DIMENSIONS OF MATURITY MODEL FOR INSTITUTIONALISING SMART CIRCULAR CONSTRUCTION: A SYSTEMATIC LITERATURE REVIEW

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The systematic adoption of Industry 4.0 technologies has potentials to achieve the transition to Smart Circular Construction (SCC). However, the construction literature lacks a systematic guidance of maturity models to inform the transition to circularity in organisational practices, give away SCC. This study aims to conceptualise dimensions of maturity for institutionalising SCC practices in construction firms. A systematic literature review including 31 peer-reviewed journal articles reporting on other industries was conducted to identify the maturity dimensions relevant to SCC and their suitability for use in construction firms was discussed. Ten dimensions and associated attributes were identified showing relevance to the eight Porter's value chain activities. This suggests their sufficiency in depicting smart circular values in construction firms. However, the weighting, i.e. importance, of the dimensions and their attributes specific to construction companies is unknown. Future research will verify the proposed dimensions and establish weighting for the dimensions. This will facilitate the development of a maturity model to assess and inform the transition to SCC in construction firms.

Keywords: construction circular economy, digital transformation, Industry 4.0, maturity model.

INTRODUCTION

The construction industry is key to urban development and economic growth (Yu et al., 2022). However, the industry faces numerous challenges that could hinder its performance. It is the largest natural resource consumer and is expected to be mindful of waste generation, but it has thus far witnessed increasing waste statistics. In the European Union, the total waste reaches up to 36% (Çetin et al., 2021). This challenge stems from the industry's adherence to a wasteful "take-use-dispose" linear model, which has resulted in escalating losses that surpass its gains. With global urbanisation on the rise, there is an urgent need to address these issues innovatively, ensuring that

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the industry meets the world's growing needs without perpetuating its current redundant linear model. Hence, the circular economy (CE) has emerged as a viable, sustainable, and innovative solution to the dominant linear model issues (Abiodun et al., 2023).

In adopting CE in construction, studies have explored several attempts to limit circularity issues, concentrating on CE concepts, procedures and drivers. Most studies have focused on enacting the R principles grouped as 3R, 6R, 10R (Illankoon & Vithanage, 2023). Moreover, emphasis has largely been placed on waste management, specific phases, and the end-of-life phase of building products (Yu et al., 2022). Other studies (see Abadi et al., 2021) have tried to reorganise the approach to CE by focusing on the life cycle to inform circularity by closing the loop of material and preventing the emergent approach of waste management practised in the construction industry. Nevertheless, the construction industry still suffers fragmentation, and the recent approaches introduced have only increased the industry's complexities. A multifaceted supply chain and more stakeholders are introduced, making the complex system more problematic (Abiodun et al., 2023). Therefore, the attention of research is tilting towards adopting Industry 4.0 (I4.0) technologies, which has been considered a potential solution to the existing problem and a major driver of CE in construction (Elghaish et al., 2022).

Industry 4.0 is expected to speed up CE adoption in CI; however, its influence towards implementation is slow. Research on I4.0 technologies such as Building Information Modelling, Internet of Things, Digital Twin, and Artificial Intelligence have been conducted for environmental impact assessment, waste prediction, management and disposal. Also, the material passport generation and planning for deconstruction have progressed recently, owing to technological advancement (Çetin et al., 2021). However, how the construction companies use these technologies to implement circular economy practices is currently unknown. Moreover, the major barriers limiting technology adoption in the industry have been the lack of knowledge and awareness, disjointed use of technology and a lack of integration (Mark, 2017; Abadi et al., 2023). Focusing on these barriers, we argue that shifting the focus to an organised and integrated use of Industry 4.0 technologies for CE is essential, considering implementation paths and plans for construction companies.

More attention on how the nexus of CE and I4.0 can deliver benefits and how it can be implemented at the company for the ecosystem level is required (Kayikci et al., 2022). It is claimed that CE and I4.0 can help companies remain competitive and accomplish the sustainability dimensions (Kayikci et al., 2022). However, the absence of I4.0 technologies in companies makes it challenging to implement CE (Kayikci et al., 2022). Consequently, Pirola et al. (2019) emphasised the need for a strategic development plan for a consistent adoption of I4.0 technologies. This emphasis is essential at this time in the construction industry since construction companies currently struggle to identify intermediate steps to embrace the change associated with I4.0 (Weking et al., 2020). Therefore, considering the existing problems, creating pathways for integrating I4.0 technologies for circularity in construction stands at the heart of this study, and it is portrayed as Smart Circular Construction (SCC). Hence, we will explore the requirements for institutionalising SCC in construction companies.

Towards institutionalising a smart circular construction: adopting maturity model perspective

The need to limit the wide gap between the research on CE-I4.0 technologies and their implementation in construction companies makes the maturity model (MM) a preferred tool. Adopting a maturity model ensures predictable patterns of how a company evolves and changes to form an anticipated, desired or logical path from an initial stage to maturity (Das et al., 2023). MMs influence better decision-making processes, helping organisations understand their state and requirements to progress in relevant domains (Bertassini et al., 2022). They are either descriptive, prescriptive or comparative models (see Bertassini et al., 2022). A detailed MM comprises (1) maturity levels, (2) a "descriptor" with the name of each level, (3) a general description of each level, (4) dimensions, (5) activities for each dimension and (6) a description of each activity of the maturity level (Caiado et al., 2021). The earliest MM, Capability maturity model (CMM), was developed for the software industries in the early 90s. CMM was followed by CMM integration, which was developed at Carnegie Mellon University. These models have witnessed the proliferation of many other MMs, especially in recent times where the industry and academia are thoroughly engaged in MM development.

Maturity models span across different fields. Most MMs developed within the construction industry have focused on health and safety, productivity, and other management domains. For CE and I4.0, existing papers have mostly been for the manufacturing industries for processes such as business improvement and supply chain management. A limited number of Industry 4.0 MMs for the construction industry are in literature (e.g. Das et al., 2024); however, none is available to assess CE maturity. Moreover, existing Industry 4.0 models focus on the maturity of individual technologies, e.g. BIM (Joblot et al., 2019). Despite the growth witnessed thus far, a model for SCC maturity, i.e. combining CE and Industry 4.0, is absent in the construction literature. Since digital transformation (DX) addresses organisations' digital needs (Haryanti et al., 2023), this study uses DX interchangeably with Industry 4.0 and combines this rationale with CE to chart a direction for SCC maturity models.

In developing a clear understanding of the procedure for maturity model development, most studies (e.g. Das et al. 2023) commenced with identifying the dimensions. The dimensions are sets of practices that, when implemented collectively, contribute to achieving key improvement goals. Hence, this paper aims to conceptualise maturity dimensions for institutionalising SCC practices in construction firms. This will be achieved with two objectives: (1) to identify the dimensions of CE, DX, and CE&DX maturity models beneficial to developing a smart circular construction maturity model for construction firms. (2) to propose a set of conceptual dimensions, through the lens of Porter's value chain model, that are relevant to developing a smart circular construction maturity model.

METHOD

A maturity model must be developed through a systematic procedure to be practical and inform generalisation and standardisation (Caiado et al., 2021). Existing MMs have been developed based on methodologies proposed by de Bruin & Rosemann (2005) and Becker et al. (2009). These procedures have been widely adopted recently, where most of the studies (e.g. Das et al., 2023) have been developed by first comparing existing MMs through a systematic literature review (SLR). Moreover, Porter's value chain depicts a company's organisation function (Sacco et al., 2021) to guide the identification, evaluation and sufficiency of value-adding activities for MM dimensions. Thus, literature can be explored to provide a background for theoretical maturity dimensions relevant to SCC for construction firms, considering the properties and elements of existing CE and Industry 4.0 MMs.

In this study, Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) were adopted and presented in Figure 1. To avoid missing essential studies, the literature search was conducted on two most commonly used databases, Scopus and Web of Science (Montag et al., 2021). For the search keywords, MMs in the construction industry, particularly CE and DX, are nascent; therefore, a broader scope was adopted for CE(C), DX(B) and CE&DX(A) MMs (See Figure 1). These keywords were aligned with those in systematic review studies considering the CE or DX MMs. Nevertheless, to ensure only relevant and reliable articles were retrieved, the excluded papers were not (1) peer-reviewed journal articles, (2) articles containing a proposed MM, and (3) articles written in English language. Further assessment focused on the DX MMs sample since articles in this domain have been enormous recently. Therefore, the only articles retrieved for the DX MMs sample were (1) those specific to or have close proximity to the construction industry, e.g. articles focusing on supply chain, business processes and organisations, (2) articles focusing on digital transformation and not the maturity of individual technology like BIM.

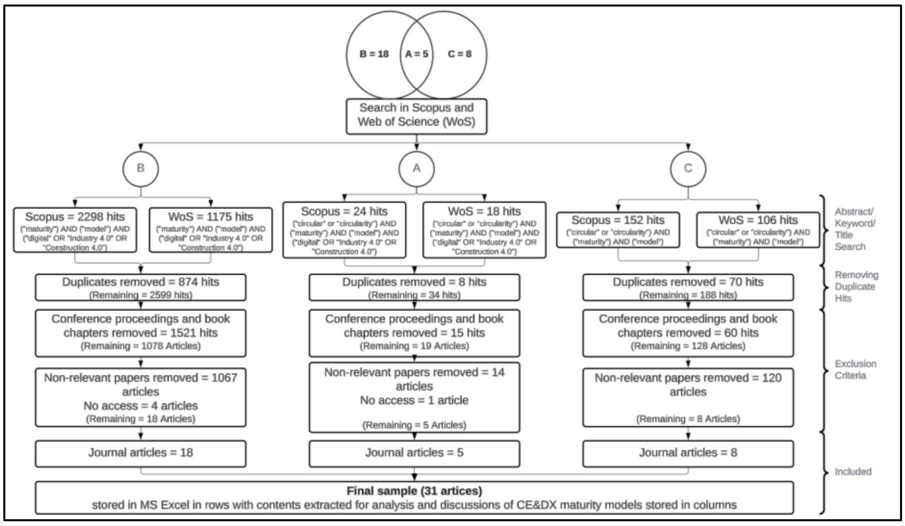

Figure 1: PRISMA flow diagram

After analysing the full text, only 31 articles with explicit comments to DX, CE and DX&CE MMs for SCC purposes were retrieved. The retrieved articles formed the study sample, which was stored in MS Excel and analysed in line with the objectives.

FINDINGS

Description of the sample

Figure 2(a) shows the annual distribution of the selected articles. CE and Industry 4.0 started to gain momentum in 2011 and 2013, respectively. Moreover, Industry 4.0 precedes CE, and I4.0-related MMs began appearing only after 2016 (Das et al., 2023). However, it was not until 2019 that studies with close proximity to the construction industry were sighted in the literature. Industry 4.0 is transforming business processes and organisations exclusive of CE. Moreover, CE and CE&DX MMs are still very limited, and research output has been fluctuating since 2019. This implies that less effort has been channelled towards ingraining CE in organisations.

Figure 3(b) presents the industries where these MMs have been applied. The manufacturing industries are the focus of most CE and DX MMs. The three publications relevant to the construction industry were focused on improving digital transformation, with none available to assess CE. This may imply a limited interest in construction CE. However, a maturity model for the construction industry adopting CE could ease their awareness and understanding, fostering the transition required for a waste inhibit industry such as the construction industry.

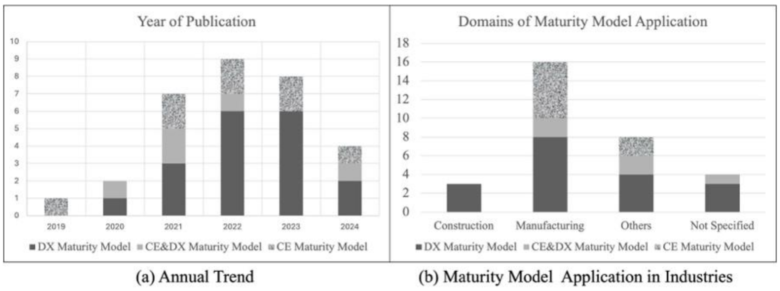

Figure 2: Chronological and industry classification of sample

Themes for SCC dimensions developed from CE, DX and DX&CE maturity models

Figure 3(a) presents 86, 58, and 19 unique dimensions retrieved from literature relevant to DX, CE, and CE&DX maturity models, respectively. However, some dimensions are synonymous, while others engulf multiple dimensions that could be spread across multiple themes. Therefore, the Pareto chart, Figure 3(b) – (3d), shows the 10 themes based on the nuance of the retrieved dimensions and their importance in representing the proposed dimensions for smart circular construction MMs.

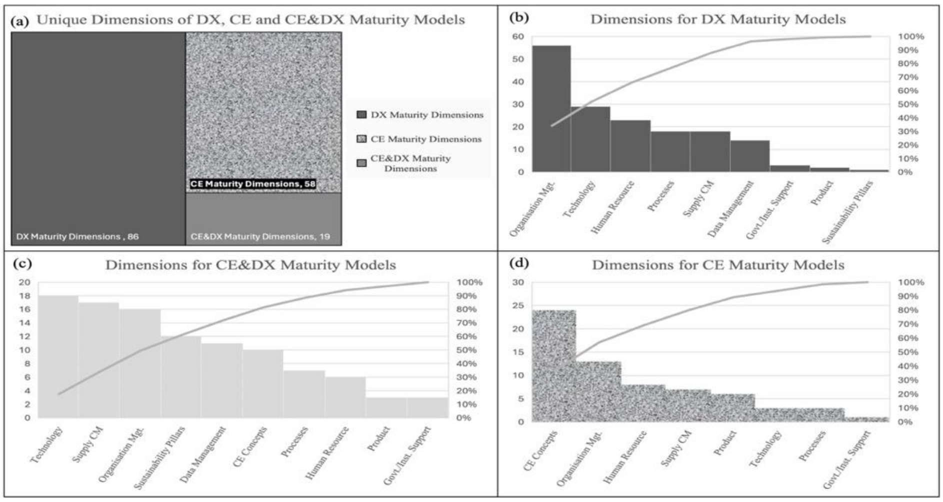

Figure 3: Dimensions of the existing maturity models

The organisation management theme had the highest engagement for the DX maturity model, and it is among the vital few (most impactful themes) for the CE and CE&DX maturity dimensions. The attributes depicting the organisation management theme as a dimension for SCC are mostly motivated by acceptance and implementation by top management (Tubis, 2023). These attributes are threefold. First, organisations should have the right structure, mindset and behaviour. This includes the facilities, capacity, capabilities, vision and knowledge to safely introduce and maintain CE and I4.0 technologies while avoiding their adverse impact on employees. Second, standardised plans for implementing, reacting to, and managing change, risk and eliminating bottlenecks should be ingrained in the system. Third, internal and collaborative dedication of resources and finance is needed to achieve the set organisation strategy. The identified attributes are pillars of an organisation to implement SCC. The results align with Skalli et al. (2023)'s findings from firms acknowledging the importance of organisation management as a top priority in implementing circularity-related concerns.

Dimensions under CE concepts and sustainability themes are intertwined in previous studies. Dimensions under CE concepts were not reflected in DX MMs. However, the sustainability dimension was the least considered dimension for DX MMs. Interestingly, a direct reference to the sustainability dimension was not seen in CE MMs. The dimensions were discussed in line with the culture and requirements of companies' dedication, awareness and compliance with CE practices, legislation and I4.0 investment. Previous studies merged other themes, including organisation management, technology and human resources, under CE concept dimensions (see Kayikci et al., 2022). However, to avoid duplication of attributes, this theme was developed only for CE practices that I4.0 technologies can facilitate. Moreover, how sustainability dimensions are reflected in the practices can be an indicator and not replicated among attributes. Our findings complement Kupilas et al. (2022) by devising ways of ensuring sustainability, a recently included dimension in DX MMs, is not confused as part of CE attributes for SCC MM. However, how CE achieves sustainability pillars should be indicated.

The technology theme is the most significant for the CE&DX MMs. Meanwhile, technology references in CE MMs concern the eco-design of products and facilities for the waste treatment process, not the application of I4.0 technologies. On the one hand, the attributes set for SCC entail digital infrastructure, ecosystem, and capabilities. On the other hand, integration, information system security management, application development, and digital innovation (research and development) are complementary to enable a dependable system. Moreover, the data processing system should be inseparable from the security system (Haryanti et al., 2023). However, security consideration is a recent development in the Construction Industry 4.0 MM (Das et al., 2023).

Although complementary, a distinction should be made between the organisation management, technology, and data management themes. The attributes of the technology themes relate to the tools and systems. Those of the organisation convey the human, procedural, and administrative aspects that allow the organisation to function. On the other hand, data management is the operation segment of technology. Its attributes entail the correct data digitisation, storage, use and sharing. The organisation should collect comprehensive, complete, real-time data related to CE practices and securely transmit and interpret them for decision-making. However, data management is currently lacking in CE MMs, which can evidence the missing significant aspect of MMs for attaining circularity within firms.

The supply chain management (SCM) and human resource themes are more people-related. SCM's attributes strictly ensure the identification and satisfaction of all relevant internal and external stakeholders for data ownership and engagement. The clear statement of obligation and expectation complying with CE & I4.0 requirements. This theme forms a dimension that can enhance a close-loop circular system, and the availability of a market for smart circularity interaction and consideration of customers is key. For the human resource theme, the dimensions retrieved emphasised attributes that were relevant to either opportunities given by the organisation to motivate employees or employee characteristics for smart circular construction. These include the organisation's provision of (1) training, (2) enabling policies to satisfy and encourage participation, and (3) recruitment procedure, talent identification, wages and incentive programs. Also, the employees' (1) experience (2) efficiency and productivity (3) theoretical knowledge and competence (know-how) (4)participation and (5) motivation, attitude and willingness are all important attributes.

The product theme was considered more for CE MMs, while the process was of higher importance in the DX MMs. The need for product dimensions in SCC MM is associated with the components and materials companies employ in construction. It deals with how well circularity innovation is embedded in products while meeting the customer's needs. A smart circular product will possess attributes to ensure that the materials embedded are monitored and can be returned to circulation at a building's end-of-life. The process theme brings a circular view that defies siloed planning and considers lifecycle thinking in delivering the product. The process is, in simple terms, the lifecycle of the product and how circularity is practised. For instance, the automation of the process to reduce waste and error are examples of attributes expected for an SCC process dimension.

Lastly, the government and institutional support theme has not yet been fully incorporated into MMs because organisations cannot directly influence them. However, how organisations benefit from government, legislation, and institutions relevant to CE and I4.0 are important attributes in this dimension. In general, the identified themes are dimensions relevant to SCC MM and their attributes beneficial to construction CE. However, assessing their sufficiency in organisations will provide a more holistic view towards approaching the complete maturity package.

Conceptual dimensions of smart circular construction maturity model

A nuance of the existing MMs has resulted in a holistic set of dimensions that can contribute to achieving maturity in SCC within construction companies. Value-adding dimensions relevant across various sectors are synthesised and streamlined for construction. The identified dimensions were classified using Porter’s value chain model, which has eight dimensions grouped under two categories, namely primary and support activities. Porter’s approach presents a combination of value-adding activities that can inform a company’s holistic transformation process. According to Figure 4, the 10 identified dimensions are basic sets to enable transformation in construction organisations. Developing an MM based on these dimensions can aid the transformation process of the construction industry towards a circular economy.

Without support activities, primary activities can stagnate. From the existing literature, the DX MM tilted more towards support activities, especially in terms of technology and organisation management. These findings align with the claim that technology within organisations is a catalyst for processes, specifically CE (Kayikci et al., 2022; Illankoon & Vithanage, 2023). The CE MMs are much more relevant to primary activities. However, little progress can be made without the organisation's involvement in creating an enabling infrastructure for CE implementation. A glimpse of the potential of transforming organisations is seen in the DX&CE MMs, which have almost an even distribution between support and primary activities. However, these MMs are still budding, with none existing in the construction industry. Interestingly, this review conceptualises dimensions that will be a point of departure for construction CE.

In determining the maturity levels, in the future, the focus should be given more to primary activities such as CE concepts, data management, processes and products to guide the progression to maturity as they are the main domain depicting maturity in an organisation. Although CE MMs are unclear on maturity levels, most previous studies support this study's inference. Hence, our findings can inform a unified level of maturity for CE in organisations. For instance, Hernandes de Paula e Silva et al. (2024) used process, product and life cycle as maturity levels while Montag et al. (2021) considered processes and products among the requirements of determining maturity levels. For Dx and CE&DX MMs, the role of data in digitising towards full optimisation is prominent in the levels depicting the evolution of technology use in existing models (see Senna et al., 2023; Acerbi et al., 2024). Similar to CE models, this is related to the primary activities of Porter's model. Therefore, we argue that levels of maturity set outside of the dimensions within the primary activities in Figure 4 may not accurately depict maturity levels for SCC.

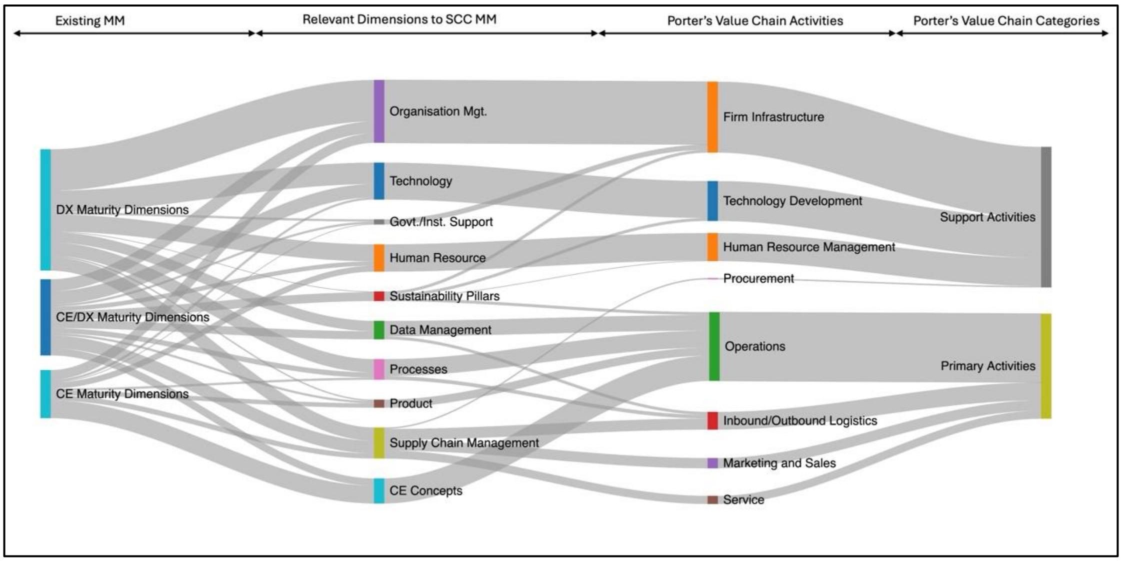

Figure 4: Porter's value chain's classification of the proposed dimensions of SCC MM

CONCLUSIONS

Smart circular construction (SCC) describes the implementation of values that can be achieved through the systemic use of Industry 4.0 technologies for circularity. This study has pioneered the state-of-the-art development of maturity dimensions for transitioning to SCC practices in construction firms. A systematic literature review (SLR) was conducted to explore existing models and conceptualise the maturity dimensions of SCC. Results revealed 86, 58 and 19 dimensions of Industry 4.0/digital transformation (DX), circular economy (CE) and CE&DX maturity models (MMs), respectively. The nuance of these dimensions resulted in ten themes forming maturity dimensions relevant to SCC. Among these dimensions, technology, human resource, organisation management, product, processes, and government/institutional support were shared by most of the existing MMs irrespective of the industry. However, some of the dimensions in the literature implied concepts that are different from the scope of this study. For instance, the technology as Industry 4.0 was not reflected in CE MMs but referred to technology as in product (eco-design) and manufacturing processes. Nevertheless, SCC maturity dimensions were conceptualised, and their attributes were described as applicable to construction. Furthermore, the ten dimensions were relevant to the eight Porter's value chain model activities, implying their sufficiency in depicting value in construction organisations. Also, the requirements for setting maturity levels for SCC MM were inferred. The conceptual dimensions in this paper can potentially transform the construction CE in a systemic way. The dimensions can result in a MM that will motivate external aid from policymakers and other institutions to alleviate hindrances limiting the transition of construction firms to a befitting state of maturity. However, there are limitations to this study. The study is conceptual and based on secondary data, and only the dimensions relevant to SCC MM were identified. The dimensions require mapping onto maturity levels, and empirical verification and validation to obtain a complete MM package. Therefore, future research will verify the proposed set of conceptual dimensions and establish their weighting. This will facilitate the development of a maturity model to assess and inform the transition to SCC in construction firms.

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