisciplinary Review in Detecting Knowledge Gaps and Future Research Trajectories

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Review

Circular Modality in Construction: An Interdisciplinary Review in Detecting Knowledge Gaps and Future Research Trajectories

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Abstract: A general consensus is that the conventional linear modalities guarantee no industrial sustenance in long run for many obvious reasons. This is where the topicality of circularity has been accentuated for the last two decades or so in socio-political arena. However, anecdotal evidence suggests that the emphasis given to circularity in the construction industry is relatively low. Tackling this issue essentially warrants a rigorous co-production of integrated knowhow preferably beyond sectorial boundaries. The present study sheds light on interdisciplinary approaches taken to deal with the slowness in transmuting circularity into construction sector. A comprehensive literature survey was undertaken to understand this phenomenon at policy, firm and site level. The analysis included one hundred twenty-eight (128) articles published in high impact journals between 2003 and 2024. Eighty seven (87) gaps in terms of theory, knowledge, practice, method, empiricism and policy were observed. Forty four (44) thematic sub-clusters have the potential of empirical research. A new framework was finally proposed to scaffold the systemic transition towards a circular construction sector. On a practical level, the study offer valuable insights and instruments for the industry personnel to gauge the efficacy of their own circular approaches and initiatives.

Keywords: circular economy; circular practices; circular principles; construction industry; drivers and barriers; policy framework; research gaps; sustainable development

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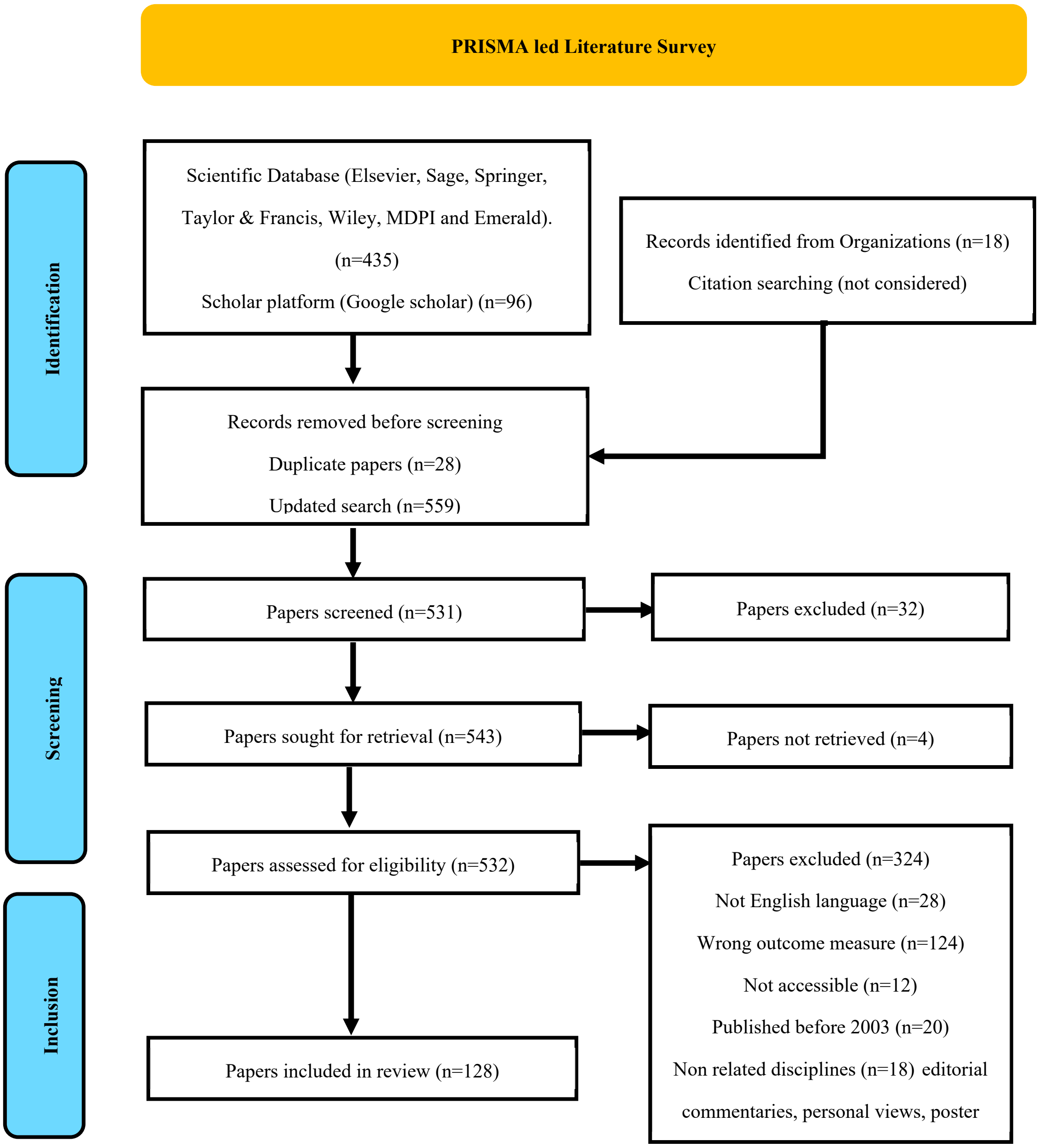
1. Introduction

By far, the construction industry is accountable for 37% of global emissions [1]. Rendering it a pollution hotspot, the construction industry is accountable for nearly 20 percent of the overall GHG emission [2]. Debris, that it generates globally, amounts to circa 10 billion tons a year [3]. Researchers predict that CO2 emission could even rise in the next two decades and stress the importance of transmuting ongoing linear practices into circular practices [4]. As perceived by researchers, such a transition would invariably support the noble cause of 'industrial resilience' [5]. Achieving industrial resilience is possible only when the activities influenced by circular principles across over sectorial, scalar, and administrative boundaries [6]. Research exponentially grows but thematic diversity [7]. Hence, it is intended that an interdisciplinary approach, combining a wide variety of expertise, will co-produce a significant body of knowledge from a wider perspective. Such an approach will further allow new value propositions [8–10]. Despite much advancement in circularity research, a massive shift like this essentially emerges an onslaught of questions. Hence, a broader scholarly approach is necessary to find out the current status-quo of research carried out to explore whether any gap of research exists. The researcher believes that it may be due to a complex mix of several distinct factors, which relatively inhibit the smooth transition to circularity. Accordingly, integrating new systems and concepts are needed to address circularity issues at policy, firm and site level. Since construction projects are temporary endeavors, technically unique and complex, a single discipline cannot simply find a solution to inculcate circularity. Instead, an integrated pursuit of co-produced knowledge is crucial. The lessons that can be gleaned from other industries are a considerable source of knowledge though it is largely un-tapped. A substantial need for a shared comprehension therefore remains [11].

Drawing upon these premises, this study reports and synthesizes the research gaps in an interdisciplinary framework.

2. Materials and Methods

Synthesizing studies from diverse disciplines enables demystifying scientific gaps [12]. This study used the PRISMA guidelines to streamline meta-analyses [13]. A review is considered systematic only when it is based on explicit methodology [14]. In order to make the secondary data relevant and rigorous enough to reasonably establish quality of the review, only scholarly research outcomes were referred to in the review after a filtering process as depicted in Figure 1. Papers have been largely drawn from peer-reviewed database such as Elsevier, Sage, Springer, Taylor & Francis, Wiley, MDPI and Emerald.



Guided by the principle that 'scientific rigor meets societal relevance', this study consolidates knowledge scattered around the issue of circularity [15]. Aiming at rationalizing and systematizing knowledge to date, the study offers an interdisciplinary knowledge mapping [16]. Grey literature is largely omitted from the review on the lack of rigor involved [17]. The papers published after 2017, following the World Circular Economy Forum (WCEF) in Rwanda, were specifically considered in

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the review. The forum brought global attention on the challenges behind slowness in embracing circular economy.

Relevant metadata and reported gaps were used for descriptive analysis and content analysis respectively [18]. Table 1 (given as Supplementary Materials) highlights eight (8) attributes of the paper namely, reference, type of study, principle or theme surrounding, affiliation of the 1st author with the aim to detect the research context unless otherwise mentioned in the text, focus area or industrial discipline, scholarly contribution (key findings) and the vacuum of knowledge (further research) recommended and finally, the research gap reported. All are presented in a succinct manner to save space. A modus operandi was subsequently provided for identifying research gaps efficiently [19]. For content analysis, a contextual mapping was undertaken to sieve theoretical gaps, empirical gaps, methodical gaps, practice gaps, knowledge gaps and policy gaps. These dimensions were determined on taxonomies already existing in the literature [20].

3. Results and Discussion

This section provides concise and precise findings of the review, largely drawn from Table 1 forming integral part of this paper.

3.1. Descriptive Analysis

Descriptive analytics enables identification of trends and relationships of a given phenomenon. This sub section will offer an overview on the focused discipline, type of paper, theme evolved and affiliation of the authors contributed in the research towards circularity in different sectors.

3.1.1. Disciplines Involved

Twelve (12) disciplines have been identified in the search for secondary data. Of them, the majority of the papers represent the discipline of business and the dispersion is largely scattered in a way that no single discipline can claim any particular custodianship for the concept of circularity. The concept of circularity has been grounded in a wide variety of ideas which has resulted in no consensus over what "Circular Economy" is all about [21,22]. Indeed, circularity is an umbrella concept encompassing a pool of principles drawn from many disciplines that foster sustenance and resilience [23]. The literature has identified many different concepts in the construct of circularity. As per [24], circularity is abstractly linked with industrial economics, systems engineering, bionics, cleaner production and physics. With the passage of time, industrial ecology and industrial symbiosis formed the nucleus of major discussions related to circularity [25]. It is seen that there is an exponential rise in the research of circularity and a wide expansion into disciplines such as logistics, information technology and cleaner production. Hence this study engaged several types of publications such as review papers, case studies and empirical studies. The outcome of these researches has been heavily influenced by the industrial context in which the research has been carried out. Existing data will offer nucleus for further analysis [26]. The results are evident in that a sizable effort has been made to identify factors that drive or inhibit the implementation of circular solutions. Overall, the study found 72 themes evolved under the overarching concept of circularity.

3.1.2. Disciplines involved

As per Alberto Alcalde-Calonge [27], there is a change in the leading role on circular economy research from China to European Union whereas the split of research is seen in two main areas: conceptualization and technicalities. Of 128 research papers, it is clear that, the findings of the foregoing researches are still valid and the majority of research is resulted in the western and eastern Europe. Research aims overlap between countries however contributes to sustainable strategies.

3.2. Content Analysis

This section of the paper will describe scholarly contribution and the vacuum of knowledge these researchers have recognized in respect to their fields of specialism. As explored the manner in

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which the lessons gleaned from other sectors can be equally exploited for the betterment of construction sector towards circularity. The paper follows [28] method of classifying scholarly contribution of research with the typology as advocated by [29].

3.2.1. Theoretical Contribution

Theoretical contributions demystify complex phenomena spanning multiple fields and promote a more holistic approach to problem-solving. Table 2 below offers an overview of theoretical contribution made by previous researchers on circularity in eight (8) aspects that are generally considered to be significant in the scientific research.

Table 2. Typology of Theoretical Contribution.

Contribution	Elaboration	Reference
Theory development	New theoretical framework/model	Lundberg, K et al., 2009, Bigliardi, et al. Tura, N et al., 2019, Chunbo Zhang et al., 2022 Shahi S, et al., 2020 Akomea-Frimpong, et al., 2023 Mohd Zairul, 2021, Jarosław Górecki et al., 2022 Timm, J.F.G et al., 2023 Nascimento,
Theory testing and validation	Validating existing theories through empirical testing their predictions, assumptions and implications	Ritala, P., 2019 , Kwasafo, Oscar et al., 2024 Akomea-Frimpong, et al., 2023Lars Repp et al., 2021e Ömer Çimen, 2023 Zhou et al.2013 Govindan, K Hasanagic, M., 2018 De Jesus, A.; Mendonça, S.2018 Zhou et al.2013 Figge, F.,et al, 2022
	Provide evidence to support, modify or reject theoretical propositions	Helbling, T., 2020 Figge, F.,et al, 2022 Santos, P.; et al., 2024
	Enhance validity and robustness of theoretical framework	Amilton Bet al, 2023 Santos, P.; et al., 2024
Conceptual clarification	Clarify conceptual ambiguities within exiting theories	Akomea-Frimpong, et al., 2023 Mário Ramos et al., 2024 Tan, J.; Tiwari, S.K, 2021
	Refine the coherence of theoretical framework	Pravin K et al.,2023 Gamage, I. et al., 2024
Integration of theoretical perspectives	Integrate diverse approaches to demystify complex phenomenon	Amilton Bet al, 2023 Salinas-Navarro, D.E.; et al., 2024
	Synthesize insights from multiple theoretical traditions	Fagone, C et al., 2023
	Foster interdisciplinary dialogue and enrich theoretical discourse	Thomas Budde Christensen, et al., 2022
Boundary expansion	Extend the boundary of exiting theories by applying them to new contexts,	Kwasafo, Oscar et al., 2024 Thuesen, C, 2012Santos, P.;, et al.,2024 Zhou et al.2013

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	Expand the scope of research and open up new avenue of inquiry	Lestari, E.R., 2022
Meta theoretical reflection	Critically evaluate underlying assumptions, epistemological foundations, or methodological approaches of exiting theories	D.L.M, et al, 2018
Synthesis of empirical findings	Synthesize form multiple studies to develop a more robust theoretical explanation or models	Gherman, I.-E et al., 2023
	Integrate diverse empirical evidence into coherent theoretical framework	Lorraine McIlrath et al., 2012, Breznitz and Feldman, 2012
	Facilitate cumulative knowledge accumulation	Breznitz and Feldman, 2012
Theoretical innovation and paradigm shift	Challenge conventoional wisdom,	Noorshella Che Nawi et al., 2024Tsui, Tanya, 2022Lorraine Noorshella Che Nawi et al., 2024McIlrath et al., 2012 Lyngby (2008
	Introduce disruptive ideas	White, K. et al., 2019 Pheifer
	Propose revolutionary paradigms and reshape intellectual landscape	Paulo de Sa & Jane Korinek, 2021 Hassan, M.R. et al., 2024

It is clear that, the majority of the previous studies provide theoretical framework to support the arguments cited in the papers. In complementarity, researchers have provided conceptual frameworks to guide research by providing a clear, visual or descriptive representation of the key concepts, variables, and their relationships. These frameworks provide a roadmap for how the study will proceed. Research on circularity in construction has significantly contributed to sustainability theory by providing frameworks that endorse reuse, recycling, and reduction of materials within the construction industry. This helps to define new principles of sustainable construction practices that go beyond traditional linear approaches. Pravin K et al., 2023 [30] introduced a conceptual framework showing the correlation between drivers and barriers. Circularity research has also impacts on organizational theory, particularly in how construction firms and supply chains organize themselves to implement circular practices. It explores new organizational structures, cultures, and leadership styles that facilitate circular economy principles. Lundberg, K et al., 2009 [31], have come up with a causal-chain framework concerning strategic and operational objectives. Meantime, Bigliardi, et al. [32] introduced an Integrative Theoretical Framework while Tura, N et al., 2019 [33], came up with a framework of drivers and barriers. Research on circularity in construction informs environmental management theories by highlighting methods to reduce environmental impacts. This includes theories on waste reduction, resource conservation, and minimizing carbon footprints. For example, Chunbo Zhang et al., 2022 [34], introduced a waste hierarchy while Govindan, K Hasanagic, M., 2018 [50] offered sound practices towards circular economy. De Jesus, A.; Mendonça, S.2018 [51] also discussed drivers and barriers in the context of eco-innovation. Zhang, A et al., 2019 [52] discussed in length how smart waste management can contribute a circular economy. Heurkens, E., & Dąbrowski, M. (2020) [6] identified barriers for circular transition at a regional scale.

Having applied the systems theory, Ritala, P., 2019 [35] examined the issue of circularity from three perspectives: skeptical, pragmatic, and ideal. Meantime, Rizos, V.; 2016 [36] focused on business models. Business modeling seems topical in the research arena that has a tail-end stake in those who implement circular practices at ground level such as construction companies. This essentially provides a link with the behavioral science which confirms that understanding the human and social aspects of adopting circular construction practices contributes to behavioral science theories. Research can reveal how attitudes, perceptions, and behaviors of various stakeholders (such as contractors, clients, and regulators) impact the adoption of circular practices. Green purchase decisions are found to be incentive as enablers from the perspective of buyers. These green purchase decisions are multifaceted and influenced by a combination of personal, social, and economic factors. Encouraging these decisions requires a concerted effort from businesses, governments, and non-profit organizations to create an environment where making sustainable choices is easy and rewarding for consumers. Lopes, J.M.M et al., 2024 [37] investigated consumers' green orientation in decision making. However, Helbling, T., 2020 [38], poised that the lapses in pricing decisions are evident in that no consideration is given to indirect costs of pollution. Many researchers held more or less a similar viewpoint [3,32,35].

Kwasafo, Oscar et al., 2024 [39], provided insights into practices involved in green procurement. Amilton Bet al, 2023 [40] studied on urban mining whereas Akomea-Frimpong, et al., 2023 [41] recognized success factors related to circular implementation in PPP projects. Shahi S, et al., 2020 [42], introduced a framework enabling precise categorization of building adaptation projects. Lestari, E.R., 2022 [43], inquired about the tax policy while Ljumović, I., Hanić, A. (2023) [44], investigated the role of crowd funding in circular projects. Successful crowd funding campaigns require careful planning, execution, and ongoing engagement. Lars Repp et al., 2021 [45], engaged in an evidence-based discussion on the European Union's (EU) transition towards the Circular Economy (CE). Mervyn Jones, et al. 2018 [46] focused on different ways of integrating circular thinking in the procurement. Matthias Multani, Kris Bachus, 2024 [47] explored the relationship between circular economy and jobs, crucial for sustainable transitions. Salinas-Navarro, D.E.; et al., 2024 [48] studied how to navigate challenges in capitalizing solid waste in business. Mohd Zairul, 2021 [49], revealed research trends in prefabrication with a circular approach. The economic implications of circular construction are significant, contributing to theories related to resource efficiency, cost savings, and new business models. It is also seen that the circularity in construction promotes advancement in LCA theory from production to end-of-life disposal or recycling. The research attempted discourse the principles of circular design into construction projects with the ability to be easily deconstructed and materials repurposed before the materials get technically perished. This approach reduces waste and creates opportunities for cost savings. Incorporating circular principles into construction also influences design theory, encouraging architects and engineers to rethink design approaches that facilitate disassembly, material recovery, and adaptability. For example, modular construction occupied a considerable added value on morphological theories. Modular construction techniques are basically standardized building components manufactured off-site and assembled on-site. Modular construction not only improves efficiency and reduces construction time but also facilitates easier disassembly in future projects. Material Recovery and Reuse is quite frequent in the circularity research including strategies for recovering and reusing materials from demolition sites. Salvaging materials can significantly reduce the demand for virgin materials and lower the project costs. Resource Sharing and Collaboration is also found to be a widely theorized topic in the circularity research. Sharing equipment, machinery, and other resources among multiple projects can help minimize idle capacity, reduce transportation costs, and optimize resource utilization. Embracing integrated project delivery methods has been suggested by the researchers involving early collaboration among project stakeholders. By working together from the initial stages of a project, stakeholders can identify prospects for optimizing resource use, minimizing waste, and achieving cost savings. Looking from the perspective of systems theory on the premises that the construction is a function of a complex system, circular construction research has advanced systems theory by emphasizing the interconnectedness of different components within the construction lifecycle. It underscores the importance of viewing buildings and infrastructure as part of a broader system where materials and resources are continuously cycled. Conducting life cycle cost assessments has therefore added a significant theoretical relevance. Stahel, W.R. 2016, [53] empirically derived a sustainability agenda for those affected by circular practices.

Nascimento, D.L.M,et al, 2018 [54] engaged in modeling symbiotic industrial ecosystems. Industry Standards are one of the eminent outcomes of this research improving overall performance and safety. However there is no conclusive evidence to show that the selective demotion is always the best option. Research revealed that results largely differ with the local conditions. S. Pantini, L. Rigamonti [126] and Mário Ramos et al., 2024 [55] find strategies that encourage selective demolition, using a behavioral approach. By understanding underlying mechanisms and causes, research helps solve complex problems in various fields, from engineering to social sciences. Tan, J.; Tiwari, S.K, 2021 [56] argue on consumers' "intention-action gap" quoting examples in adopting more sustainable food packaging options. Zhou et al.2013 [57] introduced an evaluation model based on support vector machine (SVM) assimilated with a heuristic algorithm.

In line with the foregoing principles, Thuesen, C, 2012 [58] presented a few important guiding principles on the initiation of business models for off-site system deliveries. Waris, M., et al., 2014 [59] largely researched on onsite mechanization in Malaysian construction. Timm, J.F.G et al., 2023 [60] adopted a framework in the sequence of Plan-Do-Check-Act to support trade-offs in collaborative decision-making. While Gamage, I. et al., 2024 [61] identified the relationships of highly cited circular practices in the literature, Karaca, F et al., 2024 [62] explained the concept of resource equity in the construction sector. Gherman, I.-E et al., 2023[63] introduced a novelty in structuring the research trends. By studying the implementation of circular principles, researchers contribute to innovation theory, particularly in how new technologies and processes are adopted within the construction sector. This includes the digital tools, such as Building Information Modeling (BIM), for better resource management. Fagone, C. et al., 2023 [64] created a flow of site operations on circularity based approaches. Santos, P. et al., 2024 [65] identified patterns, relationships, etc by giving further valuable insights. Tsui, Tanya, 2022[66] discussed municipal-led circular land mass coordination. Paulo de Sa & Jane Korinek, 2021 [67] contributed in offering savings to offset green premium for mass consumers. Pheifer, A Pheifer [68] demonstrated that non-pricing externalities results in low market prices especially in mass scale productions whereas Thomas Budde Christensen, et al., 2022 [69] introduced a closed-loop production and consumption value chain as an alternative to external pricing. Theoretical contributions can extend to policy and governance by providing evidence-based recommendations for regulations and policies that promote circular construction. This involves understanding the role of government, industry standards, and incentives in fostering circularity.

3.2.2. Practical Contribution

The practical contribution of research refers to the tangible and actionable outcomes that research provides to society, organizations, or individuals. These contributions can take various forms, including technological advancements, policy recommendations, best practices, enhanced understanding, and more. It is found that research in circularity often leads to new technologies, products, and services that improve quality of circular activities, enhance productivity, economies of scale, reduce cost and provide new capabilities. The starting point is to empirically gauge the perception of those who are in the loop of circularity. Table 3 offers an overview of practical contribution made by previous researchers on circularity in eight (8) aspects that are generally considered to be significant in the scientific research.

Table 3. Typology of Practical Contribution.

Contribution	Elaboration	Reference
Policy recommendation	Provide evidence based insights to inform the development of policies	Ljumović, I., Hanić, A. (2023 Melati, K et al., 2021 Czarnecki, S.; Rudner, M. et al., 2023 Kjerulf, 2022) (Kilvær, 2022

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Program development and evaluation	Work ut strategies to address specific challenges	Stahel, W.R. 2016 Järvenpää, A.Met al, 2021 Vence, X.; López Pérez, 2021 Melella, R et al., 2021
Practice influence	Guide diagnosis to finf ways of improve efficacy of practice	Govindan, K Hasanagic, M., 2018. De Jesus, A.; Mendonça, S.2018, Zhang, A et al., 2019, Heurkens, E., & Dąbrowski, M. (2020) Waris, M., et al., 2014 Hedberg, A et al., 2019 Järvenpää, A.Met al, 2021 Milios, L., 2021 Doukari, Omar & Greenwood, David. (2020
Technological innovation	Derive innovation by uncovering new scientific materials, products, processes and practices	Mervyn Jones, et al. 2018 Waris, M., et al., 2014 Masanet, E.;et al, 2020 Hacioglu, U., 2020 Doukari, Omar & Greenwood, David. (2020 M Sivers, et al., 2022 Meng, X et al., 2023
Economic development	Foster entrepreneurship by providing insights into market dynamics, consumer behavior, industry trends	Lopes, J.M.M et al., 2024 Matthias Multani, Kris Bachus, 2024 Thuesen, C, 2012 Waris, M., et al., 2014 Hacioglu, U., 2020 Bressanelli, G.et al, 2018
Environmental sustainability	Address environmental challenges such as climate change, pollution and resource depletion	Thuesen, C, 2012 Hacioglu, U., 2020
	Identify sustainable practices and technologies to promote ecological resilience	Spišáková, M et al., 2021
Social impact	Address social inequalities, and promote social justice, empower marginalized populations	Green and Erdem, 2016 Karaca, F et al., 2024 Tseng, M.L.;et al, 2018 Hacioglu, U., 2020 Järvenpää, A.Met al, 2021 White, K. et al., 2019 Kjerulf, 2022) (Kilvær, 2022 Maria Anna Cusenza et al., 2019 Noorshella Che Nawi et al., 2024
Education and training	Inform curriculum development, instructional strategies, educational policies etc	Green and Erdem, 2016. Calle Müller, C, et al., 2024
	Identify best practices and provide evidence bsed interventions	Mahboob Morshed (2022) Tseng, M.L.;et al, 2018

Melati, K et al., 2021 [80] gauged the perception of stakeholders on their own technical know-how to shift from linear practices to circular practices. Masanet, E.et al, 2020 [70] integrated cloud services into IT Infrastructure which will lead to process improvement. In this manner, innovations in manufacturing, logistics, and other processes can lead to increased efficiency and reduced costs. Hedberg, A et al., 2019 [71] reflected on how digitally enabled solutions can accelerate the transition. Tseng, M.L.; et al, 2018 [72] optimized the value chain in the context of dynamic production. Hacioglu,

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U, 2020 [73] researched on digital business strategies in Block chain Ecosystems whereas Bressanelli, G.et al, 2018 [74] introduced a Product-Service Systems (PSS) Business Models. Järvenpää, A. Met al, 2021 [75] foresaw in advance how Industry 4.0 is enhancing efficiency in dealing with waste and by-product flows.

Policy recommendations are a highly acclaimed source of practical contribution in the field of circularity. Research provides data and insights for evidence-based policymaking that helped policymakers craft laws and regulations that better address circularity related issues. Public health Initiatives also a resultant outcome of circular researchers such as studies in medicine and public health that led to new guidelines and interventions that improve population health in general and in construction in particular. A sizeable amount of research has introduced best practice guidelines, manuals and protocols via collaborative arrangements that bridge theory and practice. Breznitz and Feldman, 2012) [76] contended that the global mandate to sustainability has made the role of modern universities multifaceted. According to Green and Erdem, 2016) [77], collaborative efforts enable comprehensively representing the demands sustained link between industry and academia. Milios, L., 2021 [78] identified several implementation challenges and potential solutions with empirical sources. Informed Decision-Making is a practical contribution where organizations and individuals can make better decisions based on research findings, leading to improved outcomes in business, healthcare, and personal life. Circularity research has made a considerable economic Impact in terms of job creation for example new industries and sectors can emerge from groundbreaking research, creating jobs and boosting the economy. Innovations can lead to new markets and expand existing ones, fostering economic growth. As such, White, K. et al., 2019 [79] came up with a series of marketing-based tactics, including using social influence, to inspire a culture of green consumption.

Lorraine McIlrath et al., 2012 [81], investigated on the role of higher education in terms of its civic engagement. As many researchers identified, strategic alliances are a source of knowledge that helps enhance synergy in the pursuit of circular practices. Indeed, one of the most cited papers is Mohammad Mahboob Morshed (2022) [82], that describes the role of collaborations as a part of international mandates in favor of SDGs. Research in environmental science can lead to sustainable practices that help reduce pollution and conserve resources. One of the tangible outcomes in circular research is renewable energy. Advances in research can make renewable energy sources more viable and cost-effective, reducing reliance on fossil fuels. Research on reclaimable materials also form an integral part of circularity research. For example, Czarnecki, S.; Rudner, M. et al., 2023 [83] researched on the economical use of reclaimed materials in new constructions or renovations. Doukari, Omar & Greenwood, David (2020) [84] investigated about auditor touring and inventory making manually, or through creating a 3D digital model (BIM - Building Information Modeling) of the building. Maria Anna Cusenza et al., 2019 [88] examined the ability to reuse depleted batteries from electric vehicles in stationary second life applications. Noorshella Che Nawi et al., 2024 [89] researched on electronic wallet adoption whereas Lyngby (2008) [89] was suggesting coordinated purchasing as an effective measure to support circularity. Santos, P.; et al., 2024 [92] researched on novel block system, recycled aggregate, modular kitchen reuse, and energy efficiency retrofit whereas Melella, R et al., 2021[93] investigated on selective, low carbon disassembly and demolition. Meng, X et al., 2023 [94] empirically investigated on the integration of digital twin. Hassan, M.R. et al., 2024 [95] researched recycled rubber-based construction materials as a support to circularity. In line with these technical approaches, minimizing demolition through regulatory procedures and enforcing the existing separate-collection waste regulations for construction and demolition waste can be considered a giant step forward in circularity research.

3.2.3. Methodical Contribution

Disciplinary advances are dependent partly on the refinement in methods adopted in conducting research. More importantly, Calle Müller, C. et al., 2024 [96] advocated less carbonized approaches to scaffold a circular construction industry. Enhancing methodologies for conducting life cycle costing will better capture environmentally sensitive products and services, including recycling and reuse. For example, Maury-Ramírez, A et al., 2022 [108] developed an innovative product

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portfolio for the use of construction and demolition waste (C&DW). Further, there was research that suggested improved methods for tracking and analyzing the flow of materials through different stages of production, use, and disposal, helping to identify opportunities for circular practices. There researchers utilized big data and Internet of Things (IoT) technologies to gather real-time data on resource use, waste generation, and recycling processes, enabling more precise and timely analyses. Some of the researches included advanced remote sensing and Geographic Information Systems (GIS) techniques for monitoring environmental impacts and resource flows at larger scales. In the recent past, there was a couple of research towards developing robust indicators and metrics to measure and compare the circularity of products, processes and systems. Application of system dynamics models to simulate the interactions and feedback loops within circular systems, helping to predict outcomes and identify leverage points for intervention was also seen. Table 4 offers an overview of methodical contribution made by previous researchers on circularity in six (6) aspects that are generally considered to be significant in the scientific research.

Table 4. Typology of Methodical Contribution.

Contribution	Elaboration	Reference
Devleopment of new methods	Introduce novel methods of data colleciton, analysis interretation	Tsui, Tanya, 2022
	Design new experimental protocols	Susana Garrido et al., 2023
	Create innovative survey instruments	Brandon S. Byers1, Catherine De Wolf, 2023
	Roport novel statistical techniques	-
Refinement of eisting methods	Optimize procedures to enhance efficinecy, incresing the rreliability or validaity of measurmet otools	Bressanelli, G.et al, 2018
	Address lmitations and biases	
Intergration of multiple methods	Intergrame multipl emethods to offer comprehensive insgihts into complex phynomeno	Masanet, E.;et al, 2020
Validation and veificaiton	Condcut replication studies to confirm the reliabiiyt of estbalsihed methods	City of Richmond, 2024
Open science practices	Embrace open science practices such as sharing materials, data, coes to improve rogor	BCA Green Mark Certification Standard, 2016
Cross disciplinary methodological borrowing	Borrow methodologies from other disciplines and adopt them to new contents	Figge, F.,et al, 2022

Offering a benchmark in circularity, Kavinda, H. and Jayalath, C., 2019 [98] derived a decision-making support model to augment rationality of BAR decision. This integrated decision-making framework considers environmental, economic, and social factors to evaluate and prioritize circular strategies in building adoption. Techniques for benchmarking circular practices across different industries or regions enable the identification of gaps and opportunities for improvement. Development of dynamic LCA approaches account for temporal changes in environmental impacts and resource flows, providing a more accurate assessment over time. Combining process-based LCA with input-output analysis will also capture both direct and indirect environmental impacts, offering a more comprehensive evaluation. The study of Giulia Lucertini, Francesco Musco [126] provides impetus to unite research fields that promote collaboration on urban metabolism within a circular context. As such, these studies provide enhanced techniques for studying the material and energy flows within urban systems, supporting the design of more sustainable and circular cities. City of Richmond, 2024 [100] is one such classic case where BC Energy Step Code and Zero Carbon Step Code, phased reduction in operational carbon emissions. Susana Garrido et al., 2023 [101], introduced a new composite circularity index (CI) combining multiple indicators of circular practices which is termed 'Benefit of the Doubt' (BoD) model. Kavitha Shanmugam et al., 2022 [41], presented a five-layered assessment framework for quantitatively evaluating the sustainable value of municipality waste.

3.3. Vacuum of Knowledge

Identifying research gaps is a critical step in advancing any field of study, as it helps to pinpoint areas where further investigation is needed. Research gaps can be categorized into several types, each representing a different kind of deficiency or opportunity. By categorizing these gaps, researchers can better identify where to focus their efforts, ensuring that their work contributes to a more comprehensive and actionable body of knowledge.

3.3.1. Theoretical Gaps

Theoretical gaps refer to areas within a field of study where existing theories are incomplete, inconsistent, or insufficient to fully explain a phenomenon. These gaps represent opportunities for further research and development to enhance understanding and provide more comprehensive models or explanations. Conceptual Frameworks: Absence or inadequacy of theoretical models or frameworks that explain certain phenomena. Sometimes, a phenomenon spans multiple disciplines, and existing theories within a single discipline may not be adequate to explain it comprehensively. The researcher finds there is a need for the expansion of existing theories to cover new contexts or dimensions especially in terms of integration. Opportunities to integrate multiple theories are needed to gain a more inclusive understanding. For example, Zhou et al.2013 [56], contend that machine-to-machine communication has a theoretical gap in the circularity research arena. Emanuela Vanacore, et al., 2023 [101] find that models of public engagement in procurement decision-making process is a vacuum of theoretical knowhow. Kavitha Shanmugam et al., 2022 [40] contend that, if integrated with other fields effective strategies for improving the circularity performance would not that be far from reality. Melella, R et al., 2021 [92] confirm that a model to ease out disassembly and damage would help ease out the transition to circularity. Maury-Ramírez, A et al., 2022 [107] argue that modeling on efficient use of construction materials has a theoretical gap in the research on circularity. Addressing theoretical gaps often involves developing new hypotheses, conducting empirical research, and creating integrative frameworks that bring together disparate strands of knowledge.

3.3.2. Empirical Gaps

There may be a lack of empirical evidence to support or refute existing theories, highlighting the need for further experimental or observational research. Lack of data is one of the common sources for empirical gaps that inhibit support or refusal of existing theories or hypotheses. One of the limitations to confirm empirical gaps is the lack of data sets in the majority of papers published. The presence of conflicting results or contradictory findings in existing research is considered as a gap that needs to be empirically reconciled through further studies. However, the researcher finds no apparent contradictions in terms of findings. However, understudied contexts may pose empirical gaps leading to a lack of generalizability. For example, Kennedy & Linnenluecke (2021) [109], have specified that firm, industry and social-ecological level resilience can be achieved through CE business practices. Indeed, one of the crucial factors in CE is Circular Economy Business Models (CEBMs). Business model is a rationale of how an organization creates, delivers and captures value (Osterwalder & Pigneur, 2010) [110], Sarasini, & Loon (2017) stated that CBMs operate at

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the micro level of the economy. Aarikka-Stenroos, Chiaroni, Kaipainen, & Urbinati (2022) [110], and Linder, Kirchherr et al. (2017) , [112], Geissdoerfer et al. (2020) , [113], and Bocken, Pauw, Bakker, & Grinten (2016) , [22], have signified that CBMs are essential instruments that are crucial to the transition towards circularity. However, only a few scholars have concentrated on integrating CE concept with business resilience in the construction industry. Circularity is still a novel concept in Sri Lanka (Wijewansha, et al., 2021) [114], The literature available related to circularity in the Sri Lankan context is comparatively less. Mainly, researchers such as Samarasinghe &amp [115], Wijayatunga (2022), [116], Bekchanov & Mirzabaev (2018) [117],, and; Samarasinghe & Visvanathan (2021) [115],have given attention to the application of circularity in waste management and a few researchers such as focused on circularity in the cooperative sector. It must be highlighted that researchers have focused adequately on areas such as the applicability of circularity in materials selection (Wanaguru, et al., 2022) [118], and the pre-construction phase (Wijewansha, et al., 2021) [114], but there is a need for broader scholarly contributions. The researcher concludes that there is a clear empirical gap to study how CEBMs enhance business resilience in construction industry. Further, Santos, P.; et al., 2024 [65] emphasize that the integration of technological advancements, such as AI, robotics, and block chain, is essential for optimizing waste management efficiency.

3.3.4. Methodological Gaps

Existing methods for testing theories might be inadequate, or sometimes found to be irrational or inappropriate, calling for the development of new research methods or tools. Rizos, V.; 2016 [10] confirms that knowledge sharing mechanisms are needed to foster collaborations, boost research and encourage innovative endeavors. A need would arise for new or improved research methodologies to better investigate certain phenomena. Challenges related to the measurement of variables, including reliability and validity concerns may pose methodological gaps. For example, Masanet, E.;et al, 2020 [70] insists that IT architecture may require a different methodological approach to support circular initiatives. In some cases, longitudinal studies may be warranted due to lack of long-term studies that track changes and developments over time. Life cycle costing studies has this longitudinal dimension. Andersen, S.C et al., 2022 [25] confirms that LCA in all stages of the building life cycle is warranted for empirical validation. Another classic example is Tsui, Tanya, 2022 [66] which derived a spatial algorithm in allocating lands for waste disposal. Brandon S. Byers Catherine De Wolf, 2023 [103] looked at the use of linked building data and semantic web technologies.

3.3.5. Practical Gaps

Research in circularity aims to create sustainable systems that minimize waste and maximize resource efficiency. Despite the growing body of research in this area, several practical gaps remain. Quite often, the researchers have concluded their studies highlighting the need for interdisciplinary research that combines insights from economics, environmental science, engineering, and social sciences. These researchers emphasize the significance of having collaboration between academia, industry, and government. Limited interdisciplinary approach will in no doubt hinder the practical application of research findings. More specifically, the difficulty in implementing research findings in real-world settings, require studies on best practices for implementation. There will be a need for research on how to scale successful interventions or replicate findings across different settings. Nascimento, D.L.M,et al, 2018 [54] suggests that working out strategic relationship between decision makers worldwide using Industry 4.0 is of timely importance. Few researchers such as Tseng, M.L.;et al, 2018 [72] on lean production, Stahel, W.R. 2016, [53] on Sustainable Technological Infrastructure Development, Pravin K et al.,2023 [30] on reverse logistics confirmed that their findings will enhance circularity in construction at firm and site level provided an interdisciplinary approach is taken at all times. M Sivers, et al., 2022 [87] detected a practical gap in reuse market solutions that are offline or only superficially online. Synchronizing demolition & construction across sites in order to facilitate reuse, minimize storage requirements, and begin to balance supply and demand. Thuesen, C, 2012 [58] confirmed that coordinated purchasing results in economies of scale, however, a practical gap exists can be eased out only in a coordinated effort. Addressing these practical gaps therefore requires a coordinated effort among researchers, policymakers, industry leaders, and consumers. More comprehensive and applied research, combined with effective collaboration, is essential to advance the principles and practices of the circularity.

3.3.6. Knowledge Gaps

Despite growing interest and research in this area, several knowledge gaps persist that hinder the adoption of circular practices. These gaps are relating life cycle assessment, materials innovation and recycling, design for deconstruction, business models, policy and regulations, supply chain, data sharing, stakeholder collaboration, skills and capacity building, technological integration etc. Knowledge gap basically arise when the fundamental questions remain unanswered, limiting the foundational understanding of a given topic. For example, Lifecycle Assessment (LCA) are pervasive in the circularity research, however, the researchers, Ömer Çimen, [123], Damian Coughlan, [105], Anastasiades, K [107], all confirm limited comprehensive LCA studies specific to construction materials and processes and stress the need for standardized methods over their entire lifecycle. As such, insufficient researches on innovative materials that are sustainable, durable, and recyclable generate a knowledge gap. Researchers confirm that the lack of effective recycling technologies for construction and demolition waste (CDW) pose a challenge in reclaiming and reusing high-quality materials from existing buildings. Kavinda, H. and Jayalath, C., 2019. [98], in their research on building adoptive reuse, suggested a gap of knowledge in the arena of deconstruction. Design for Deconstruction (DfD) has been topical, however, limited application of DfD principles in architectural and structural design has created a vacuum that inhibit the transition towards circularity. Hence, there is a need for design guidelines and best practices that facilitate the disassembly and reuse of building components.

Circular business modalities continue to generate a knowledge gap in the field of construction. Many recent researches such as Melati, K et al., 2021, [81], Bressanelli, G.; [74], Nascimento, D.L.M [54] Aarikka-Stenroos [111],emphase the fact there due to lack of robust business models, it has become almost stagnant to demonstrate the financial viability of circular construction practices. These researches confirm the reason being the limited case studies and real-world examples of successful circular construction projects that can be used as references. Product-as-a-Service (PaaS) is one of the classic examples. Researchers have identified that construction companies are an ideal niche in implementing processes to recover and reuse waste materials from production or after product use. This can include recycling materials or converting waste into energy. Different industries collaborate to use each other's by-products or waste materials. Data and information sharing has also generated a considerable knowledge gap according to many recent research projects such as BCA Green Mark Certification Standard, 2016. Insufficient data on material properties, building performance, and end-of-life options has created challenges in data sharing between stakeholders due to proprietary concerns and lack of standardized data formats. Technological integration is another potential where digital technologies such as Building Information Modeling, IoT, and AI to support circular construction practices are largely unexplored. This arises a need for more research on how digital tools can facilitate material tracking, lifecycle assessment, and efficient resource management. Addressing these knowledge gaps requires concerted efforts from academia, industry, and policymakers to foster innovation, create supportive regulatory environments. Interdisciplinary research and real-world pilot projects are essential to develop and demonstrate effective circular construction solutions. In a nutshell, gaps exist at the intersection of multiple disciplines, where integrated knowledge is lacking.

3.3.7. Policy Gaps

Studies revealed several policy gaps that hinder the widespread adoption of circular construction practices. These basically include not only policy development even in changed circumstances but also policy impact studies and comparative policy analysis. Lack of research on the impact of existing policies, regulations, or programs are evident. Hedberg, A et al., 2019 [71] points out the need of effective strategy formulation by correspondence among IT and CE

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practitioners whereas Naveed, W et al., 2022 [119] emphasize developing economic policies and agendas in support of circular activities. According to Ritala, P., 2019 [35], it is imperative to take the long view and pursue complementary strategies. Without proper knowledge and skills, the workforce is less equipped to implement circular construction methods effectively. Lorraine McIlrath et al., 2012 [81] and Mohammad Mahboob Morshed (2022) [82] emphasize the importance of industry-university strategic partnership for enhancing circular systems, methods and processes via education, training, research, network and financing. In a way, this can be considered as a gap of policy in circularity related education and training. White, K. et al., 2019[79] has identified lack of awareness and incentives for circularity based marketing as a gap of policy at the outset. Green and Erdem, 2016 [77] insists on research on industry networking and business incubation. There is a lack of comprehensive data and transparency regarding the environmental impact and lifecycle of building materials. Without detailed data, it is difficult to make informed decisions about material selection and to measure the benefits of circular construction. Policies may not sufficiently support research and development in innovative circular construction technologies and practices. The impact is that it slows down the adoption of new methods and materials that could otherwise enhance circular construction. Hence, it is important to strengthen End-of-Life policies and enhance regulations for managing construction and demolition waste to promote recycling and reuse, for example. In the meantime, research has revealed that tax policies too have an impact on the propagation of circularity. For instance, Milios, L., 2021 [78] contends that each of the tax proposals needs a more detailed examination for its specificities of implementation. According to Lestari, E.R., 2022 [43], more detailed inquiry is required for tax policies applicable. Vence, X.; López Pérez, 2021[85] confirm that a total revamping of the tax measures are imperative for fostering a circular economy. Mervyn Jones, et al. 2018 [46] emphasize integrating circular criteria into their procurement processes. Table 5 (given as Supplementary Materials) offers a framework for interdisciplinary research related to construction circularity in future.

4. Conclusions

As an impetus, more research is needed to address the gaps identified in this review for a genuine support the transition to circularity in the construction sector. The analysis highlighted several areas of focus for the support of circularity in construction, including business models, impact assessment, education and awareness and finally the social readiness. Lack of standard practices, protocols, training and guidelines have been identified as barriers and the patronage given at policy, firm and site level are relatively at a low position. Thus, evidence-based policy recommendations for governments and regulatory bodies are made to promote circular construction. These include incentive schemes that can be implemented at local, regional, or national levels to circular practices with guidelines on how to structure these incentives for maximum impact. Best practice frameworks and toolkits that integrate life cycle assessments into circular economy principles are needed. More importantly, strategies for engaging stakeholders representing multiple sectors and industries having some kind of a stake in construction are needed in the policy development in order to ensure that regulations and incentives are practical and widely supported. For example, specific policy changes or new regulations will support circular construction in urban areas; townships etc. and pave the way for local governments to implement these policies effectively. Researchers have suggested various tools and metrics for evaluating the environmental, economic, and social impacts of circular construction practices, on the other hand. Pilot projects that demonstrate the integration of circular principles in urban planning and construction are also proposed. Researchers have developed best practices and guidelines for effective international collaboration platforms and capacity building programs to scaffold knowledge transfer and sharing in circular construction.

At firm level, portfolio of innovative business models take a pivotal role to promote circularity in construction while addressing financial constraints and guidance on the scaling of these models in different contexts. It is important to incentivize the adoption of circular business models that enable innovation and investment in circular construction practices. In these initiatives, partnership-building has been identified as a nexus connecting stakeholders with complementary interests and expertise. Academic publications, industry reports, and stakeholder workshops are important to foster a community of practice around circular construction business models to facilitate knowledge sharing and peer-learning. A portfolio of innovative technologies and solutions are implementable at firm level with demonstrable economic benefits. Hence, it is imperative to revisit the guidelines and toolkits for technology developers, construction firms, and policymakers on integrating innovative technologies for an optimized circular supply chain model. At site level, technological solutions and tools to support material tracking, traceability, and reverse logistics processes have been widely researched for the last two decades. In addition to knowledge-sharing platforms at site level to enhance expertise in circular supply chain management designing for deconstruction, selecting sustainable materials, and implementing effective waste management practices have also been topical in the latest research arena. These include digital platforms, sensors, and data analytics. Again, evidence-based recommendations have been made to policymakers, regulatory bodies, and industry stakeholders on integrating for example DfDR requirements into building codes, standards, and certification systems. Quantifying the environmental and economic benefits of DfDR approaches through life cycle assessments, cost-benefit analyses, and comparative studies with conventional construction methods are equally important at firm and site level circularity. Quite importantly, optimized designs for integrating on-site renewable energy systems into circular construction projects, considering factors such as site conditions, building orientation, and energy demand profiles enable smooth transition to circularity. In nutshell, interdisciplinary research would be an impetus and play a pivotal role to ease out smooth transition. Based on the literature review findings, a novel framework for circularity in construction can be proposed, aiming at systematizing knowledge and guiding the future research agenda in the field. Strong emphasis can be placed on the importance of holistic sustainability (economic, environmental, and social) and the central role that governments have in its adoption. Table 3 is a detail outcome of the literature survey finally offering a research agenda underpinning policy, firm and site level research. The key message is that this essentially requires the exploration of multi-disciplinary holistic assessment.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Table 1: Scholarly contribution and vacuum of knowledge; Table 5: Future research and intended outcome.

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