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Building a data-driven future for construction team? Capabilities matter

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Abstract
Emerging technologies in the construction industry are generating an astounding amount of data, pointing to an optimistic digital future with data analytics. Despite the potential benefits, many big data projects fail to deliver value. Talent and skill shortages are significant challenges in the journey to become data-driven. Construction project managers (CPMs) play the lead role in creating innovative ways for successful project delivery. Therefore, this study seeks to understand the capabilities of a CPM that are important for developing a data-driven team in which the potential of data is highly valued and leveraged to enhance project efficiency.

Through a literature review, the opportunities and challenges of data usage in construction project teams were identified. Questionnaire surveys were distributed to collect information on the data awareness and usage in the project teams and how the CPMs evaluated their peers demonstrating data-oriented capabilities. The Mann–Whitney, Kruskal–Wallis non-parametric tests and Pearson correlations were used for data analytics. The top three CPMs capabilities which were strongly correlated to project team data usage are: (1) Ensure basic tasks to be completed proficiently; (2) Keep a problem-solving mind-set; and (3) Maintain a high ethical standard when capturing and using data. This study supports CPMs and maps the skills and training required for the future-oriented CPMs as they respond to the digital challenge in the construction industry. Outputs of this research that develops future capability in the digital age will support the construction industry in a journey towards a safer, more productive and sustainable future.

Keywords
Construction industry, construction project manager (CPM), data-driven capability, use of data.

1 Introduction

As the unprecedented COVID-19 pandemic upended global societies, a silver lining was found amid the crisis. COVID-19 crisis significantly accelerated the shift to digital and fundamentally changed the business landscape (Fitzpatrick et al. 2020). Organisations, then, must rethink how technology can enable virtual work, support the workforce, and be integrated as competitive differentiator. New technologies are generating ever-increasing amounts of data and a data science industry has grown rapidly. The construction industry is no exception with huge amounts of data generated throughout the life cycle of a construction project (Bello et al. 2021; Opoku et al. 2021). The scale of data generated in various construction phases provides great potential with studies showing that the use of data-driven project management platform could reduce project cost by estimated 18%, and cut the completion time by up to 12 weeks (Hisham, 2018; Opoku et al. 2021).

Despite the opportunities and benefits of delivering value through data for business insights, there are challenges in this adventure to the data-oriented future for the construction industry. In the recent review study, Yan et al. (2020) claimed that data security was one main concern for data usage yet insufficient attentions were paid to address this issue. Yu et al. (2016) raised the challenges of poor data quality due to the lack of adequate equipment on site. Other challenges that were mentioned in previous studies, include regulatory challenges, additional cost, lack of awareness, technical difficulties, etc. (Hwang et al. 2022; Ibrahim et al. 2021). Among all the challenges for data usage in the construction industry, talent and skill shortages can be formidable hurdles in this data-oriented journey. The construction industry needs digital leaders to develop a data culture, manage dynamic relationships with multiple stakeholders, and to focus on enabling collaborative processes in complex settings (Danneels et al. 2021). It has been suggested by many digital transformation guides that digital leaders should have the agility to drive top to bottom organizational transformation with advanced data analytics technologies in times of uncertainty (De Araujo et al. 2021; Koeleman et al. 2020; Evans-Greenwood et al. 2019). Despite the importance and urgency, the skill requirements for construction leaders in the digital era are not clear.

Construction project manager (CPM) plays an irreplaceable role in ensuring successful project delivery (Khamaksorn, 2016). Duties of CPM cover a range of activities from determining the work scope, allocating resources, quality and safety assessment to connecting multiple stakeholders and building team morale (Alvarenga et al. 2019). A positive link was found between the level of CPM competency and overall team performance (Dziekoński, 2017; Ribeiro et al. 2021). Alvarenga et al. (2019) proposed seven categories of CPM's core competencies in improving project performance: leadership, self-management, interpersonal, communication, technical, productivity and managerial. As the existing studies mostly focused on the general competencies of CPMs in achieving project success. It remains unclear what are the specific capabilities of future-oriented CPM in improving the efficiency of leveraging data in project teams. Therefore, this study aims to address this gap by investigating the capabilities of data-driven CPMs as they respond to the digital challenge in the construction industry.

This study is reported in the following sections. Through a literature review, the opportunities and challenges of data usage in construction project as well as capabilities of a future-oriented CPM were identified. A questionnaire survey was distributed to 374 CPMs in China to collect information on the current use of data in their project teams and the extent of their peer CPMs demonstrating data-driven capabilities. It was found that CPMs data-driven capabilities were linked to the efficiency of data usage in the project teams. The study sheds light on steps for developing next-generation workforce capabilities in the digital age. Outputs of this research that develops future capability in the digital age will support the construction industry in a journey towards a safer, more productive and sustainable future.

2 Literature Review

2.1 Current Use of Data in the Construction Industry

Emerging technology trends, such as cloud computing, smart building technology, augmented reality (AR) have trigged and enabled the generation and analytics of extensive amount of data in the construction industry (Bello et al. 2021; Hwang et al. 2022). Ismail et al. (2018) identified five research areas in the construction industry that have great potential in leveraging data analytics techniques: construction project management, safety, energy management, decision making design framework and resource management. Among the above five areas, Ismail et al. (2018) further claimed that construction project management attracted comparably more attention of the construction scholars. This supported the notion that there was huge potential in improving the efficiency, enhancing productivity and reducing risks by leveraging data analytics in managing construction projects. Data analytics were reported in monitoring construction safety with wearable technologies (Awolusi et al. 2018), managing construction contract (Safa et al. 2017), managing database in construction engineering (Boonpheng et al. 2021) and building audit systems for construction financials (Vigneault et al. 2020). More recently, Bello et al. (2021) identified the current application areas of cloud computing evidenced by the soaring interest in construction industry, including construction safety, supply chain management, project management informatics, energy control and waste minimisation. Despite the potential of data analytics techniques, the adoption of data technologies remains at a nascent stage in construction as compared to other industries due to the existing challenges (Opoku et al. 2021; Hwang et al. 2022).

2.2 Challenges to the Use of Data in Construction

Four main challenges to the use of data in the construction industry have been widely identified, these are: data security concerns; poor data quality; additional cost and skill shortage (Ibrahim et al. 2021; Hwang et al. 2022; Yan et al. 2020). Yan et al. (2020) argued that data security was the predominant barrier yet it received inadequate attention from researchers, as only 1 out of the 119 papers in their reviewed studies discussed solutions to address the privacy issues. The quality of data was also highlighted by Bilal et al. (2016) as paramount in ensuring the accuracy of analytics results, as approximately 80% of the projects time was used to clean and prepare noisy datasets for analytics. Hence, poor data quality could jeopardise the efficiency and accuracy of data analytics projects (Petzold et al., 2020). Besides, Salleh and Fung (2014) pointed out that the high cost of getting the new technology, setting up the data infrastructure, collecting, cleaning and governing data as well as upskilling their employees to conduct data analytics will prohibit construction organisations in this data-oriented process. In addition, skill and technique shortage was identified as critical obstacles in the various phases of data project life cycle (Mikalef et al., 2018). Salwati et al. (2021) claimed that the lack of awareness of the importance and potential of data analytics could lead to construction professionals' reluctance in adopting data solutions, as well as their reduced proactivity in learning advanced data analytics techniques.

2.3 The Leadership Role of CPM in Construction

Construction project manager (CPM) plays an irreplaceable role in ensuring successful project delivery (Khamaksorn, 2016). Duties of CPM cover a range of activities from determining the work scope, allocating resources, quality and safety assessment to project coordination, connecting multiple stakeholders and building team morale (Alvarenga et al., 2019). The importance of project manager leadership role has been identified in project performance improvement (Anantatmula, 2010), project-based relationship management (Meng and Boyd, 2017), benefits realization management (Mossalam and Arafa, 2016), project planning optimisation (Globerson and Zwikael, 2002) and mobilising project knowledge (Kelly et al., 2013), etc. Therefore, the leadership role of CPM is essential in driving and promoting the leverage of valuable data assets in the data era of the construction industry.

2.4 Data-Driven Capabilities of CPM

Leaders are key actors in the development of a digital culture, dynamic relationships with multiple stakeholders, and collaborative processes in complex settings (Danneels et al. 2021). Therefore, having data driven CPMs to drive top to bottom organizational transformation in a context of uncertainty is critical for the data future of construction industry (Koeleman et al. 2020). Despite the importance and urgency, the existing CPM capability studies mostly focused on the CPM's general capabilities to promote project success. There is currently no clear framework or system in the mainstream construction literature to guide CPM management practices to support data usage and initiatives in managing digital projects. Based on the current literature on the CPM competencies in improving general project performance, considering the CPM role in driving the innovative process to deliver business outcomes, a list of CPM data-driven capabilities was proposed and presented in Table 1.

Table 1. Data-oriented CPM Capabilities.

Capability statement	**References**
1. Ensure basic tasks to be completed proficiently.	Alvarenga et al. (2019); Edum-Fotwe & McCaffer (2000); Hanna et al. (2016); Khamaksorn (2016)
2. Keep a problem-solving mindset.	Dziekoński (2017); González et al. (2013);
3. Be able to effectively manage work priorities.	Ribeiro et al. (2021)
4. Have good knowledge of project management practices.	Dziekoński (2017); Edum-Fotwe & McCaffer (2000); González et al. (2013); Khamaksorn (2016); Ribeiro et al. (2021)
5. Be able to effectively use project management programs.	Alvarenga et al. (2019); Dziekoński (2017); Edum-Fotwe & McCaffer (2000)
6. Be able to effectively use digital devices to access and manage information.	Back & Moreau (2001); Martínez-Rojas et al. (2016); Ribeiro et al. (2021)
7. Have good understanding of the available data at the workplace and know how to access and use it.	Back & Moreau (2001); Madter et al. (2012); Martínez-Rojas et al. (2016)
8. Maintain a high ethical standard when capturing and using data.	Ribeiro et al. (2021); González et al. (2013);
9. Communicate effectively with people in their work team.	Alvarenga et al. (2019); Dziekoński (2017); Khamaksorn (2016); Ribeiro et al. (2021)
10. Develop rapport within working teams.	González et al. (2013); Madter et al. (2012); Ribeiro et al. (2021)
11. Coordinate work using multiple media platforms.	Edum-Fotwe & McCaffer (2000); Ribeiro et al. (2021)
12. Be able to present information to using various technologies.	Edum-Fotwe & McCaffer (2000); González et al. (2013); Khamaksorn (2016)
13. Be able to quickly learn new skills and adapt to changes in core work tasks.	Madter et al. (2012); Ribeiro et al. (2021)
14. Generate new ideas to improve the way completing core tasks.	Alvarenga et al. (2019); Madter et al. (2012)
15. Remain calm under stress.	Dziekoński (2017); Ribeiro et al. (2021)
16. Be able to adjust and adapt quickly when organisations use new tools.	Alvarenga et al. (2019); Ribeiro et al. (2021)
17. Look for and highlight long term opportunities/threats for the company.	Alvarenga et al. (2019); Madter et al. (2012)

3 Research Methodology

3.1 Sample and Procedure

Participants were CPMs in the construction industry. The online survey incorporates three sections: 1) demographic characteristics; 2) general evaluation on data awareness and usage in the project teams; and 3) how the respondents evaluate the extent of their peer CPMs demonstrating the above data-oriented capabilities. Meanwhile, participants were assured that their responses were confidential and would not be identified in the final dataset. A high level of anonymity and voluntary participation were maintained in the current study to reduce biases in survey responses.

The data collection was conducted in June 2021 in China. A total of 374 questionnaires were distributed through the online platform Wenjuanxing. The final sample included 290 questionnaires from the investigated CPMs, yielding a response rate of 77.5%. Figure 1 shows specific regions and the detailed numbers of questionnaires in each region. The demographic characteristics of the CPMs included gender, current position, work experience, and educational level (Table 2). The gender distribution of workers showed 56.2% (n = 163) were male, and the balance were female. Concerning work experience, 57.9% workers had been working in their current positions for more than five years (n = 168), while 42.1% had fewer than five years' experience. The majority (96.9%, n = 281) held a bachelor degree or above, while only 3.1% held a junior college diploma or below.

Table 2. Demographic Characteristics of Respondents (n =290)

Characteristics	Items	Frequency	Percentage (%)
Gender	Male	163	56.2
	Female	127	43.8
Current position	Client	10	3.5
	Contractor	152	52.4
	Consultant	126	43.4
	Others	2	0.7
Work experience	No more than 5 years	122	42.1
	6–10 years	139	47.9
	11–15 years	24	8.3
	16–20 years	4	1.4
	More than 20 years	1	0.3
Educational level	Senior high school or below	1	0.3
	Junior college	8	2.8
	Bachelor degree	219	75.5
	Master degree	60	20.7
	Doctoral degree	2	0.7
Project type	Infrastructure project	62	21.4
	Residential building	68	23.4

	Commercial building	149	51.4
	Public & community building	9	3.1
	Others	2	0.7

Figure1. Distribution of the questionnaires in China.

3.2 Measures

Items were developed in this study to measure data usage in construction project teams and data-oriented CPM capabilities. CPMs' general evaluation on data usage was measured by three items. A sample item is "In general, is your team aware of the importance of available data (e.g. collected from sensors, historical behaviour of the assets, data in maintenance work orders, etc)?" Items were measured on a six-point scale (1-Not at all, 2-Very little extent, 3-Little extent, 4-Good extent, 5-Large extent, 6-Very Large Extent). Data-oriented CPM capabilities were measured by 17 items identified from literature, as shown in Table 1. Items were rated on a six-point scale (1-Strongly disagree, 2-Disagree, 3-Slightly disagree, 4-Slightly agree, 5-Agree, 6-Strongly agree).

3.3 Analytic Strategy

The following process was adopted for data analyses in this study. First, means and standard deviations of the studied variables were presented. Second, the correlations between project team data usage and data-oriented CPM capabilities were performed. The Kolmogorov–Smirnov test for normality was applied to the ratings, and the values of the statistic were below 0.01 for all items in each scale, indicating a violation of the assumption of normality. Nonparametric techniques were thus employed to examine differences between groups in terms of gender, profession background and experience. Mann–Whitney U-test and Kruskal–Wallis H-test statistics were used. Specifically, the Mann–Whitney U-test was used to test for differences on the basis of gender, and the Kruskal–Wallis H-test for differences in different groups of profession background and experience (Corder and Foreman, 2014; Pett, 1997).

4 Findings and Discussion

Mann–Whitney U-test and Kruskal–Wallis H-test in Table 3 showed that there were no significant differences in different groups of gender and profession background. However, a Kruskal–Wallis H-test indicated significant differences of project team data usage led by CPMs with less than 5-year work experience (*mean* = 4.085, *n* = 122), 6-10 year work experience (*mean* = 4.091, *n* = 139) and more than 11-year work experience (*mean* = 4.092, *n* = 29). CPMs with longer work experience were shown leading project teams that use data better.

Regarding the peer-evaluated CPM data-oriented capabilities, Mann–Whitney U-test revealed significant differences between male (*mean* = 4.108, SE =±.589, *n* = 163) and female (*mean* = 4.104, SE =±.586, *n* = 127) perceptions on C1 (Ensure basic tasks to be completed proficiently) ($p < .001$). Hence, male respondents were more likely to believe their peer CPMs were capable in ensuring basic tasks to be completed proficiency. According to Kruskal–Wallis H-test results, there were no significant differences among different profession background groups evaluating CPM capabilities.

However, respondents with different level of work experience might evaluate their peer CPMs data-oriented capabilities differently in terms of C2 (Keep a problem-solving mind-set), C3 (Be able to effectively manage work priorities), C7 (Have good understanding of the available data at the workplace and know how to access and use it), and C15 (Remain calm under stress).

Pearson correlations were calculated to show how CPMs capabilities were linked with data usage of project teams. The results indicated that all the data-oriented CPM capability items were significantly correlated to project team data usage at 0.01 level. Notably, the top three capabilities strongly correlated to project team data usage were: C2 (Keep a problem-solving mind-set.) ($r = .403$, $p < .01$), C1 (Ensure basic tasks to be completed proficiently.) ($r = .401$, $p < .01$), and C8 (Maintain a high ethical standard when capturing and using data.) ($r = .369$, $p < .01$).

5 Conclusions and Further Research

Emerging technologies in the construction industry are generating an astounding amount of data, pointing to an optimistic digital future for extracting new business insights from data analytics. However, there is a lack of evidence regarding capability requirements of future-oriented CPMs in improving the efficiency of leveraging data. Acknowledging this void, this study proposed a set of capabilities to support CPMs in leading data-oriented project teams. The findings highlighted the importance of CPM data-driven capabilities in improving the efficiency of data usage in the project teams. This study provided insights into digital capability development for the next-generation workforce in the construction industry. Despite these implications, limitations and future research directions were also suggested. First, this study adopted a cross-sectional design, caution needs to be taken when drawing causal inferences regarding the impacts of the CPMs' capabilities on data usage in the project team. Future longitudinal designs are recommended to validate findings from the current study. In addition, future qualitative approaches, such as field observations, interviews, workshops and discussion forums are recommended to enhance the understanding of how CPM data-driven capabilities could innovatively release the potential of data analytics in the project team.

Table 3. Mean, Standard Deviation, and Correlation between Variables

Item	Mean (±SE)	Gender			Profession background				Work experience				Pearson correlation
		Male (n = 163)	Female (n = 127)	P-value[a]	Client (n = 10)	Contractor (n = 126)	Consultant (n = 152)	P-value[b]	<5 years (n = 122)	6-10 years (n = 139)	>10 years (n = 29)	P-value[b]	
Use of data	4.087(±.470)	4.091 (±.469)	4.087 (±.475)	.756	4.096 (±.485)	4.092 (±.468)	4.087 (±.475)	.867	4.085 (±.476)	4.091 (±.471)	4.092 (±.483)	.003	–
C1	4.107(±.587)	4.108(±.589)	4.104(±.586)	**.001**	4.112(±.605)	4.107(±.588)	4.104(±.586)	.379	4.105(±.582)	4.110(±.595)	4.110(±.599)	.901	**.401**
C2	3.921(±.910)	3.917(±.911)	3.920(±.911)	.059	3.920(±.912)	3.917(±.909)	3.920(±.911)	.710	3.920(±.912)	3.917(±.090)	3.920(±.911)	**.002**	**.403**
C3	4.097(±.801)	4.094(±.802)	4.093(±.800)	.911	4.108(±.823)	4.093(±.800)	4.093(±.800)	.550	4.108 (±.823)	4.093(±.800)	4.093(±.800)	**.016**	.257
C4	4.179(±.782)	4.181(±.784)	4.180(±.783)	.474	4.173(±.787)	4.180(±.783)	4.180(±.783)	.921	4.173(±.787)	4.180(±.783)	4.180(±.783)	.882	.293
C5	4.086(±.901)	4.090(±.902)	4.090(±.901)	.996	4.108(±.889)	4.090(±.901)	4.090(±.901)	.437	4.108(±.889)	4.090(±.901)	4.090(±.901)	.601	.158
C6	4.048(±.801)	4.052(±.801)	4.045(±.800)	.416	4.072(±.774)	4.052(±.800)	4.045(±.800)	.415	4.072(±.774)	4.052(±.800)	4.045(±.800)	.112	.174
C7	4.003(±.787)	4.003(±.785)	4.000(±.786)	.995	4.036(±.805)	4.007(±.786)	4.000(±.786)	.166	4.360(±.805)	4.007(±.786)	4.000(±.786)	**.003**	.277
C8	3.931(±.916)	3.934(±.918)	3.931(±.918)	.579	3.960(±.911)	3.931(±.918)	3.931(±.918)	.329	3.960(±.911)	3.931(±.918)	3.931(±.918)	.488	**.369**
C9	4.221(±.676)	4.219(±.676)	4.218(±.675)	.296	4.201(±.684)	4.221(±.677)	4.218(±.675)	.058	4.201(±.684)	4.221(±.677)	4.218(±.675)	.095	.256
C10	4.128(±.865)	4.128(±.868)	4.128(±.867)	.286	4.137(±.888)	4.128(±.867)	4.128(±.867)	.629	4.137(±.888)	4.128(±.867)	4.128(±.867)	.121	.279
C11	4.121(±.846)	4.125(±.846)	4.128(±.838)	.363	4.149(±.827)	4.121(±.847)	4.128(±.838)	.396	4.149(±.827)	4.121(±.847)	4.128(±.838)	.137	.224
C12	3.990(±.874)	3.993(±.876)	3.986(±.874)	.378	4.040(±.865)	3.990(±.876)	3.986(±.874)	.749	4.040(±.865)	3.990(±.876)	3.986(±.874)	.484	.208
C13	4.041(±.860)	4.045(±.860)	4.038(±.859)	.104	4.080(±.843)	4.042(±.861)	4.038(±.869)	.425	4.080(±.843)	4.042(±.861)	4.038(±.859)	.191	.333
C14	3.828(±.914)	3.830(±.916)	3.827(±.915)	.310	3.827(±.932)	3.827(±.915)	3.827(±.915)	.401	3.827(±.932)	3.827(±.915)	3.827(±.915)	.434	.346
C15	3.935(±.876)	3.938(±.877)	3.94(±.877)	.821	4.000(±.857)	3.938(±.876)	3.934(±.877)	.326	4.000(±.857)	3.938(±.876)	3.934(±.877)	**.001**	.219
C16	3.931(±.759)	3.941(±.751)	3.927(±.758)	.682	3.948(±.763)	3.934(±.759)	3.927(±.758)	.783	3.948(±.763)	3.934(±.759)	3.927(±.758)	.060	.314
C17	3.907(±.971)	3.913(±.968)	3.907(±.973)	.174	3.936(±.961)	3.907(±.973)	3.907(±.973)	.630	3.936(±.970)	3.910(±.961)	3.907(±.973)	.335	.195

Note: C = Capability, n = total possible, varies across items.
[a] *p*-values are from the Mann–Whitney U-test.
[b] *p*-values are from the Kruskal–Wallis H-test.
All the Pearson correlations were significant at 0.01 level.

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