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Capitalising knowledge management (KM) for improving project delivery in construction

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ABSTRACT

Given the lack of systematic construction industry knowledge management (KM) approaches, particularly in the developing world, an increased understanding of their value for organisational and operational process improvement is needed to improve performance growth through their adoption rate. In response, this study appraised the usefulness of KM practices and KM-enabling tools and techniques used by construction-based organisations. Drawn on a Malaysian field survey, the perceived importance of variables were prioritised using the relative importance index (RII) technique. Spearman's rank correlation tests were used to appraise the degree of agreement between the respondent groups. Then, a factor analysis revealed five major underlying dimensions of KM benefits for project delivery. Conventional techniques are rated more effective than IT-based tools for construction applications. The association between benefits and tools and techniques were also analysed. This paper contributes meaningfully to the value of KM for improving construction project delivery.

1. Introduction

Knowledge management (KM) is usually associated with the management of organisational knowledge to increase competitiveness and is important for organisational survival [1,2]. Thus, KM can be defined as "the systematic and organised attempt to use knowledge within an organisation to improve performance" [3: p. 6]. As such, KM capitalises on the organisation's collective knowledge and the expertise of its employees and business partners in such terms as lessons learned, best practices, problem-solving methods and creative processes [4]. KM processes typically involve the continuous activities of knowledge creation, sharing, storage and application [5].

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Past studies of the construction industry linked KM practices to continuous improvement, productivity and efficiency improvement, and enhanced project performance [6–10]. Notwithstanding the relevance of KM and the various benefits involved, its adoption has ironically been relatively slow in the global construction industry [11,12], resulting in a high rate of knowledge leakage as KM is an emerging concept particularly in the developing world [13]. Although practitioners acknowledge the significance of knowledge, its management is still lacking [14,15] and often fails to deliver intended results [16]. As such, KM capabilities are not fully exploited in construction as a strategic resource for developing competitive and sustainable benefits [17,18].

A number of studies have identified a clear link between poor project performance and lack of knowledge and/or ineffective learning [19–22], resulting in a high failure rate of construction projects. This has motivated researchers to appraise the relevance of construction KM for core competencies and sustainable competitive advantage. In appraising the repercussions of knowledge loss, Massingham [23] observed such adversarial impacts on organisational performance as low productivity, capability gaps, poor performance, higher learning costs and increased search cycle times. This is particularly so when construction projects continue to be poorly delivered because of human- and management-related

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problems [21]. In this connection, many construction projects persistently suffer from inefficacies, not learning lessons from mistakes, and ignorance due to the poor utilisation of KM practices [24,25]. As highlighted by Dang and Le-Hoai [15], many construction organisations are still managing knowledge haphazardly due to lack of guidance documents. On the other hand, overall project performance can be significantly enhanced using knowledge assets [26].

Despite KM studies having gained traction in operations research internationally, there is a lack of consensus over approaches to improve the effectiveness of the KM practices of construction organisations [27]. It is also worth noting that most KM studies have been conducted in the context of developed countries, with little corresponding work in the developing world [13]. At the same time, there is little evidence of research into the association between benefits and various associated tools and techniques, and, most notably, few empirical studies have been carried out in project-based construction settings. There also remains a substantial gap in the knowledge of KM taxonomies for the construction industry, especially in developing countries. Here, the term "taxonomy" refers to the "dimensionality" (underlying factors) of KM practices. Therefore, research and theories of KM practices in the construction industries of developing countries remain incomplete and in need of further exploration. This being the case, it is necessary to develop a general concept of how KM can deliver high values to positively influence organisational performance and uncover the taxonomy framework needed for the application of KM in the construction industry. The research questions in the present study are:

Q1: What are the benefits of KM to construction organisations?
Q2: What are the taxonomies of KM (dimensionality) for the construction industry?
Q3: What are the relevant KM tools and techniques for project-based construction.
settings?
Q4: How are the KM benefits, tools and techniques associated?

By answering these questions, this paper aims to contribute by appraising KM practices in project-based construction organisations and how these can be capitalised to attain the desired benefits. The specific objectives are:

(1) To identify and rank the benefits of KM in construction work
(2) To uncover the dimensionality of these benefits using factor analysis
(3) To examine the effectiveness of KM tools and techniques for project-based construction settings and
(4) To investigate the association between KM benefits, tools and techniques.

The paper is organised into five sections. Following this introduction, the second section deals with the literature review of the benefits of KM in construction and the tools and techniques for KM practices. This is followed in Section 3 by a description of the methodological approach and context of study. The research findings are illustrated and discussed in Section 4. Finally, the concluding remarks are presented in Section 5.

2. Literature review

2.1. Relevance of knowledge management and associated benefits

In 2000, a KPMG Consulting survey of 423 organisations in the United Kingdom, mainland Europe and the United States found that KM significantly helps increase competitive advantage, devise marketing solutions, enhance customer satisfaction, innovative product development, realise revenue and profit growth, and boost employee proficiency levels. Regarding the real benefits of a KM programme, 71% of the organisations involved agreed that their decisions are more effective, 68% had reduced response times to deal with critical business issues, and 64% delivered a greater customer experience [3]. As construction work is intrinsically highly labour- and knowledge-intensive, the strategic importance of such tacit knowledge as the skills, ideas and experiences of people is crucial to both individual and organisational performance [28]. In Malaysia, Yap and Lock's [11] investigation of the KM practices of construction SMEs found primary competitive edges to be related to efficiency improvement, quality improvement, faster delivery and an enhanced decision-making capability. In contrast, the lack of KM practices can result in knowledge being unavailable when needed, knowledge loss and repetition of mistakes. In Vietnam, Dang and Le-Hoai [15] explored the association between knowledge creation factors and construction organisations' effectiveness, including novel and useful ideas, creative and innovative ways of working, better decision-making, increased productivity and effective resource management, as well as enhanced market responsiveness. In Spain, the highest benefits of KM for contractors are perceived to be associated with employee experience exchange, group work improvement and efficiency improvement; while for design companies, KM practices lead to decision-making improvement, quality improvement and product improvement [12].

An important first step for the success of this study was to identify a comprehensive list of KM benefits by addressing the research question: *What are the benefits of KM to construction organisations?* Following the background systematic review of the literature, Table 1 presents a list of the most frequently cited benefits of KM, the most common being time and cost reduction, capability and productivity improvement and retaining tacit knowledge. However, there is not a clear consensus of the benefits of KM for improving project delivery. While previous studies aimed to identify the relevance of KM, they do so in a disjointed manner, leaving the underlying dimensions of KM benefits unexplored. Addressing the aforementioned critical gaps in the literature, this research was directed towards realising the potential benefits associated with KM practices in a construction setting and investigating their importance, quantitative links and underlying dimensions associated with KM in construction project delivery.

2.2. Tools and techniques in KM

KM tools and techniques can be categorised into information technology (IT) tools and non-IT techniques [14]. KM techniques (non IT-based) do not require technological support, whereas KM technologies (IT-based) are pivoted to digital platforms [29]. Paradoxically, in a Spanish study, Forcada et al. (2013) revealed that the majority of construction professionals confuse KM with ICT systems. In investigating the usage and efficacy of KM IT and non-IT tools, Perreira and Rankin [14] found that ICT may complement non-IT techniques to create an integrated environment for knowledge sharing and dissemination. Intriguingly, a recent study in the UK found that IT systems rather than people factors contribute the most to impeding the dissemination of knowledge through an organisation [36].

The range of tools and techniques to facilitate KM processes can be further categorised into *tacit* (e.g. project meetings, post-project reviews, brainstorming sessions, communities of practice, technical dialogues and seminars) and *explicit* (e.g. project post-mortem reports, expertise-locator systems, lessons-learned repositories, best practice and standards guides, corporate intranet and wikis, audit records and defect avoidance and feedback systems) tools,

Table 1
Summary of KM benefits.

No.	Benefits of KM	[11]	[29]	[3]	[30]	[31]	[32]	[33]	[34]	[35]	[24]	Frequency
B1	Efficiency improvement	√	√									2
B2	Quality improvement	√							√			2
B3	Time reduction (response time reduction)	√	√	√	√							4
B4	Delivery time reduction	√	√									2
B5	Decision-making improvement	√	√	√								2
B6	Employees' experience exchange/facilitate transfer of knowledge	√	√									2
B7	Product/service improvement	√			√							2
B8	Customers' and suppliers' relationship improvement	√		√								2
B9	Costs cuts/reduced costs	√		√			√					3
B10	Group/teamwork improvement	√										1
B11	Reducing rework				√			√				2
B12	Improve capability and productivity		√	√		√						3
B13	Better expert judgement						√					1
B14	Continuous improvement				√					√		2
B15	Reducing the cost of poor quality										√	1
B16	Avoid repeating past mistakes		√									1
B17	Retain tacit knowledge		√		√	√						3
B18	Minimise risk		√									1
B19	Better response to organisation changes		√									1
B20	Better sharing of best practices			√								1

in which the most informative methods are those involving face-to-face human interactions [37]. This finding is aligned with Nonaka and Toyama's [38] claim that knowledge-creation starts with socialisation in the sharing of experiences over time. Likewise, Yap and Shavarebi's [10] construction project learning framework incorporates project experiences and personal constructs for competency development. In Spain, the KM tools preferred by both consultants and contractors are email, intranet and internet, while communities of practice and decision-making tools are viewed as less effective [12]. However, the Malaysian counterparts are more inclined to the conventional approaches of face-to-face discussions, mentoring and hardcopy documents for project communication and knowledge exchange [11]. Recent developments in ICT have advanced the way people share knowledge and ideas – facilitating collaborative knowledge management [31]. In essence, the application of knowledge management systems is influenced by the availability of tools to locate knowledge, advanced search using multiple criteria, remote access from anywhere and at anytime, resourcefulness and the ability to input useful knowledge from the users' memory [39]. The evaluation criteria for KM tools and techniques encompass robustness, cost, user-friendliness, dynamism, training, impact and adaptability [40]. With respect to the research question – *What are the relevant KM tools and techniques for the construction industry?* – Table 2 presents the common IT- and non-IT-based tools and techniques used to deliver KM solutions. The popular KM techniques (non-IT-based) are face-to-face interactions and recruitment and followed by brainstorming, communities of practice, post-project reviews, mentoring, training and job rotation. On the other hand, the most frequently cited IT-based tools are data and text mining, intranet and extranet, knowledge bases and helpdesks. However, most studies only focus on identifying the various tools and techniques for KM practices, while it is crucial to measure their effectiveness in construction work. In addition, the association between benefits, tools and techniques has not received widespread coverage. This study, therefore, sought to correct these shortcomings.

3. Research methodology

A cross-sectional survey design was adopted to solicit the views of Malaysian professionals from contractors, consultants, and developers to uncover the benefits, tools and techniques associated with KM practices in the construction industry as synthesised from the detailed literature review. Consistent with previous construction management studies, a survey was chosen to provide a large amount of data within a short time for a relatively low cost and for quantitative analysis techniques to produce valid and meaningful results [12,53,54].

3.1. Questionnaire design

The questionnaire comprises three parts. Part I solicits the respondents' background information concerning themselves and their organisations. Part II requires the statements concerning the benefits of KM to be rated on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). In Part III, the respondents select the KM tools and techniques used in their organisation and indicate their perception of their effectiveness on a 5-point Likert scale from 1 (not at all effective) to 5 (extremely effective).

3.2. Data collection

The target sample size was based on the Yamane (1967) equation, which led to the determination of 100 samples at the 90% confidence level [55,56]. Employing purposeful and stratified sampling techniques, 140 questionnaires were dispatched to construction professionals working in contractor, consultant, and developer organisations in the Klang Valley region, which is the epicentre of Malaysia's construction activities. 97 valid responses were returned, providing a high response rate of 69.2% for statistical reliability analyses [57,58]. Of the respondents, 54 (55.7%), 22 (22.7%) and 21 (21.6%) were contractors, consultants and developers, respectively, with the majority (89.7%) holding managerial or higher positions. Over 80% had worked over 10 years in the construction industry and received a tertiary education. The respondents are therefore considered to be sufficiently well-qualified practitioners to provide sound judgement in this perception-based research [57,58].

3.3. Analyses

Cronbach's α values of the KM benefits and tools and techniques are 0.941 and 0.918, respectively, both exceeding the value of 0.70 needed for scale reliability [59], which indicates the survey items delivered consistent scores. The relative importance index (RII) – a commonly employed method to assess and prioritise hypothe-

Table 2
Summary of KM tools and techniques.

No.	KM tools and techniques	[11]	[41]	[29]	[42]	[43]	[44]	[45]	[46]	[47]	[48]	[49]	[50]	[51]	[52]	[40]	Frequency
Non-IT-based																	
T1	Brainstorming	√	√	√				√									4
T2	Communities of practice	√	√	√	√												4
T3	Face-to-face interaction	√	√	√	√		√										5
T4	Post project reviews (best practices and lessons learned)	√	√	√	√												4
T5	Apprenticeship	√		√		√											3
T6	Mentoring	√	√	√	√												4
T7	Training	√		√	√	√											4
T8	Job rotation	√					√		√	√							4
T9	Interaction with the supply chain	√					√				√						3
T10	Recruitment	√	√	√	√	√											5
T11	Project meetings and reviews					√						√					2
T12	'Live' capture of project knowledge					√						√					2
IT-based																	
T13	Data and text mining	√	√	√				√					√				5
T14	Groupware	√	√	√													3
T15	Intranet and extranet	√		√		√	√										4
T16	Knowledge bases	√	√	√							√						4
T17	Helpdesk	√					√							√	√		4
T18	Knowledge mapping	√					√									√	3

sised variables in construction management research [11,60,61] – was used to rank the identified variables. This is given by.

$$RII = \frac{\sum_{i=1}^{5} W_i}{\text{AxN}} \quad (1)$$

where W_i denotes the weighting given to each variable (ranging from 1 to 5), A is the highest weight (i.e. 5 in this case) and N is the total number of respondents.

Spearman rank correlation was employed to assess the consensus of the three types of respondents over their ranking of the variables' importance and the association between the benefits, tools and techniques, with an exploratory factor analysis used to uncover the underlying benefits involved.

4. Results and discussion

4.1. KM benefits

Table 3 presents the RII of the KM benefits, showing the five most desired KM benefits to be, *overall*:

1. improved efficiency (RII = 0.893)
2. improved decision-making (RII = 0.870)
3. improved quality (RII = 0.860)
4. avoiding repeating past mistakes (RII = 0.860)
5. facilitating knowledge transfer and exchange of experiences (RII = 0.858)

These findings align with previous construction industry knowledge management studies in Malaysia [11], Turkey [30] and Australia [34], for example, underscoring the need for KM best practices to deliver enhanced operational efficiency, facilitate informed decision-making, support continuous quality improvement, create a platform for error management and promote effective knowledge sharing within and between projects.

For the *contractor* respondents, the five most agreed benefits of KM were improved efficiency (RII = 0.878), improved quality (RII = 0.874), improved decision-making (RII = 0.863), improved capability and productivity (RII = 0.856) and reduced rework (RII = 0.852). The equivalent for the *consultant* respondents were improved efficiency (RII = 0.909), improved quality (RII = 0.882), facilitated knowledge transfer and exchange of experiences

Table 3
Ranking of perceptions of the benefits of KM.

Benefits of KM	Overall (97)		Contractors (54)		Consultants (22)		Developers (21)	
	RII	Rank	RII	Rank	RII	Rank	RII	Rank
Improve efficiency (B1)	0.893	1	0.878	1	0.909	1	0.914	1
Improve decision-making (B5)	0.870	2	0.863	3	0.873	4	0.886	2
Improve quality (B2)	0.860	3	0.874	2	0.882	2	0.867	4
Avoid repeating past mistakes (B16)	0.860	3	0.848	6	0.864	8	0.819	12
Facilitate the transfer of knowledge and exchange of experiences (B6)	0.858	5	0.841	8	0.882	2	0.876	3
Improve capability and productivity (B12)	0.856	6	0.856	4	0.873	4	0.838	7
Provide continuous improvement (B14)	0.852	7	0.848	6	0.873	4	0.838	7
Reduce rework (B11)	0.849	8	0.852	5	0.873	4	0.819	12
Retain tacit knowledge (B17)	0.835	9	0.830	11	0.845	10	0.838	7
Provide better judgements (B13)	0.831	10	0.833	9	0.855	9	0.800	18
Reduce response time (B3)	0.827	11	0.815	14	0.845	10	0.848	6
Better sharing of best practices (B20)	0.827	11	0.811	16	0.845	10	0.838	7
Improve teamwork (B10)	0.825	13	0.830	11	0.845	10	0.790	19
Reduce costs (B9)	0.821	14	0.833	9	0.791	17	0.819	12
Improve products and services (B7)	0.816	15	0.800	18	0.818	15	0.857	5
Respond better to changes and improve flexibility (B19)	0.812	16	0.804	17	0.818	15	0.829	11
Reduce poor quality (B15)	0.808	17	0.822	13	0.773	19	0.810	17
Reduce delivery time (B4)	0.806	18	0.815	14	0.773	19	0.819	12
Improve customers' and suppliers' relationships (B8)	0.804	19	0.796	19	0.845	10	0.781	20
Minimise risk (B18)	0.798	20	0.793	20	0.791	17	0.819	12

(RII = 0.882), improved decision-making (RII = 0.873), improved capability and productivity (RII = 0.873), continuous improvement (RII = 0.873) and reduced rework (RII = 0.873). While, for the *developers* respondents, these were improved efficiency (RII = 0.914), improved decision-making (RII = 0.886), facilitated knowledge transfer and exchange of experiences (RII = 0.876), improved quality (RII = 0.867) and improved products and services (RII = 0.857).

The Spearman rank correlation revealed significant agreement over the ranking of KM benefits between the consultants and contractors (r_s = 0.801, ρ < 0.01) as well as the consultants and developers (r_s = 0.548, ρ < 0.05) groups. However, there was no consensus between the contractors and developers: the contractors placing a higher priority on quality aspects (e.g. avoiding repeating past mistakes and reducing rework) with developers being more concerned with improving products and services to end-users.

4.2. Factor analysis

Factor analysis is a statistical technique for summarising and reducing data to uncover theoretical latent constructs, and exploratory factor analysis was used in this study to uncover the underlying dimensions of KM benefits. As Table 4 indicates, the Kaiser-Meyer-Olkin (KMO) value of sample adequacy was 0.873, which is greater than the 0.50 needed for reliable factor analysis [59], and Bartlett's Test of Sphericity of 1222.370 (ρ = 0.000) indicated that the variables were sufficiently inter-correlated [59]. Employing the latent root criterion with varimax rotation, five components were extracted with a cumulative variance of 70.50%, which was greater than the threshold value of 60% needed to establish validity [59]. All variables yielded loadings over 0.50. Cronbach's α for the five-factor solution ranged from 0.808 to 0.891 and the item-to-total correlations ranged from 0.563 to 0.789, affirming the internal consistency of the extracted factors [54,59].

As presented in Table 4, the average RII for the five-factor solution ranged from 0.817 to 0.870, the lowest and highest being Factors 5 and 3, respectively. For factor interpretation, the meaning of the variables with the highest factor loadings were combined to construct the dimension labels as discussed below.

4.2.1. Dimension 1: Organisational performance management

This first dimension had the largest total variance of 18.38%, explaining six benefits concerning continuous organisational development, improvement, and innovation. The leading attribute (with a factor loading of 0.744) that contributes to organisational impact was to "better respond to changes and improve flexibility", found to influence an organisation's strategic capability to respond to change, productivity, and performance improvement. Santos-Vijande et al.'s [62] study of a sample of 181 medium-sized Spanish manufacturing firms concluded that organisational learning is linked to improved customer value and overall performance, with an organisation's ability to learn being significantly influenced by its strategic flexibility and competitive conditions to adapt to a rapidly evolving market. In the context of a team project, the key variables affecting individual, team and project performance are tools, best practices and management support [63]. Previous research has emphasised the capitalisation of best practices to ensure project outcomes [26,64] – best practice being defined as "a process or method that, when executed effectively, leads to enhanced project performance" [46: p. vii]. In this connection, benchmarking can be utilised to align with industry best practices that lead to superior performance [66]. According to Yap and Toh [67], the synergic working culture critical for KM in construction organisations are collaboration and an open communication climate.

4.2.2. Dimension 2: Capability-building management

This dimension accounted for the second-largest variation of 17.24% and contained four benefits that explain the criticality of

Table 4
Factor solution.

Details of the dimensions and benefits	Factor loading	Variance explained (%)	Cronbach α	Average RII
Dimension 1: Organisational performance management	–	18.38	0.891	0.823
Better respond to changes and improve flexibility (B19)	0.744			
Improve customers' and suppliers' relation (B8)	0.694			
Products and services improvement (B7)	0.691			
Better sharing of best practices (B20)	0.652			
Improve teamwork (B10)	0.635			
Provide continuous improvement (B14)	0.584			
Dimension 2: Capability-building management	–	17.24	0.827	0.839
Reduce rework (B11)	0.768			
Improve the capability and productivity (B12)	0.679			
Provide better judgement (B13)	0.649			
Reduce costs (B9)	0.619			
Dimension 3: Knowledge exchange and reuse management	–	12.89	0.815	0.870
Improve efficiency (B1)	0.789			
Facilitate the transfer of knowledge and exchange of experiences (B6)	0.717			
Improve quality (B2)	0.618			
Improve decision-making (B5)	0.510			
Dimension 4: Quality and risk management	–	12.33	0.808	0.825
Reduce poor quality (B15)	0.707			
Minimise risk (B18)	0.689			
Avoid repeating past mistakes (B16)	0.662			
Retain tacit knowledge (B17)	0.563			
Dimension 5: Efficiency management	–	9.66	0.814	0.817
Reduce delivery time (B4)	0.790			
Reduce response time (B3)	0.733			
Cumulative variance explained		70.50	0.941	0.835
Kaiser-Meyer-Olkin measure of sampling adequacy		0.873		
Bartlett's test of sphericity approx. $\chi 2$		1222.370		
df		190		
Sig.		0.000		

building capabilities for performance. The factor loadings ranged from 0.619 to 0.768. In investigating the salient problems undermining construction performance, Yap et al. [21] revealed incompetent and inexperienced construction stakeholders to be one of the underlying reasons for poor performance and project delivery issues. Against this background, previous studies have linked the project team's lack of competency with frequent design changes [22], excessive rework [68], low productivity [69] and poor quality [70]. In rework management, Zhang et al. [71] found the influential learning parameters involved to include micro factors (people, approaches, processes and tools) and a macro factor (project environment). Thus, continuous and effective project learning is needed to acquire valuable knowledge to develop competencies and build a capability for improvement [10,70].

4.2.3. Dimension 3: Knowledge exchange and reuse management

The third dimension accounted for 12.89% of the total variance explained, which underscores the relevance of knowledge sharing for the better management of knowledge resources and application for reuse. Employing a SEM approach to investigate high technology firms in China, Wang et al. [72] concluded that knowledge sharing contributes to intellectual capital (comprising human, structural and relational aspects) to ultimately enhance organisational performance, finding that explicit knowledge has a greater effect on financial performance while tacit knowledge tends to influence operational performance. Yap and Skitmore's [26] knowledge-based project control model incorporated the processes of knowledge creation, knowledge sharing and integration and knowledge exploitation, and provides guidance to effective project time and cost control by leveraging reusable knowledge assets. For example, Ribeiro and Ferreira [73] presented a novel framework for the project team to create, capture, share and leverage knowledge to improve project preparation, while Yap and Toh [48: p. 55] maintain that "effective KM practices are about finding the best ways to deliver the right knowledge to the right person at the right time, enabling informed decision-making and improving operational efficiencies".

4.2.4. Dimension 4: Quality and risk management

The fourth dimension comprised four benefits with factor loadings ranging from 0.563 to 0.707, with the leading benefit being "reduce poor quality". In investigating rework mitigation in construction, Love et al. [33] observed that a cooperative learning and error management culture resulted in a significant reduction of poor quality incidents due to rework, attributing the principal factors contributing to poor quality in construction to human resource capability, leadership and communications, engineering and reviews, construction planning and scheduling, as well as material and equipment supply [74]. For this reason, 'lessons-learned' workshops can be held regularly for project personnel to openly share their knowledge and experiences about rework events to ensure compliance and continuous improvement [74]. Suresh et al.'s [24] mixed-methods study in the UK found that KM practices could positively reduce the cost of poor quality in construction projects – the most impactful knowledge transfer methods being apprenticeships and mentoring. As such, KM provides effective risk management for dealing with non-conformities and inefficient processes due to poor skills, design changes, errors and omissions that may result in rework, delays, and wastage, which suggests that construction organisations need to work on the spiral of knowledge creation and integrate operational knowledge with quality and risk management.

4.2.5. Dimension 5: Efficiency management

The fifth dimension accounted for 9.66% of the total variance explained, consisting of two distinct states of being efficient. This factor was created by "reduce delivery time" (0.790 factor loading) and "reduce response time" (0.733 factor loading). Efficiency is the ability to *'get things done correctly'*: to this end, Griffith and Watson [57: p. 24] explain that "an efficient manager is one who achieves higher outputs (results, productivity, performance) relative to the inputs (labour, materials, money, machines and time) needed to accomplish them". Therefore, it is a mathematical concept: the ratio of output to input. To be efficient, project personnel must have attained a sound knowledge of construction and the competencies needed to overcome daily obstacles [10]. In investigating KM for sustainability in an organisation's operations, López-Torres et al. [76] revealed that KM enables organisations to be creative and innovative in meeting market demands with high-quality products in the most efficient way. They further assert that organisations need to leverage their most valuable resource – humans – as the intangible force to organisations' survival power and the foundation for raising capabilities.

4.3. Commonly used KM tools and techniques in construction

Table 5 presents the prevailing tools and techniques for managing knowledge in the construction industry according to the level of usage. Interestingly, overall, the five most popular methods are non-IT-based platforms of (1) project meetings and reviews (96.9%), (2) training (90.7%), (3) brainstorming sessions (88.7%), (4) face-to-face interactions (87.6%) and (5) post-project reviews (87.6%). The leading tools and techniques are consistent across all three groups of respondents, suggesting the commonality of the non-IT-based methods used. This is consistent with Yap and Lock [11], Kivrak et al. [30] and Egbu and Botterill [44] in claiming that the construction industry is fixated with conventional methods of communication and knowledge sharing. In this connection, the magnitude of ICT adoption in construction practices remains low compared to such other sectors as manufacturing and services [77]. The key barriers are social (cultural habits) and technological (technical challenges) factors [78]. A close examination of Table 6 also reveals that IT tools are yet to be fully exploited to maximise the benefits of KM. This is further echoed by Yap et al.'s [21] assertion of the need for a revolutionary movement towards ICT enhancement for improved productivity and competency management. To advance collaborative knowledge management, Dave and Koskela [31] have suggested capitalising on IT-based solutions. According to Yap and Skitmore [26], ICT tools have a significant impact on enhancing project communications management in construction, particularly in accelerating the process of information, making information more easily accessible and improving information management systems. As people tend to prefer familiarity over change, sufficient training and education are required to ensure project personnel have sufficient skills, knowledge and attitudes to make them competent in the use of advanced technologies in KM applications [44].

Table 6 shows the effectiveness ranking of the KM tools and techniques. Overall, the five most effective tools and techniques are:

1. post-project reviews (RII = 0.800)
2. face-to-face interactions (RII = 0.794)
3. project meetings and reviews (RII = 0.788)
4. brainstorming sessions (RII = 0.767)
5. training (RII = 0.742)

As most construction industry knowledge is experience-based and tacit [79], the tools and techniques for effective for learning and development need to be capable of capturing tacit knowledge. Given that knowledge resides in the minds of people, a collaborative environment with an atmosphere of trust is needed before

Table 5
Ranking of KM tools and techniques used in the construction industry (based on number of 'yes' responses).

KM tools and techniques	Type	Overall (97)			Contractors (54)			Consultants (22)			Developers (21)		
		No	Percent	Rank	No	Percent	Rank	No	Percent	Rank	No	Percent	Rank
Project meetings and reviews (T11)	Non-IT	94	96.9%	1	53	98.1%	1	21	95.5%	1	20	95.2%	1
Training (T7)	Non-IT	88	90.7%	2	51	94.4%	3	19	86.4%	2	18	85.7%	2
Brainstorming session (T1)	Non-IT	86	88.7%	3	53	98.1%	1	16	72.7%	5	17	81.0%	3
Face-to-face interactions (T3)	Non-IT	85	87.6%	4	49	90.7%	4	19	86.4%	2	17	81.0%	3
Post project reviews (T4)	Non-IT	85	87.6%	4	49	90.7%	4	19	86.4%	2	17	81.0%	3
Knowledge bases (T16)	IT	76	78.4%	6	43	79.6%	7	16	72.7%	5	17	81.0%	3
Mentoring (T6)	Non-IT	76	78.4%	6	48	88.9%	6	15	68.2%	9	13	61.9%	9
Communities of practice (T2)	Non-IT	70	72.2%	8	43	79.6%	7	16	72.7%	5	11	52.4%	13
Live capture of project knowledge (T12)	Non-IT	69	71.1%	9	39	72.2%	11	16	72.7%	5	14	66.7%	7
Interaction with the supply chain (T9)	Non-IT	68	70.1%	10	43	79.6%	7	12	54.5%	12	13	61.9%	9
Intranet and extranet (T15)	IT	66	68.0%	11	39	72.2%	11	14	63.6%	10	13	61.9%	9
Recruitment (T10)	Non-IT	64	66.0%	12	41	75.9%	10	9	40.9%	13	14	66.7%	7
Data and text mining (T13)	IT	61	62.9%	13	36	66.7%	13	13	59.1%	11	12	57.1%	12
Knowledge mapping (T18)	IT	53	54.6%	14	35	64.8%	14	7	31.8%	16	11	52.4%	13
Apprenticeships (T5)	Non-IT	50	51.5%	15	30	55.6%	15	9	40.9%	13	11	52.4%	13
Groupware (T14)	IT	45	46.4%	16	29	53.7%	17	6	27.3%	17	10	47.6%	16
Job rotation (T8)	Non-IT	44	45.4%	17	30	55.6%	15	8	36.4%	15	6	28.6%	18
Helpdesk (T17)	IT	33	34.0%	18	20	37.0%	18	4	18.2%	18	9	42.9%	17

Table 6
Ranking of perceptions towards the effectiveness of KM tools and techniques.

KM tools and techniques	Type	Overall (97)		Contractors (54)		Consultants (22)		Developers (21)	
		RII	Rank	RII	Rank	RII	Rank	RII	Rank
Post project reviews (T4)	Non-IT	0.800	1	0.804	2	0.773	3	0.819	1
Face-to-face interactions (T3)	Non-IT	0.794	2	0.819	1	0.782	2	0.743	5
Project meetings and reviews (T11)	Non-IT	0.788	3	0.793	3	0.809	1	0.752	3
Brainstorming sessions (T1)	Non-IT	0.767	4	0.781	4	0.745	4	0.752	3
Training (T7)	Non-IT	0.742	5	0.748	7	0.709	8	0.762	2
Mentoring (T6)	Non-IT	0.736	6	0.770	5	0.682	10	0.705	7
Knowledge bases (T16)	IT	0.734	7	0.737	9	0.736	5	0.724	6
Communities of practice (T2)	Non-IT	0.722	8	0.759	6	0.709	8	0.686	8
Live capture of project knowledge (T12)	Non-IT	0.722	8	0.748	7	0.664	11	0.667	9
Data and text mining (T13)	IT	0.701	10	0.707	10	0.736	5	0.648	13
Intranet and extranet (T15)	IT	0.687	11	0.681	12	0.718	7	0.667	9
Interaction with the supply chain (T9)	Non-IT	0.670	12	0.689	11	0.627	12	0.667	9
Knowledge mapping (T18)	IT	0.660	13	0.681	12	0.609	14	0.657	12
Recruitment (T10)	Non-IT	0.641	14	0.667	14	0.573	17	0.648	13
Groupware (T14)	IT	0.635	15	0.659	15	0.618	13	0.590	17
Apprenticeship (T5)	Non-IT	0.627	16	0.644	17	0.573	17	0.638	15
Job rotation (T8)	Non-IT	0.621	17	0.659	15	0.609	14	0.533	18
Helpdesk (T17)	IT	0.606	18	0.619	18	0.582	16	0.600	16

people can be motivated to share what they know or to pay attention to what others know [66]. According to Nesan [80], people's knowledge sharing behaviour is predominantly influenced by their trust, creativity, motivation, ability and learning. In contrast, inhibiting factors include lack of teamwork, mistrust, knowledge hiding, adversarial relationships and lack of long-term commitments. As outlined in the Project Management Institute's PMBOK Guide, face-to-face interactions can significantly affect the levels of trust and communication needed to manage knowledge. As such, initial personal contact provides an effective way of developing human relationships. It is only once positive relationships are established that a virtual team can be effective [66]. As such, organisational learning is facilitated through communication and collaboration positive social interactions between people in working meetings, reviews and training [81,82]. For example, Yap and Skitmore [26] have explained that tacit knowledge can be captured by talking to experts and reflection on the lessons learned from others.

From the *contractors*' point of view, these were face-to-face interactions (RII = 0.819), post project reviews (RII = 0.804), project meetings and reviews (RII = 0.793), brainstorming sessions (RII = 0.781) and mentoring (RII = 0.770). While, for *consultants*, these were project meetings and reviews (RII = 0.809), face-to-face interactions (RII = 0.782), post project reviews (RII = 0.773), brainstorming sessions (RII = 0.745), knowledge bases (RII = 0.736) and data and text mining (RII = 0.736). For *developers*, they were post project reviews (RII = 0.819), training (RII = 0.762), project meetings and reviews (RII = 0.752), brainstorming sessions (RII = 0.752) and face-to-face interactions (RII = 0.743).

The Spearman rank correlation results further revealed a good homogeneity between all three groups in ranking the effectiveness of KM tools and techniques. The highest agreement was between contractors and developers (88.9%), followed by contractors and consultants (85.3%) and consultants and developers (78.6%). This further corroborated the relevance of the identified approaches for the construction industry.

4.4. Correlation between KM benefits and tools and techniques

Table 7 presents the Spearman's correlation test utilised to appraise the relationship between KM benefits and tools and techniques. Spearman correlation r_s values ranged from 0.161 to 0.395, indicating a moderate positive correlation. Each of the tool/techniques had at least three significant correlated benefits, suggesting that a combination of KM tools and techniques are needed in realising the potential benefits. Taken together, these different IT-

Table 7
Correlated between KM benefits, tools and techniques.

Tools & Techniques Benefits	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	Total correlation
B1	0.271**															0.240*			2
B2			0.245*				0.295**					0.302**	0.218*			0.206*			5
B3				0.311**	0.219*	0.202*	0.330**	0.239*		0.295**	0.316**	0.224*		0.298**	0.378**	0.269**	0.311**	0.267**	13
B4	0.226*								0.223*	0.236*								0.239*	4
B5	0.251*			0.249*			0.206*				0.235*								4
B6	0.308**										0.270**								2
B7	0.281**	0.211*		0.203*		0.270**	0.386**		0.293**	0.204*	0.300**	0.376**	0.297**					0.202*	11
B8	0.222*	0.210*			0.202*	0.209*			0.264**		0.244*	0.306**	0.309**	0.202*				0.239*	10
B9												0.258*							1
B10	0.287**					0.247*	0.379**	0.249*				0.224*	0.278**	0.316**		0.161*	0.254*	0.278**	10
B11	0.313**	0.255*	0.253*	0.252*		0.242*		0.256*	0.266**		0.239*	0.312**	0.215*	0.288**		0.286**		0.219*	13
B12	0.264**			0.245*					0.211*							0.223*			4
B13										0.244*	0.203*			0.246*					3
B14	0.274**						0.249*		0.286**		0.287**	0.303**	0.203*	0.254*	0.244*	0.382**		0.253*	10
B15						0.245*	0.219*		0.252*			0.261**						0.235*	5
B16			0.218*	0.278**					0.225*	0.204*			0.202*						5
B17	0.231*								0.213*			0.248*			0.221*				4
B18					0.223*					0.269**									2
B19	0.224*				0.205*	0.252*	0.315**		0.330**	0.207*	0.223*	0.395**		0.207*		0.308**	0.202*	0.248*	12
B20		0.236*					0.353**	0.221*	0.237*			0.334**		0.215*		0.295**		0.260*	8
Total correlation	12	4	3	6	4	7	9	4	11	7	9	12	7	8	3	9	3	10	–

Note: ** and * denote correlation significant at the 0.01 (two-tailed) and the 0.05 (two-tailed) level, respectively.

based tools and non-IT-based techniques complement one another. The strongest association was between 'live capture of project knowledge' and to 'better respond to changes and improve flexibility' with $r_s = 0.395$ ($p < 0.01$). The second and third highest correlations were between 'knowledge bases' with 'provide continuous improvement' ($r_s = 0.382$, $p < 0.01$), and 'training' with 'improve teamwork' ($r_s = 0.379$, $p < 0.01$), respectively. Table 7 reveals that the most significant tools and techniques were 'brainstorming' and 'live capture of project knowledge', both with 12 significant correlations, followed by 'interaction with supply chain' (11 correlations) and 'knowledge mapping' (10 correlations). Intriguingly, the highly-correlated tools and techniques for managing knowledge in construction projects were non-IT-based approaches except for 'knowledge mapping'. The least effective methods, with only three significant correlations, were 'face-to-face interaction', 'intranet and extranet' and 'helpdesk'. On the other hand, the benefits with the highest correlations, both at 13 significant correlations, were 'reduce response time' and 'reducing rework'. The next benefits were to 'better respond to changes and improve flexibility' (12 correlations) and 'retain tacit knowledge' (11 correlations). It is also worth noting that 'reduce cost' only had one significant correlation with 'live capture of project knowledge' ($r_s = 0.258$), implying the importance of live capture and reuse of project knowledge for continuous improvement and ultimately leading to cost savings. The other lowly-correlated benefit was 'improve efficiency', 'facilitate transfer of knowledge and exchange of experiences' and 'minimise risk', each having two significant correlations. These findings suggest that more effective KM tools and techniques may be needed to fully harness the benefits of KM in the construction industry.

5. Conclusions and implications

The aim of this research was to contribute to deepening the understanding of the benefits of KM practices to project-based construction organisations, with the second objective of developing a taxonomy of KM benefits for the construction industry. Twenty benefits of KM practices pertinent to the construction industry were identified from the published literature and incorporated into a questionnaire survey to prioritise the benefits involved using the relative importance index (RII) technique. The five most desired benefits in the overall context are related to *efficiency, decision-making, quality, error management* and *knowledge sharing* improvements. A Spearman rank correlation analysis showed the rankings between contractors and consultants to be significantly homogeneous, as well as those of the consultants and developers groups, but not with the contractors and developers. As a corollary, the desired KM benefits are significantly influenced by organisational activities and operational needs. To uncover the underlying dimensions of KM benefits, an exploratory factor analysis was employed, which revealed a five-factor taxonomy, namely:

(1) organisational performance management
(2) capability-building management
(3) knowledge exchange and reuse management
(4) quality and risk management, and
(5) efficiency management.

The third and fourth objectives were to examine the effectiveness of KM tools and techniques for project-based construction settings, and to investigate the association between KM benefits, tools and techniques, respectively. The most widely used KM tools and techniques were: *project meetings and reviews, training, brainstorming sessions, face-to-face interactions* and *post project reviews*. Notably, these are non-IT-based approaches. These findings confirm that ultramodern IT-based KM systems are still lacking in the construction industry in Malaysia. Many organisations seem to be fixated with traditional methods to satisfy their technical and knowledge needs. There was a good consensus between all three groups in ranking the effectiveness of KM tools and techniques. The association between benefits, tools and techniques was also presented to guide the selection of the most appropriate means of attaining the desired KM solution as well as addressing the specific operational needs of different organisations.

5.1. Implications

This study adds to the body of knowledge by investigating the quantitative values of KM and the associated tools and techniques that are relevant to the construction industry. Given the limited implementation of KM systems in the construction industry, taking cognisance of the capabilities of KM is necessary to motivate and inspire construction organisations to embrace KM practices. In essence, KM allows organisations to leverage their knowledge-based assets to attain a sustainable competitive advantage - more and better knowledge than the competitors. To do this, their knowledge creation, refining and dissemination processes and strategies need aligning with business operations – leading to improved project performance.

The implication for research is that empirical evidence of the perceived benefits of KM, and effective tools and techniques for managing project knowledge in construction, is now provided. Most notably, this study bridges the identified taxonomy of KM benefits by uncovering the underlying dimensions applicable to construction projects. The research also contributes to practice by showing that KM contributes to improving construction project management capabilities. To learn from each project, knowledge assets need sharing effectively and efficiently and transferred deliberately and systematically. As such, construction organisations need to integrate KM processes to improve project management practices, which should then lead to higher project and business performance. Although there are various commonalities of KM benefits, KM approaches need to be tailored to meet the unique needs of an organisation in the delivery of a construction project. Emphasis should be given to assessing the right KM strategy and avoiding one-size-fits-all solutions. To ensure KM success, different KM tools and techniques are needed to complement each other to identify and exploit existing and acquired knowledge. It is evident that the Malaysian construction industry still prefers conventional KM techniques. Practitioners tend to prefer familiarity over change and incorporating new tools takes time. Indeed, it is worth exploiting the advantages of digital technologies in construction KM practices. The digital transformation process has a relevant effect on knowledge management practices - involving the interconnectedness of machines and their ability to learn and share data autonomously [83]. Specific to the construction industry, the five dimensions of KM benefits presented in this study are useful in benchmarking the integration of KM strategies with project management practices where the corresponding benefits specify the gauging parameters.

5.2. Limitations of study and future research

While this empirical study presents an overview of KM practices in the construction industry, it is limited by the singular data collection method of field survey not allowing any triangulation to assure internal validity. It is also worth noting that, while correlation provides an indication of the strength and direction of the relationship between two variables, it does not necessarily imply causation; future studies could use a sensemaking approach or case studies to further validate the statistical results. Finally, while the study is restricted to a survey of construction practitioners in Malaysia, that its results are nevertheless likely to be also applicable outside its borders suggests the need for future such research to be conducted in other similar-developing countries and regions. In the current era of the fourth industry revolution (Industry 4.0), future studies can explore the evolution of KM practices in the digital age and further develop the KM field in the construction context.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further reading

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