A Systematic Literature Review of Enablers and Technologies for Development of Digital Construction Management Capabilities Framework

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Abstract

The study aims to enhance the understanding of how Industry 4.0 enabler technologies can improve construction project management, which has been limited due to the industry's diverse processes. This study utilizes 6Ws' systematic review design and protocol to develop a framework for digital construction management capabilities (DCM-Cs). In this research, a conceptual and systematic phase-wise implementation strategy is suggested to help and encourage the adoption of Industry 4.0 and modern technologies in construction project management. Nine enabler technologies and nine capabilities were integrated to develop nine propositions for project teams to enhance their current capabilities and create a framework for DCM-Cs. Academicians and practitioners in the project management industry have tried to develop their own DCM techniques, which are based on their own goals. As a result, significant future DCM developments demand a separate blueprint for each to optimise their DCM capabilities. Thus, by creating sub-frameworks, the presented implementation framework can be improved to best serve both academics and practitioners. The research provides a phase-wise implementation strategy and framework for DCMCs, integrating nine enabler technologies and capabilities. It enhances the adoption of Industry 4.0 technologies in construction project management and provides insights into how enabler technologies can optimize and improve project management.

Keywords
Industry 4.0; Construction project management; Construction 4.0; Internet of Things; Artificial intelligence.

1. Introduction
Industry 4.0, also known as the fourth industrial revolution, involves digitizing products, processes, and organizations using digital technologies such as artificial intelligence, blockchain, internet of things, robotics, additive manufacturing, and cyber physical systems. Construction project management involves dealing with a wide range of issues, such as cost control, quality control, scheduling, stakeholder management, risk assessment, procurement, scope control, resource management, and communication management (Büyüközkan & Göçer 2018). Hence, is plagued by low productivity due to manual and unique processes. Construction industry is responding to Industry 4.0 by adopting Construction 4.0 (Muñoz-La Rivera et al. 2021), which aims to automate and digitize engineering, procurement, and construction processes to reduce costs, increase worker safety, and improve quality control.

Technologies such as enterprise resource planning (ERP), building information modeling (BIM), AutoCAD, drones, analytics, and cloud solutions are driving the change in the Engineering, Procurement & Construction (EPC) business (Ding et al. 2019). However, the adoption of new digital trends and the level of digitization vary by industrial sector, and the construction industry faces challenges in identifying, appraising, and selecting digital technology due to one-off designs and unique projects. The implementation of digital technologies in the construction industry is viewed as an enabler towards enhancing productivity, and governments of several countries are promoting the use of Industry 4.0 technologies in the construction sector. The sector recognizes the significance of the digitalization trend, but implementation is hindered by a lack of a robust framework. Some works have tried to propose framework for Construction 4.0 from methodological-technological standpoint (Muñoz-La Rivera et al. 2021) while others are only limited to bibliometric reviews (Forcael et al. 2020); (Zabidin et al. 2020) or focus only on developing the subset of construction capabilities with Industry 4.0.

A capability or value driver is what adds worth to a product or service by increasing profitability, reducing risk, increasing stakeholder value, increasing competitive edge and customer appeal. Since, there does not exist any framework in the literature which combines all possible project related capabilities into one comprehensive phase wise implementation plan. By examining the relevant literature, this study tries to close that gap and develop a Digital Construction project Management capabilities (DCM-C) framework. First, the capabilities of construction project management should be clearly identified so that, digital technologies can be leveraged to improve them. Then, a systematic phase-wise implementation framework should be developed so that the project teams can use it as a basis to develop their capabilities accordingly.

1.1 Objectives

To develop this novel framework, we integrate all we've gathered from the literature review in the next section. The following research questions can help to attain the goal of developing the DCM-C framework:
RQ 1: What are the basic capabilities of a digital construction management?
RQ 2: Which key enabler technologies are used in Digital Construction Management?
RQ 3: What are the barriers for adoption of enabler technologies of the basic capabilities?
RQ 4: Is there any conceptual framework that can be implemented by project teams to develop their digital construction management capabilities phase-wise?

The developed DCM-C framework clearly describes the construction project management capabilities and discusses how the enabler digital technologies can be leveraged to improve each of the capability's performance output. In section 2 of this paper, the research methodology & review protocol has been discussed which explains the article screening procedure. Section 3 analyses the literature from the point of view of digital construction management and highlights the basic capabilities & enabler technologies used. Section 4 highlights the barriers to adoption of the enabler technologies. Implementation plan of the DCM-C framework has been discussed in the section 5 of this article. Theoretical & practical implications of the DCM-C framework have been highlighted in section 6. Section 7 & 8 provides future research direction & conclusion respectively.

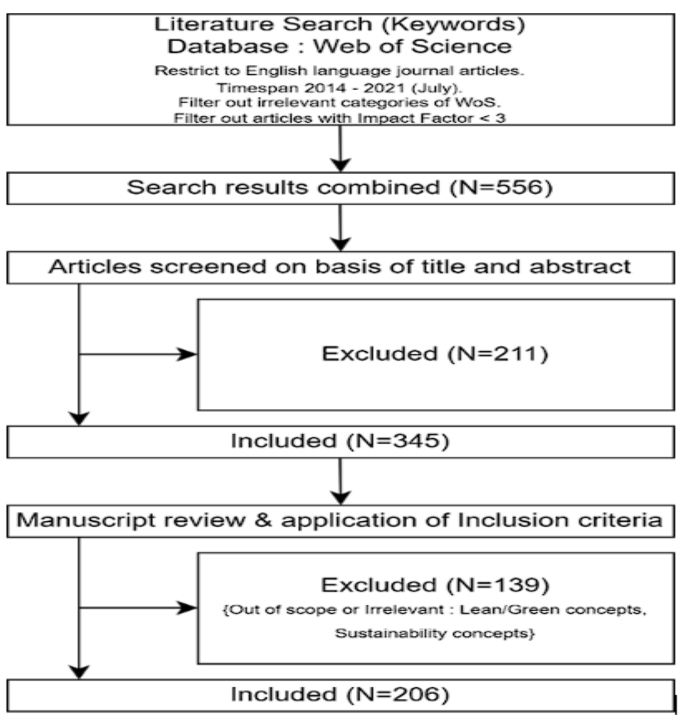

Figure 1- Article screening process

2. Methodology

2.1 Review design

The procedure of researching, reviewing and summarizing the most conspicuous concerns explored in the subject in order to provide synthesis, trends, and direction, along with developing new conceptual models, is referred to as a literature review. A good literature review should be "concise, clear, critical, convincing, and contributive". By combining existing research, summarizing earlier contributions, identifying knowledge gaps, and building novel frameworks, a systematic review provides multiple critical perspectives on a specific research subject. This paper follows a 6Ws systematic review protocol (Xie et al. 2017).

2.2 Review protocol: 6Ws

The concept of DCM or Construction 4.0 is still very diffuse and in the early stages of development with limited number of review papers available and even fewer systematic review papers. As a result, our methodology for conducting a literature review follows "6Ws – Who, When, Where, HoW, What, and Why".

I. "Who"

This research forms part of the author's doctoral study. The researchers (author and co-author) gathered hundreds of academic articles from prestigious publishers like Elsevier, Taylor & Francis, John Wiley etc on Web of Science (WoS) database. Thus, the author and co-author were in charge of the article search.

II. "When"

The researchers collected several articles, starting from the year 2014 to July 2021 (Table 1). The timespan starts from the year 2014 (Manzoor et al. 2021), as the major publication work relating Industry 4.0 and construction management started from 2014 onwards (Zabidin et al. 2020). After July 2021, the researchers started analyzing and summarizing the collected articles as per the review procedure elaborated further.

III. "Where"

Journal articles are highly acknowledged in engineering, sciences, social sciences and management, as compared to conference proceedings and books. It is because many respectable journals (SSCI, SCI-EXPANDED, A and HCI) use a double-blind review procedure, require multiple revisions, and take an average of one year to reach a final conclusion. The acceptance rate is significantly lower than that of other indexing journals (e.g., Scopus). Clarivate analytics retrieved data from Web of Science core collection platform, the world's premier database for published articles and citations, in order to obtain information relevant to this study. It includes articles published in prestigious journals. The same keyword search string when entered in the Scopus database, showed 500 Internal server errors, because of the fact that Scopus indexes more journals than WoS. So, the authors used WoS database only, for this literature review. Only journal publications were considered in our review of the literature, which are published in English language.

IV. "How"

Unlike other review studies that have already been published in the literature, we followed 6W review protocol for selecting and summarizing the journal articles. Following list of keywords were used for advanced searching on WoS database.

Table 1. Keyword search results from WoS

Search no.	No. of articles	Keywords & filters used by the author on Web of Science
# 1	258,892	(TS=("industry 4.0"OR"construction 4.0"OR"digital construction"OR"building information model*"OR"PMIS"or"Project Management Information System"or"internet of things"or"IoT"OR"wearable*"OR"blockchain"OR"artificial intelligence"OR"automation"OR"machine learning"OR"analytics"OR"big data"OR"3D printing"OR"additive manufacturing"OR"system integration"OR"augmented reality"OR"cloud computing"OR"cybersecurity"OR"digital twin"or"UAV*"or"Unmanned Aerial Vehicle"or"Drone*"or"Sensor Technology"or"radio frequency identification"or"RFID"or("simulation"and"industry 4.0"))) AND LANGUAGE:(English) AND DOCUMENT TYPES:(Article)

		Indexes=SCI-EXPANDED, SSCI, A&HCI Timespan=2014-2021
# 2	9,929	(TS=("project management"OR"construction project*"or"construction management"OR"project life cycle"OR"project stage*"or"project integration"or"project scope"or"project schedule"or"project cost*"or"project quality"or"project resource*"or"project communication*"or"project risk*"or"project procurement"or"project stakeholder*"or"project initiation"or"project plan*"or"project execut*"or"project monitor*"or"project control*"or"project clos*"or"project commission*"))AND LANGUAGE:(English)AND DOCUMENT TYPES:(Article) Indexes=SCI-EXPANDED, SSCI, A&HCI Timespan=2014-2021
# 3	977	(#1 AND #2)AND LANGUAGE:(English)AND DOCUMENT TYPES:(Article) Indexes=SCI-EXPANDED, SSCI, A&HCI Timespan=2014-2021

V. "What"

We first included all articles published on this topic from WoS database which resulted in 977 articles (Table 1). Given the sheer number of research papers published on this topic, it is incredibly difficult to include all of them in this review article. First refinement criterion was to include articles of relevant categories of WoS, which reduced the search to 902 articles. Second refinement criterion was to exclude all source titles with Impact factor<3 to maintain the quality of this review article. This further narrowed down the number of articles to 574. For the third step, irrelevant research areas were excluded and details of thus finalized 556 articles were downloaded for further review and scrutiny.

VI. "Why (final selection criteria)"

One of the most important aspects of a good integrative review is article selection. All the 556 articles downloaded were screened based on reading title, abstract and conclusion for their relevance to the review topic. Some articles were outright irrelevant, while others were out of the scope (lean, green, sustainability concepts) of this review paper as depicted in Fig. 1. After applying these criteria, only 206 articles were left for in-depth study. Relevant information was extracted from these 206 articles as per the Research Questions. The DCM-C framework has been developed by the inputs gathered from these 206 articles.

3. Literature Review

3.1 Industry 4.0

Industry 4.0 involves advanced technologies such as BIM, IoT, Blockchain, AI, and big data analytics. It enables machines and objects to interact autonomously, impacting traditional project management processes and driving the shift towards digital project management. To achieve better project management performance, organizations must develop basic capabilities while considering the digitalization of these technologies. Resources and capabilities impact an organization's strategy, and decision-makers and enterprises must develop a comprehensive understanding of project management capabilities. However, without a framework, the construction project management industry is unaware of how to develop and manage capabilities critical to performance improvement in digital project management (Queiroz et al. 2019).

3.2 Digitization vs Digitalization

In the literature, there is still a lack of awareness about digitalization. The distinction between the phrases digitization and digitalization is sometimes misunderstood. According to (Legner et al. 2017), the process of transforming analogue signals (physical activity) into a digital model is known as digitization, whereas digitalization relates to the effect of these technologies on organizational and social viewpoints as a consequence of its implementation. Combining digital initiatives with project management goals and using a digital approach to unleash the potential of available resources and capabilities, resulting in increased performance, is what digitalization means.

3.3 Digital Construction Project Management (DCM)

The DCM concept is still developing. DCM integrates BIM and other industry 4.0 technologies to improve information utilization during different phases of a project (Ding et al. 2019). Companies of all sizes, whether small or large, must consider creating some form of digital organization capability. The DCM is critical to the long-term growth and performance of multinational enterprises.

Project managers in the construction industry must be informed about their digitization plans and concentrate on strengthening the digitalization capabilities of the projects they are working on. It is critical not just to survive but also to capitalize from the digitalization megatrend.

With the growth of new technology, a new term known as Construction 4.0 has been introduced, which was originally articulated in Germany in 2016 (Forcael et al.2020). The foundations of Construction 4.0 are two: digitalization of the construction sector and modernization of the construction process. Despite the numerous definitions and absence of a single standard, there appears to be agreement that Construction 4.0 refers to “the application of Industry 4.0 to the construction industry”, or construction digitalization in broad terms (Muñoz-La Rivera et al. 2021). (Craveiro et al. 219) examines the construction industry's digital transition, focusing on the prospects of 3D printing for construction activities as a crucial Construction 4.0 enabler technology. The focus of this paper is not on proposing the definition for Construction 4.0. From the literature, the authors can conclude that Construction 4.0 is synonymous to DCM, since both talk about implementation of Industry 4.0 technologies to Construction project management industry.

3.4 Defining Basic Capabilities and Derived Propositions

Table 2 summarizes the findings and contributions from the literature and categorizes them into 9 identified basic capabilities. It also highlights the key enabler technologies explored within each of the capabilities. Propositions are then derived based on the explanation of each capability. A theoretical DCM-C framework with key enabler technologies as pillars and basic capabilities as improvement levers is proposed in fig 2.

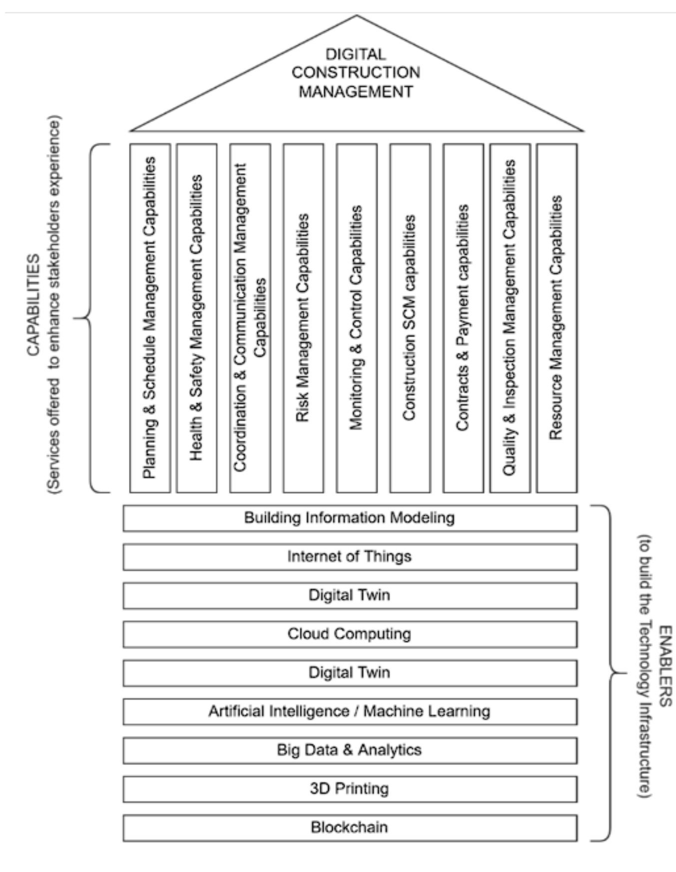

Figure 2: Theoretical DCM-C framework

Table 2. Capabilities, findings and propositions

Basic capabilities	**Findings and contributions from the literature about the Basic Capabilities**	**Enabler**	**Explanation of the Basic capabilities**	**Proposition**
Quality & Inspection management capabilities (Q&I)	Laser scanning and BIM enable non-contact quality assurance for precast concrete & machine learning detects faults in digitized masonry (M. K. Kim et al., 2016). Digital twin allows automatic comparison of 3D as-built and as-designed models in prefabricated construction (Tran et al., 2021). Hybrid ML strategy for defect management using association rule mining & Bayesian network (Fan, 2020). Utilizing BIM, AR technologies and image-matching techniques to prevent reinforcement concrete work defects proactively (Kwon et al., 2014).	BIM IoT ML AR DT	Frequent defects cause cost overrun and time delay in construction projects. Relying solely on human inspection is often problematic for site managers, resulting in skipped inspections, poor quality workmanship, and rework. Industry 4.0 Enabler technologies will improve quality and inspection management by allowing remote inspection through sensors, reducing rework expenses and saving time and costs on construction sites.	Digital technologies have a positive influence on Quality & Inspection Management capabilities, resulting in better project performance.
Contracts & payments management (C&P)	Smart contracts automate secure payments by comparing BIM model to as-built (Chong & Diamantopoulos, 2020). A contractor pre-qualification method based on multiagent systems combines fuzzy and crisp big data for decision-making (Kog & Yaman, 2016). Automating subcontract scope extraction with machine learning and NLP can save contractors time and increase accuracy, compared to manual drafting (Hassan & Le, 2021).	BIM AI BDA ML BC	Contractor selection (a multi-criteria problem) and timely payment of project participants are essential to the completion of construction projects successfully, yet the industry suffers from inadequate contractor evaluation procedures and payment practices around the world. In DCM era, this capability may be improved by adopting various AI techniques and Blockchain.	Digital technologies have a positive influence on contracts & payment Management capabilities, resulting in better project performance.
Construction SCM capabilities (CSCM)	RFID improves supply chain efficiency and provides IoT enabled real-time information and item-level identification, resulting in cost savings, shorter lead times lowering paper work and WIP inventory (Wang et al., 2017). SmartSite: multi-agent system using AI and decision theory for real-time automated information sharing in supply chain (Kuenzel et al., 2016). New BIM plugin allows material comparison from multiple sources in supply chain management (Chen & Nguyen, 2019).	IoT ML AI CC	Construction supply chain management in the DCM era includes data-driven cost management, cost estimation and control, supplier evaluations, and material planning, improving efficiency, reducing costs, and lead time. It strengthens stakeholder relationships (Muñoz-La Rivera et al., 2021).	Digital technologies have a positive influence on Construction SCM capabilities, resulting in better project performance.
Monitoring & control capabilities (M&C)	Computer vision & audio-based field monitoring document progress, while low-cost 3D scanners compare as-built to BIM models (Golparvar-Fard et al., 2015)(Asadi et al., 2019) (S. Kim et al., 2020) (J. Yang et al., 2015) (L. Yang et al., 2020). The authors developed model for automatic schedule updating using digital twin technology and IoT sensors (Son et al., 2017) (Lee et al., 2021).	IoT BIM ML DT	Construction management monitoring is still done manually and in person, resulting in unnecessary costs. However, there are ways to automate these operations (Pučko et al., 2018) thereby saving time, money & effort resulting in efficient project control.	Digital technologies have a positive influence on Monitoring & control capabilities, resulting in better project performance.
Risk management	The research highlights that BIM supports project life cycle with simulation, 3D visualization, collision detection, and risk management (Zou et al., 2016).	BIM AI ML	Effective risk management is crucial in all stages of a project's lifecycle, as different risks can occur, potentially	Digital technologies have a positive

Basic capabilities	**Findings and contributions from the literature about the Basic Capabilities**	**Enabler**	**Explanation of the Basic capabilities**	**Proposition**
capabilities (RM)	Developed hybrid model predicts project delays using big data analytics & RF-GA techniques (Owolabi et al., 2020).	BDA	compromising the entire project. Accurately predicting and managing risk, such as structural damage, injury, budget overruns, and schedule delays, can enable proactive strategies and ensure successful, safe, and sustainable projects.	influence on risk management capabilities, resulting in better project performance.
Health & Safety management capabilities (H&S)	Using UAVs for safety inspection and visualization of unsafe conditions on jobsites (Melo et al., 2017). Smartphones and motion sensors are used to detect worker activity automatically on construction sites (Akhavian & Behzadan, 2016). A mobile Augmented Reality system facilitated by robots, is created for safety monitoring (Xiang et al., 2021). BIM, remote sensing, and GPS loggers improve construction safety by visualizing workspaces and tracking worker movements (Zhang et al., 2015). Stochastic model & AI predict construction accidents from historical and real-time data (Li et al., 2016). Developed deep learning system to classify near-miss data in safety reports (Fang et al., 2020). A BIM user interface for near-miss visualisation that enables for the detection of hazardous locations and the frequency of near misses (Shen et al., 2015). Develop automatic safety facility planning with BIM and add-in algorithm, monitor workers using Cloud-Enabled RFID and BIM (Pham et al., 2020).	IoT ML AR VR CC BDA	Construction safety is crucial due to high fatality rates and economic loss. Technology, like automated worker action recognition, enables efficient management of health, safety, and productivity. Industry 4.0 technologies can aid in safety planning using historical records and arranging training sessions.	Digital technologies have a positive influence on health & safety management capabilities, resulting in better project performance.
Collaboration & Coordination management capabilities (C&C)	Study proposes a web-based EVM system for expense tracking by project team members (Elghaish et al., 2019). Developed mobile AR systems using cloud computing to offer 3D field reporting and on-demand access to project information (Bae et al., 2015). Research develops BIM Table for interdisciplinary collaboration and AR-enabled mobile devices for private information (Lin et al., 2014). CoVR is a cloud-based VR solution for collaborative project collaboration (Du et al., 2018).	BIM CC IoT AR VR ML BDA	Collaborative management in the DCM era involves active involvement of all project members and using digital technologies to promote transparency and real-time access to project information. This helps in early identification of potential problems, accurate predictions, and improving planning to optimize construction operations efficiently through data sharing.	Utilizing digital technologies have a positive influence on Collaboration & coordination capabilities and hence improve project's performance.
Planning & Schedule management capabilities (P&S)	ANN-based interval forecasting method to predict the material price in a project (Mir et al., 2021). Mobile ICT helps in Improved Work Planning by accessing weekly/daily/hourly data (Hasan et al., 2019). Integration of PERT/CPM, DES, and BIM to reduce uncertainties and optimize project planning (M. Y. Cheng & Chang, 2019). The NN-LSTM model is used to estimate the completion timeline for construction projects based on the determinants of project duration (M.-Y. Cheng et al., 2019).	ML AI IoT	DCM will enhance the P&S capability by developing optimal project schedule & facilitating accurate planning of the time, cost, risk performance of projects thereby enhancing project's operational performance, workflow efficiency, minimizing safety risks, reducing manual work and facilitating informed decision-making (Mahdavian et al., 2021).	Utilizing digital technologies have a positive influence on Planning & Schedule management capabilities and hence improve

Basic capabilities	**Findings and contributions from the literature about the Basic Capabilities**	**Enabler**	**Explanation of the Basic capabilities**	**Proposition**
				project's performance.
Resource management capabilities (ReM)	The authors propose an audio-based Bayesian system to process recorded audio files at construction jobsites to extract useful information (Sabillon et al., 2020).	ML IoT BIM AI	DCM framework helps in developing an automated activity recognition system using DCM to monitor, track and predict project resources (labor, tools, equipment, materials) can improve productivity, efficiency, safety, and sustainability of construction projects (Mansuri et al., 2017).	Utilizing digital technologies have a positive influence on Resource management capabilities and hence improve project's performance.
	Machine learning predicts equipment motion, while sensors monitor machinery condition, such as oil pollution, emissions, and vibrations (Jiang & He, 2020).			
	Cameras monitor site resources; ML recognizes activities; Reinforcement learning controls machinery (J. Yang et al., 2016) (Lee & Kim, 2021).			
	Radio Frequency Identification (RFID) and other automated locating technologies have shown to be useful in tracking various construction site objects (Cai et al., 2014).			

3.5 Defining Enabler Technologies

Table 3 summarizes the enabler technologies industry identified from the literature and their description in construction industry.

Table 3. Enabler technologies & their description as used in construction industry

Sl. No.	**Enabler Technologies**	**Description of the Enabler Technologies as used in construction industry**
1	BIM	Collaborative workflow for construction project planning, design, construction, and operation management using parametric digital modeling and interconnecting with other technologies.(Muñoz-La Rivera et al., 2021).
2	Internet of Things (IoT)	Connects physical devices with digital BIM models for on-site monitoring and control of materials, equipment, workers, and logistics. (Büyüközkan & Göçer, 2018).
3	Digital Twin	Virtual representations of physical entities that engage in simulation disciplines by synchronizing virtual and physical systems for preventive and predictive maintenance(Jamwal et al., 2021) (Lee et al., 2021).
4	AR/VR	AR adds computer-generated information to the real world while VR creates realistic-looking surroundings (Büyüközkan & Göçer, 2018). Both are useful for visualizing and interacting with BIM models on construction sites, reducing rework, improving safety, and ensuring deadlines are met(Alizadehsalehi et al., 2020).
5	Big Data & Analytics (BDA)	Big data involves processing difficult-to-handle data sets, and analytics uncover patterns and correlations to aid decision-making. BDA assists the construction industry in cost management, SCM, knowledge discovery, risk and safety prediction (Jamwal et al., 2021) (Muñoz-La Rivera et al., 2021).
6	ML & AI	"AI is the ability of systems to solve problems using intelligent behavior" (Muñoz-La Rivera et al., 2021). ML is an AI discipline that predicts behavior using existing data. It automates design features and assists in decision-making during construction for logistics, safety and processes.
7	3D printing	3D printing is a process of creating 3D objects by superimposing thin layers of material. This technology has the potential to revolutionize the construction industry by reducing waste, automating the construction process, and offering more flexibility in reinforced concrete design (Mechtcherine et al., 2019).
8	Cloud computing (CC)	Enables data sharing across organizational boundaries, aiding communication, work relationship, and information management on-site. Features include mobile and web access, BIM integration, document management, scheduling, and financial management (Hasan et al., 2019) (Chong et al., 2014).

Sl. No.	Enabler Technologies	Description of the Enabler Technologies as used in construction industry
9	Blockchain	Decentralized public ledger recording verified digital data events and transactions carried out or communicated among network participants, offering new ways to handle sustainability issues, system security, and efficiency (Jamwal et al., 2021).

4. Barriers to Adoption of Enablers to the Capabilities

The article analyzes potential barriers to implementing Industry 4.0 technologies in construction projects, identifying 8 key challenges based on existing research as described in Table 4. This information can help practitioners and policymakers better understand the adoption process and constraints.

Table 4. Barriers to adoption of enablers to the capabilities

Sl No.	Barrier Category	Barrier explanation
1	High Investment in Industry 4.0 Implementation	The upfront cost of implementing digital technologies, such as AR/VR and other hardware & softwares, is a challenge for SMEs (Alizadehsalehi et al., 2020). Vendors could modify pricing strategies to attract contractors by offering subscription-based models.
2	Interoperability issues/ Lack of Standards & Regulations	Poor interoperability between different digital data sources causes communication problems and poor information management. Lack of standardization and a robust framework at an industrial level contributes to such issues (Petri et al., 2017).
3	Risk of Security Breaches	Security breaches (Chong & Diamantopoulos, 2020) and data leakage are major concerns in digital construction management. A comprehensive cyber-physical security framework is needed to integrate value-creation networks.
4	Low Maturity Level of Preferred Technology	Most developing technologies are still in early ideation or prototyping stages, requiring testing and improved accuracy and reliability. Digital maturity models should be adopted for growth (Mechtcherine et al., 2019).
5	Lack of Digital Skills	The complexity of advanced optimization models requires significant training. Existing project teams lack the necessary skills, and personnel training is essential.
6	Difficulties in Ensuring Data Quality	Ensuring data consistency, accuracy, completeness, and integrity is a challenge, particularly with heterogeneous and complex data in the era of big data. A project management platform should be developed to ensure data quality.
7	Resistance to Change	Employees' resistance to accepting digital technologies can hinder DCM implementation. Creating a supportive environment and fostering trust-based collaboration is essential, and the leadership team plays a critical role in this process (Liao & Ai Lin Teo, 2018).
8	Legal & ethical Issues	Possible legal problems may arise regarding data copyrights, civil aviation regulations, privacy concerns, and payment disagreements. Developing policies/standards/protocols could tackle these issues (Ahmadisheykhsarmast & Sonmez, 2020).

5. Conceptual DCM-C Framework or Implementation Plan

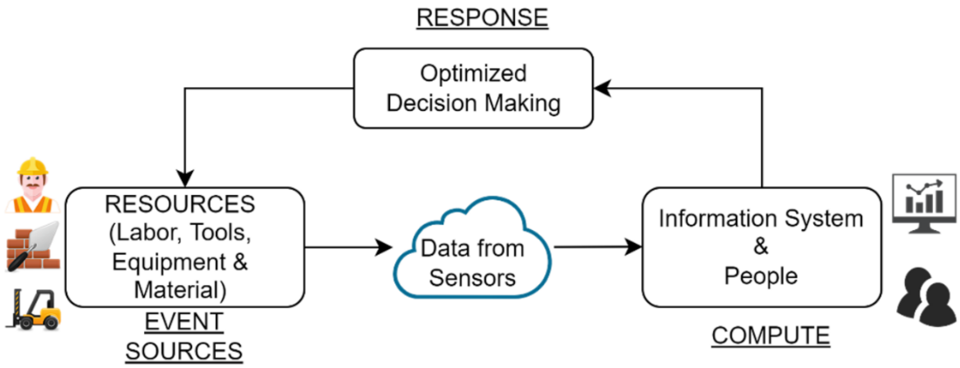

Figure 3: Smart Construction Management: End to End

This paper proposes a framework for Digital Construction Management capabilities based on a literature review. The framework identifies and develops basic digital capabilities of construction project management, represented in Fig. 4. Since, a capability is what adds worth to a product or service, this framework first identifies, then develops the basic digital capabilities of construction project management for a better and more efficient construction project management It can serve as a starting point for firms looking to implement Industry 4.0 technologies phase-wise for smart construction management, integrating key enabler technologies with identified capabilities.

The main intention of the DCM-C framework is to familiarize the users with probable configurations and interconnections to the emerging digital construction in Industry 4.0. The generalized phases of a smart end to end digital construction management comprises of data collection from various event sources, performing computations and analysis on the data, optimum decision making as shown in fig. 3.

The enabler technologies have also been categorized into phases of Data generation, Analysis & Decision making in the DCM-C conceptual framework. However, they can be used interchangeably and most of the times have to be used together to achieve end to end smart construction management. Each basic capability is further decomposed into simpler & actionable activities/services which are needed to be performed in order to make digital construction management a reality and execute projects with improved project performance resulting in better stakeholder satisfaction.

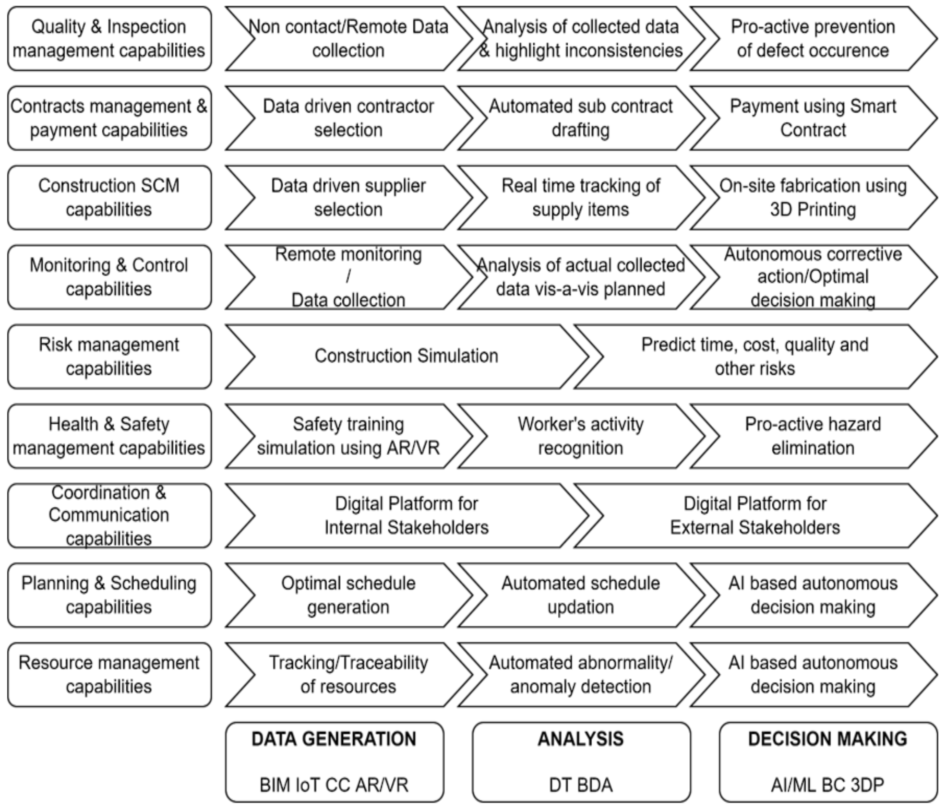

Figure 4: Conceptual DCM-C Framework or Implementation Plan

For improving Q&I capabilities, data regarding quality parameters of the project needs to be collected during different phases of a project in digital format and analysis should be done on the collected data to promote timely decision making. The data hence generated should be used for prediction & pro-active Q&I management. The C&P capabilities starts with data driven contractor & sub-contractor selection while also supporting digital payment using smart contracts which can execute payments automatically depending on the project's progress calculated by M&C capabilities. The CSCM capabilities include data driven supplier selection, real time tracking of supply items using IoT devices for further analysis and decision making.

It also includes fabrication of items on site by means of additive manufacturing, if needed. The M&C capabilities act as a support to other capabilities & offer remote data collection, analysis & decision making for progress monitoring & other purposes. The RM capabilities include performing construction simulation to identify risks and using AI/ML techniques to predict time, cost, quality performance of a project and take corrective actions to mitigate risks. H&S capabilities includes safety training using AR/VR, worker's activity recognition on site and using the collected data for pro-active hazard elimination. C&C capabilities focuses on developing a digital platform for internal and external stakeholders and hence allows all other capabilities to interact with each other seamlessly. P&S capabilities deal with planning of activities for all other capabilities & hence optimal schedule generation. It also includes automated schedule updating based on M&C capabilities and reports delay reasons so that corrective actions can be taken. ReM capabilities are associated with managing & optimizing performance of resources for other capabilities.

6. Theoretical & Practical Implications

Our work has theoretical implications for academics concerned with digitalizing the construction industry. We contribute a plausible perspective for transforming the capabilities in construction project management through the concept and framework for DCM-Cs, as well as their enablers. Our paper provides a basis for incorporating cutting-edge digital technologies and offers scholars and practitioners opportunities to experimentally test the framework's 9 propositions in a range of scenarios. The DCM-C framework can serve as a starting point for academics interested in extending the DCM-C literature. This is, as far as we know, the first attempt to formalize the DCM-C concept.

The DCM-C framework offers practical insights for decision-makers, identifying nine fundamental DCM capabilities and nine enabler technologies that interact with and facilitate these capabilities. The framework's implementation plan can be tailored to the needs of organizations, providing real-world applications for practitioners. However, decision-makers and practitioners must consider organizational culture when transitioning to a digitalized business model. The proposed framework is a useful tool for developing construction management digitalization strategies and generating insights. The DCM framework must interact with the organization's network to be successful, and project managers must consider the costs and risks of a digitalization project. Overall, the DCM-C framework serves as a starting point for practitioners working on construction digitalization projects.

7.Conclusion

This article reviews and summarizes previous research on digital construction management (DCM) and develops a comprehensive conceptual framework that defines DCM's features, components, technology enablers, difficulties, and success factors. The framework aims to help practitioners apply DCM more effectively and provides perspectives and insights for applying digitalization concepts to construction projects. Project managers should increasingly utilize industry 4.0 technologies to drive efficiency and effectiveness in construction projects.

Future Research & Limitations

Prospective DCM research trends listed below, derived from comprehensive literature review and professional experience, suggest further study in these areas for new knowledge and theories

- Further research on inclusion of sustainability and lean concepts in DCM-C framework.
- Thorough testing of the proposed DCM-C framework for real-world industrial applications.
- Customization of DCM frameworks by creating sub-frameworks for each EPC company's goals and needs.

The barriers in adopting Industry 4.0 technologies have been discussed at length in this literature and the future studies should attempt to solve the issues described. This article, however, has its own limitations. These potential limitations are summarised in the sections below:

- WoS articles with impact factor>3 were reviewed. Other databases can be considered for future research.
- Keyword-based search may have excluded relevant studies with different keywords.
- DCM-C framework integrates digitalization, industry 4.0 tech, and project management. Sustainability and lean concepts are not included in this study.

Considering the limitations, DCM is still a long way from realizing its complete potential, and as this study demonstrates, there are a lot of difficulties that must be addressed promptly.

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