Technical Competency Enhancement Framework for Civil Engineers Towards Successful Public Projects Delivery in Malaysia : Strategists Influence Challenges

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ABSTRACT

The process of applying project management standards to public sector construction projects is based on a rationalist conception that defines technical competence as an established set of predictable knowledge qualities. However, the lack of empirical data is found in the way civil engineers practice these qualities on the workplace surroundings, and especially in the public project context. Technical competency has long been recognised as one of the critical factors in determining the individual performance, but the research has taken little action in terms of establishing the key technical competencies that may be needed to successfully implement the public projects. Through the use of an established competency framework based on the human resource management theory, the study work empirically assesses the technical competencies of civil engineers at the different stages of the delivery of the public projects. It determines key issues which lead to the lack of technical competency, evaluates the consequences of these issues on project performance, and provides specific measures to boost technical competency. Through literature review and pilot study, a questionnaire survey on 359 respondents amongst the civil engineers who are directly involved in managing public project in Jabatan Kerja Raya (JKR) Malaysia have been obtained and the analysis was conducts using Statistical Package of Social Sciences (SPSS) to analyse quantitative data and Partial Least Squares Structural Equation Modelling (PLS-SEM) to analyse the structural relationships of the proposed framework. The results suggest that too much non-technical and administrative work are the most significant constraints on technical competency development and there is a strong preference towards work-integrated learning, on-site technical exposure and real-time project involvement found as the most effective strategies in improving technical competency. Therefore, this study aims at developing a model, which can be integrated to improve technical competency in civil engineers working on public projects in Malaysia. The results provide applicable knowledge to the organisations in the public sector, thus making it possible to plan and manage technical competency better and implement public projects in Malaysia in a more effective and successful way.

Keywords: project management, technical competency, civil engineer, public project, Malaysia

INTRODUCTION

Civil engineers have a central role to play in the implementation of public sector construction projects where the success of any such project depends on the smooth fusion of technical expertise and managerial skills. The acquisition of the resources, budgets, and schedules is required only in the context of public infrastructures, highways, hospitals, and government buildings, where the strict implementation of engineering design expertise, safety standards, regulatory requirements, and construction techniques are required (Ling and Chan, 2020). Unlike general managers, civil engineers also have specialised competencies to interpret technical drawings, design options, oversee construction, and more, as well as progressively include sustainability principles and digital technologies, such as Building Information Modelling (BIM) into the project delivery (Mohd-Rahim, Aziz, and Zainon, 2021; CIDB, 2022).

Civil engineers in Malaysian public agencies, especially Jabatan Kerja Raya (JKR) Malaysia, have a role in making sure publicly funded projects deliver on national development priorities laid out in the 12th Malaysia Plan (EPU, 2021; JKR Malaysia, 2022). The empirical evidence has shown consistently that engineers with strong technical skills are in a better position to face frequent challenges associated with the project in the public sector, such as cost increase, schedule overruns, and lack of quality (Salleh, Bahauddin, and Mohamad, 2020; World Bank, 2020). In addition to their technical capacity, civil engineers act as a vital resister between the technical team and policy makers whereby engineering standards are converted to reflect the expectations of the masses. As a direct result of this, their level of competency directly has implications on efficiency, transparency and long term sustainability in delivery of public projects.

Irrespective of the strategic value of civil engineers, performance gaps are still evident in the execution of the projects that are carried out by the Malaysian government. Though the regulating organisations, including the Board of Engineers Malaysia (BEM) and the Construction Industry Development Board (CIDB), have proposed competency frameworks and professional guidelines, issues related to project delays, cost increases, and lowquality remain common (BEM, 2021; CIDB, 2022). These recurrent problems are evidence of the latent incompetence of technical skills of civil engineers in the processes of delivering the public projects. Specifically, poor mastery of technical competencies essential to effective decision-making, coordination of stakeholders, quality management, and integration of digital tools, including BIM, affect the successful use of digital tools (PMI, 2021; Rahmat and Latif, 2023).

According to the previous research, these gaps can be explained by the fact that training is not always provided, little mentoring is provided, curricula are outdated, and access to further development of the profession is unequal, particularly in under-resourced public agencies (Ismail and Karim, 2020; Zainuddin et al., 2022; Yusof and Jamaluddin, 2023). More importantly, the literature shows the lack of a phase-based technical competency framework, which outlines the competencies needed at each phase of the public project delivery, such as planning, design, construction, and operation (Abdullah and Alias, 2021). Although, as international organisations like the Project Management Institute (PMI), and the Engineers Australia advocate the idea that the civil engineer should have digital literacy, environmental compliance, risk management, and interdisciplinary communication competencies (PMI, 2021; Engineers Australia, 2021). The mentioned requirements are not sufficiently designed and contextualised in the context of the Malaysian public sector.

Even though the changing competence demands of civil engineers have been well recognised, the current literature is still disjointed and fairly descriptive. There is limited existing empirical research that researches systematically into the technical competency requirements throughout the entire lifecycle of public projects and subsequently translates the research into practical strategies of improvement. In turn, an empirically based context-specific framework matching the Malaysian context of the public sector realities to the international best practices in such countries as Japan, Australia, and South Korea is clearly needed (Japan Society of Civil Engineers, 2019; Engineers Australia, 2021; Korean Institute of Civil Engineering and Building Technology, 2020).

To fill this gap, the present study develops a technical competency enhancement framework for civil engineers involved in public project delivery in Malaysia. The study can help in creating more efficient technical competency planning and improved public project performance because it would explore competency requirements at various project stages, currently relevant challenges and the effects they produce, and recommend the relevant improvement strategies.

LITERATURE REVIEW

Technical Competency

The definition of technical competency is the ability to apply specialised knowledge, skills, and professional judgement to perform task-specific engineering activities effectively, accurately, and in compliance with technical, regulatory, and safety standards. It has been well established as an important aspect of professional performance and it is generally described as job specific knowledge, skills and abilities that are needed to effectively carry out the occupational tasks with appropriate tools, techniques and processes (Boyatzis, 1982; Spencer and Spencer, 1993). Unlike interpersonal competencies, technical competency is based on the use of domain specific knowledge in the production of correct, efficient and quality work (Dubois and Rothwell, 2004).

In the context of project management and construction, technical competency can be defined as the ability to employ project management procedures and engineering knowledge during the lifecycle of the project and to include the elements of scheduling, cost management, quality management, and risk management, as well as engineering design, regulatory compliance, and use of digital applications like Building Information Modelling (BIM) (PMI, 2021; Kerzner, 2022; Othman et al., 2023). Similar to the complex and high-risk setting, empirical evidence indicates that technical competency is a key predictor of the project success, especially in terms of design errors or construction mistakes, safety incidents, cost increases, and schedule overruns (Alvarenga et al., 2020; Zwikael and Meredith, 2022).

Technical competency is also dynamic and goes with the change in technology as a result of ensuring sustainability. Recent research findings shows the significance growing of digital literacy, sustainable design, systems integration, and data-driven decision-making in the current construction projects (Silvius and Schipper, 2020; Ahern et al., 2023). In this regard, the synthesis of technical competency can be explained in the following way: the capability to use specialised knowledge, professional judgment, and adaptive skills and produce highquality and sustainable project results under changing technological and organisational conditions.

Civil Engineers in Public Project Delivery

Civil engineers involved in the planning, design, supervising, and implementation of public construction projects. In addition to giving technical designs, their responsibility also includes administration of contracts, cost management, quality assurance, risk management, and compliance with the regulatory models provided by organisations like the Construction Industry Development Board (CIDB). Specifically, in the Malaysian setting, the civil engineers working in the public organisations are acting as custodians of the public resources, whereby publics projects are undertaken in an efficient, safe, and sustainable way, whilst, at the same time, fulfilling the expectations of the stakeholders (CIDB, 2021; Alias et al., 2018). As a result, it leads to the competency of engineers becoming a critical factor in determining the performance of the public project.

Technical competency is one of the numerous aspects of professional competency, which has generally been popularly agreed upon as the pillar of the competent practice of the profession of engineering. It consists of professional skills in the areas of geotechnical and structural design, drainage and flood controls, and digital technology integration (Building Information Modelling (BIM)). These knowledge areas cannot be disregarded in terms of regulatory compliance, cost and schedule control, and high-quality results during the project lifecycle (PMI, 2021; Nguyen et al., 2021). Experience shows that failures in technical competency were always related to design flaws, construction mistakes, project delays, cost overrun, and loss of stakeholder trust, which supports the need to have systematic competency models (Crawford et al., 2021).

Another important focus of the literature is the role of non-technical competencies, namely, the leadership, communication, and stakeholder engagement, in handling the complexity and uncertainties of the work with the public infrastructure (Tabassi et al., 2016; Turner, 2016). However the technical and non-technical competencies do not exist alone but complement each other. Technical proficiency ensures structural integrity, safety, and regulatory compliance, whereas non-technical acumen is a more effective solution as it improves coordination, flexibility, and satisfaction of the stakeholders. To this integrated competency viewpoint, it demands detailed frameworks that give more emphasis on technical competence but clearly acknowledge their interactive synergy with managerial and interpersonal abilities that are needed to attain successful outcomes with the public projects.

Technical Competency in Engineering Practice

The combined use of knowledge, skills, and professional judgment to perform competently in compliance with the set standards and the ethical requirements in engineering practice is often referred to as technical competency (Boyatzis, 2008; Crawford et al., 2021). The notion involves the mastery of the basic areas of engineering, namely structural and geotechnical design, hydraulics, and construction management, and the skill to apply digital technologies, risk management tools, and quality control measures to the practical environment of a project. In turn, the foundation of the provision of engineering projects in a safe, sustainable and statutory and stakeholder-abiding manner is the technical competency.

Technical competency is also paramount by the international standards of professionalism and competency models that direct the practice of engineering across jurisdictions. Engineering design, project delivery, risk

management and professional ethics are all structured competency standards of the institutions like the Institute of Civil Engineers (ICE) and the European Federation of National Engineering Associations (FEANI) to facilitate consistency and professional mobility. In Malaysia, the technical competency development is controlled by the Board of Engineers Malaysia (BEM) using Continuing Professional Development (CPD) requirements and professional tests that are intended to align the local practice with the international standards (BEM, 2020). Such paradigms place greater focus on innovation, sustainability, and digital transformation as a reaction to Industry 4.0 and the needs of infrastructure modernisation (Hosseini et al., 2018).

In project management and construction projects in the public sector, technical competency models offer mechanisms of identifying, evaluating, and training the ability to manage project scope, cost, time, quality, and risk (PMI, 2021; Nguyen et al., 2021). In spite of the fact that managerial and interpersonal skills are still significant, the fundamental support of engineering practice is technical competency. Lack of technical control limits efficient project delivery especially in a complicated public projects venture where safety, durability and regulatory conformity significantly matter. Thus, the integration of the systematised technical competency models in the Malaysian public-sector organisations becomes critical in enhancing the performance of projects and achievement of the national sustainable development outcomes.

Challenges Leading to Inadequate Technical Competency

Despite the fact that technical competency is generally agreed as a crucial factor that determines the performance of a public project, the literature shows that there are deep-rooted challenges that limit the development of technical competency among civil engineers in the public organisations. These challenges work on five dimensions that are inter-related namely the technological, institutional, individual, organisational, and contextual dimensions that make a difference on the level of technical competency and the overall results of the project.

Technologically, low exposure to Building Information Modelling (BIM), Artificial Intelligence (AI), and project simulation solutions, along with gradually implementing digital construction technologies, limit the capacity of engineers to optimise integration and collaboration in design, as well as the execution of the project (Hosseini et al., 2018; Succar and Kassem, 2015; CIDB, 2021). Poor digital literacy and the poor quality of competency standards enforcement also worsen adherence to international best practices (BEM, 2021).

Institutionally, limited exposure to systematic training and Continuing Professional Development (CPD), the lack of correlation between the academic programs and industry requirements, and budgeting and policy limitations lead to the lack of up-to-date technical expertise and the imbalance of the development of professional competence among the agencies of the state (IEM, 2022; Zainuddin et al., 2022; Shrestha et al., 2020).

On the personal side, inadequate mentoring, ineffective incentive scheme, and lack of career growth opportunities inhibit experiential learning and motivation to develop continuous skills, and ongoing skill deficiencies in specialised field knowledge, including geotechnical engineering, flood management, and sustainable infrastructure, inhibit technical performance (Darling Hammond et al., 2020; CIDB, 2021).

These issues are further intensify by the organisational and contextual factors such as poor cultures of knowledge sharing, high employee turnover rates, bureaucratic hierarchies, excessive workload on the administration team, insufficient training funds, and geographical barriers that limit access to professional development opportunities (Noe et al., 2017; PMI, 2021; Ismail and Karim, 2020).

All these multi-level issues are the antecedents to the technical competency of civil engineers, and subsequently, the performance of the public projects. This generalization informs the conceptualization of the current research, where technical competency is seen as a mediator between the systemic issues and the outcomes of the project and the necessity to have an integrated context-dependent framework of technical competency enhancement in relation to projects in Malaysian public sector.

The Impacts of Technical Competencies Adequacy for Successful Public Project Delivery

Technical competencies are recognised as one of the key determinants of construction project success since they have a direct impact on the planning, execution, monitoring, and control of the project. Engineers and project

managers with strong technical skills have better skills to control project scope, time, cost, and quality, thus preventing delays, overruns, and rework (PMI, 2021). In the context of complex construction settings, technical skill is a foundational element of efficient decision-making and problem-solving by offering the following capabilities: risk management, contract administration, quality assurance, and site supervision, compliance with technical specifications, regulatory requirements, and expectations (Ahsan et al., 2013; Crawford et al., 2021).

Technical competency is even further enhanced by the fact that construction projects are inherently uncertain and technical in nature. Empirical research shows that strong technical competency boosts resource efficiency and generates innovation and survival in project deliverables (Tabassi et al., 2016). However, most construction organisations, especially those operating in the public sector, do not have well-designed technical competency schemes, and this leads to skill gaps at an individual level and an organisational level and limits uniform project performance (Nguyen et al., 2021; Shrestha et al., 2020).

Technical competency at the operational level ensures correct interpretation of the design requirements and successful use of digital resources, including Building Information Modelling (BIM), which enhances design coordination, accuracy in construction, cost-effectiveness, and minimisation of the rework (PMI, 2021; Olanrewaju and Abdul-Aziz, 2015). The expertise of the project scheduling and management of the contract also boosts the continuity of the flow of work and minimisation of the disputes, which promotes and increasing the likelihood of timely project completion (Nguyen et al., 2021). Specific knowledge in discipline, such as geotechnical knowledge and awareness of local regulatory requirements, ensures structural stability, compliance with regulation and high-safety performance (Abdul-Rahman et al., 2016; Chileshe et al., 2020).

All in all, the literature supports the fact that the combination of technical expertise in design, construction, and management functions is the key to achieving performance standards, regulatory compliance, and stakeholder satisfaction. As a result, such competencies are not only the key to the project success, but also organisational performance and quality sustainable construction results in the public sector.

Strategies for Enhancing Technical Competency

Technical competency represents a key factor of the successful implementation of the public projects and can be described as the competent use of specialised knowledge, skills and abilities to deliver the project objectives (Boyatzis, 2008; PMI, 2021). In the Malaysian context, the high rate of technological change, the lack of skill correlations, and the shortage of professional development opportunities have demonstrated that there are large competency gaps between civil engineers who work with the public sector, which, in turn, leads to an increased need to systematically enhancement strategies (CIDB, 2021; Alias et al., 2018).

The constant finding in literature is the continued and systematic training as a main process of strengthening technical competency. Also formal technical courses, workshops and certified Continuing Professional Development (CPD) programmes provided by professional bodies, including the Board of Engineers Malaysia

(BEM) and the Institution of Engineers Malaysia (IEM) help to keep pace with the changing standards and technologies (IEM, 2022). Experience and transfer of tacit knowledge are also promoted by mentorship and coaching, especially in younger engineers (Darling-Hammond et al., 2020).

Digital competencies integration is considered a crucial one as well. The use of Building Information Modelling (BIM), project simulation tools, and digital project management systems will increase the accuracy of designs, collaboration, and resource optimisation of the public project (Hosseini et al., 2018; Succar and Kassem, 2015). The schemes of competency-based assessment and certification allow a systematic assessment and benchmarking of technical capacity in relation to international best practices (Crawford et al., 2021).

Knowledge-sharing practices, government-driven training programs, and competency development-career progression-key performance indicators alignment on the organisational level, respectively, all contribute to motivation and institutional capacity (Tabassi et al., 2016; CIDB, 2021; Turner, 2016).

Altogether, systematic training, digital capacity building, and organisational support systems should be integrated to enhance the technical competency and, as a result, the effectiveness, quality, and sustainability of the delivery process of the public projects in Malaysia.

Theoretical and Conceptual Frameworks

The study is based on the existing theories in management and competency that explains the influence of individual skills on project performance in a multidimensional organisational environment. A theoretical framework provides the explicatory basis of identifying the relationships between critical constructs by placing the investigation in the context of existing knowledge (Creswell and Creswell, 2018). On the other hand, the conceptual framework transforms these theoretical assumptions into actual variables by defining the areas of interest and the expected correlations of these variables in the research (Adom et al., 2018).

The theoretical basis of the current research incorporates supplementary views such human capital theory assumes that there is increased productivity and organisational performance through systematic investment in training and professional development (Becker, 1993). These opinions imply that strengthening technical competency in civil engineers is a crucial step towards improving the performance of delivery of projects to the people.

Based on theoretical framework as in Figure 1, the conceptual framework places technical competency as the key mediating construct, that is guided by competency improvement strategies and limited by multi-level challenges. The framework provides a connection between the technical competency formation and the outcomes in the form of public project performance, thus, offering a systematic foundation on how the specific interventions could be used to enhance the effectiveness and sustainability of the performance of the projects in the public sector.

Figure 1. Proposed conceptual framework of Technical Competency Enhancement Framework for Civil Engineers Towards Successful Public Projects Delivery in Malaysia (Strategists Influence Challenges)

METHODOLOGY

Research Methodology

This study use Design and Development Research (DDR) methodology in order to design and test a technical competency improvement framework of civil engineer in the delivery of a public project. DDR is a systematic research design, where problem analysis, design, development, and evaluation are combined to provide solutions to real-world issues and make theoretical contributions (Saedah, Rachey, and Klein, 2013; Ismail, 2020). DDR process is an iterative cycle that includes problem analysis, framework design and development and evaluation, making it possible to refine it by formative and summative assessment.

Statistical Package of Social Sciences (SPSS) is used to analyse quantitative data. Partial Least Squares Structural Equation Modelling (PLS-SEM) is applied to the analysis of the structural relationships of the

proposed framework as it is the approach that is appropriate to use in exploratory research and when the model and latent constructs are complex. The variables that are statistically significant are determined using outputs of PLS-SEM.

Normalised Mean Analysis (NMA) and the Relative Importance Index (RII) are used to prioritise the significant variables to support the interpretation and prioritisation based on the study objectives.

Sampling Strategy and Respondents

This study deals with civil engineers working in Jabatan Kerja Raya (JKR) Malaysia which is directly involved in the management and delivery of the public projects. The overall population is composed of 2,556 civil engineers (JKR, 2025). A suitable sample size is essential to the validity and generalizability of the study findings in terms of its statistical aspect is shown in Table 1.

As the generally accepted principles of Krejcie and Morgan (1970), a minimum sample size of 335 respondents is sufficient for a population of approximately 2,600. This sample size is supported by methodological suggestions of factor analysis and structural equation modelling (SEM). The prior research has set the minimum at 100-300 observations with a ratio of at least 10 responses per estimated parameter and a ratio of 15 in situations where the data is not normal to enhance the study (Bentler and Chou, 1987; Hair et al., 2006, 2010; Tabachnick and Fidell, 2007).

Recent methodological studies point out that adequacy of the sample ought to be made to consider the complexity of the model and practical considerations as well (Kline, 2016; Wolf et al., 2013; Kyriazos, 2018). With such considerations, the sample size of 335 respondents will be considered methodologically correct in terms of factor analysis and framework development in this study.

Table 1. Jabatan Kerja Raya (JKR) Malaysia civil engineers' data

Employees	**Population**	**Target**	**Reference**
Civil Engineer in Jabatan Kerja Raya (JKR) Malaysia	2,556	335	Krejcie and Morgan (1970) (N = 2,600)
Total	**2,556**	**335**	

RESULTS AND DISCUSSION

Questionnaire Survey and Respondents Profile

The questionnaire survey was conducted to answer the aim of this study. During this study, over 450 questionnaires were distributed via Jabatan Kerja Raya (JKR) Malaysia email system to the respondents, especially amongst the civil engineers who are directly involved in managing public project in Jabatan Kerja Raya (JKR) Malaysia. However, it was found that only 359 were successfully reassembled and fully answered by the respondent with 80 % of response rate.

Most of the respondents, 340 (94.71%), belong to the professional and management group, which pointed to the fact that the majority of the respondents had considerable technical and managerial duties. This was then followed by 20 respondents (5.57%) who were in top-management positions. The proportions of those in supporting roles (3 respondents, 0.8%) and other unspecified positions (2 respondents, 0.5%) were extremely small. The sample was constituted mainly by professional and management staff. This distribution shows that the study mainly represents the view of the respondents who have professional and managerial obligations, which is consistent with the orientation to technical competency in the project management and civil engineering.

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The Challenges for Inadequate Technical Competencies

Table 2 ranked 36 challenges contributing to inadequate technical competency among civil engineers based on normalised values (NV). The top-ranked challenges are related to the workload pressures, namely, the overload of non-technical tasks (Rank 1, NV=0.932), administrative workload (Rank 2, NV=0.932), and heavy designated workload (Rank 3, NV=0.918). Such results suggest that too much non-technical and administrative work are the most significant constraints on technical competency development.

The second level of challenges is the organisational and developmental constraints. They are poor budget expenditure on technical training (Rank 4, NV=0.847), inadequate practical experience (Rank 5, NV=0.779) and limited mentorship or knowledge transfer (Rank 6, NV=0.711). The findings highlight the shortcomings in training materials and learning through experience.

The challenges in the moderately ranked list include inadequate exposure to emerging technologies (Rank 9, NV = 0.544), lack of alignment between individual competencies and job requirements (Rank 10, NV=0.371), and disjointed learning strategies (Rank 11, NV=0.340). Such problems are viewed as not as important as workload and training-related problems are.

The most less significant challenges are the absence of digital literacy (Rank 36, NV=0.000), geographical isolation as a barrier to training (Rank 35, NV=0.014), and the lack of digital adaptability (Rank 34, NV= 0.017). These findings indicate the fact that there is minimal impact as compared to organisational workload factors.

The results collectively show that the workload intensity, administrative burden, and the lack of support in terms of training are the main factors that contribute to the lack of technical competency, with the factors of digital readiness and the geographic constraints playing a relatively minor role.

Table 2. Ranking of the challenges for inadequate technical competencies

Construct Code	Item	Normalised Value (NV)	Rank
[B1] Challenges			
B1.6	Overload of non-technical duties	1.000	1
B1.5	Overload of administrative duties	0.932	2
B1.4	Heavy designated workload	0.918	3
B1.7	Insufficient organisational budget allocation for technical training and upskilling	0.847	4
B1.11	Limited hands-on experience	0.779	5
B1.2	Limited mentorship, coaching, or knowledge transfer from experienced personnel	0.711	6
B1.12	Insufficient practical exposure	0.677	7
B1.30	Frequent organisational restructuring disrupting skill development continuity	0.558	8
B1.3	Inadequate exposure to evolving or emerging technologies	0.544	9
B1.32	Lack of alignment of individual competencies	0.371	10
B1.36	Fragmented learning and development strategies not tailored to professional engineering paths	0.340	11

B1.20	Overdependence on senior staff for critical decision-making	0.337	12
B1.1	Lack of training and Continuing Professional Development (CPD) opportunities	0.323	13
B1.17	Inconsistent job roles and technical responsibilities	0.320	14
B1.29	Inequitable access to training opportunities across different departments or roles	0.303	15
B1.35	Absence of technical subject-matter expert/ champions	0.235	16
B1.8	Absence of a structured competency development framework	0.235	16
B1.23	Absence of incentive mechanisms for linking career advancement with competency improvement	0.221	18
B1.13	Low intrinsic motivation	0.221	18
B1.21	Poor interdisciplinary collaboration	0.201	20
B1.31	Lack of alignment of job functions	0.167	21
B1.10	Outdated performance appraisal/evaluation systems	0.139	22
B1.27	Lack of access to up-to-date tools	0.133	23
B1.9	Ineffective performance appraisal/ evaluation systems	0.119	24
B1.28	Lack of access to up-to-date databases	0.116	25
B1.34	Absence of technical leadership	0.116	25
B1.15	Disengagement from skill development	0.116	25
B1.26	Lack of access to up-to-date technical references	0.116	25
B1.22	Poor interdepartmental collaboration	0.099	29
B1.14	Low interest in skill improvement	0.099	29
B1.16	Unclear job roles and technical responsibilities	0.099	29
B1.33	Resistance to change or organisational culture unsupportive of innovation	0.048	32
B1.18	Poorly defined job roles and technical responsibilities	0.031	33
B1.25	Lack of digital adaptability to digital transformation	0.017	34
B1.19	Geographical isolation/barriers or remote work postings limiting access to training resources	0.014	35
B1.24	Lack of digital literacy to digital transformation	0.000	36

A pattern of challenges that hinders the acquisition of technical competence amongst civil engineers is highlighted in Table 2. Workload issues, including non-technical tasks, administration, and excessive tasks assignments, are found to be the major contributors to inadequate technical competency. Such findings highlight work overload as the main limitation to the ability of the engineers to maintain and develop their technical skills.

The challenges associated with training and development such as inadequate organisational budgets on training, weak mentorship and knowledge transfer and inadequate practical exposure were all ranked high. The findings indicate that the lack of organised training systems and hands-on learning experiences are critical to the competency development.

On the other hand, there were challenges related to digital that were relatively ranked lower like poor digital literacy and poor adaptability to digital transformation. Although the concept of digital transformation is a newer challenge in the industry, it is viewed as a minor less pressing obstacle compared to workload and trainingrelated restrictions in Malaysian public organisations.

In general, the results indicate that the priority interventions must strive to reduce excessive workload and strengthen systematic training and mentorship processes with the digital competency gaps, relevant as they are, having lower priorities at the moment.

Most Effective Strategies in Improving Technical Competencies for Civil Engineer

Table 3 ranked support mechanisms that have been deemed as most effective in the development of technical competency amongst civil engineers. The results show that there is a strong preference towards work-integrated learning. On-site technical exposure (Rank 1, NV=1.000) and real-time project involvement (Rank 2, NV=0.875) topped the list with the highest rank, which means that engineers give a significant value to the learning experience that they are getting as a direct result of the field and project experience. The importance of experiential learning and knowledge transfer is also supported by mentorship and coaching by senior engineers (Rank 3, NV=0.812) and multidisciplinary teams (Rank 4, NV=0.687).

Career development and organisational alignment support mechanisms, including clear promotion pathways (Rank 5, NV=0.656), training in digital tools (Rank 7, NV=0.625), case-based learning (Rank 8, NV=0.594), and the integration of technical competency into organisational KPIs (Rank 9, NV=0.562) were also ranked rather high. Formal mechanisms, such as accredited CPD programmes, structured training, and competency based assessments, had lower rankings, implying that these methods are less perceived to be effective than the direct learning strategies.

Project simulation tools (Rank 24, NV=0.187) and attendance at technical seminars and workshops (Rank 25, NV=0.000) had the lowest rank. Generally, the findings shows that project-based exposure, mentorship, and well-organised career pathways are the most effective supports regarding the development of technical competencies, and formal and seminar-based support is rather a minor role.

Table 3. Ranking of the most effective support systems in improving technical competencies for civil engineer

Construct Code	Item	Normalised Value (NV)	Rank
[C2] Support Systems			
C2.4	On-the-job learning technical exposure	1.000	1
C2.5	On-the-job real-time technical exposure	0.875	2
C2.2	Mentorship and coaching by experienced senior engineers	0.812	3
C2.19	Participation in multi-disciplinary project teams	0.687	4
C2.13	Clearly defined and structured career development pathways	0.656	5
C2.14	Clearly defined and structured career promotion pathways	0.656	5
C2.21	Training in up-to-date digital tools, software, and modelling systems	0.625	7
C2.17	Use of engineering project real-world case-based learning	0.594	8
C2.25	Integration of technical competency development in organisational KPIs	0.562	9
C2.18	Participation in cross-functional project teams	0.531	10

C2.3	Continuous Professional Development (CPD) programmes accredited by professional bodies (e.g., BEM, IEM)	0.531	10
C2.1	Formal training programmes (e.g., structured classroom-based technical courses)	0.500	12
C2.6	Competency-based technical assessments	0.437	13
C2.15	Regular performance reviews linked with personal training and development plans	0.375	14
C2.9	Organisational culture that encourages knowledge sharing	0.375	14
C2.20	Access to up-to-date digital tools, software, and modelling systems	0.375	14
C2.23	Incentives for technical excellence (e.g., awards, fast-track programmes)	0.344	17
C2.22	Engagement and collaboration with international engineering organisations and professional networks	0.344	17
C2.10	Organisational culture that encourages peer learning	0.312	19
C2.11	Job rotation across project phases or engineering departments	0.250	20
C2.12	Government-sponsored upskilling and retraining initiatives (e.g., CIDB programmes)	0.219	21
C2.7	Competency-based certification schemes	0.219	21
C2.24	Recognition for technical excellence (e.g., awards, fast-track programs)	0.219	21
C2.16	Use of engineering project simulation tools	0.187	24
C2.8	Participation in technical seminars, colloquia and workshops	0.000	25

Table 3 indicates that the most effective support mechanisms that civil engineers are interested in, in terms of developing technical competence are the practical and field-based learning and mentorship. Although organisational integration and career pathways represent also important variables, formal training, professional recognition and external programmes have rather a weak impact unless they are clearly also connected with reallife applications.

Technical Competency Enhancement Framework for Civil Engineers Towards Successful Public Projects Delivery in Malaysia (Strategists Influence Challenges)

The performance of civil engineers in the planning, design, supervision, and management of projects is directly associated with the technical competency of the civil engineers, as these engineers are the key players in the Malaysian public projects. These findings point out that development of technical competency is limited by too much administrative and non-technical workload, poor access to formal training, poor exposure to new technology, and poor organisational support. These challenges lead to chronic discontinuities between necessary and real technical competencies.

To this end, this study propose a technical competency enhancement model built around three interrelated dimensions, namely (i) decreasing workload and organisational barriers, (ii) enhancing formal training, mentoring, and exposure to modern engineering practices, and (iii) incorporating digital preparedness, performance management systems, and competency-based career pathways. It creates systemic connections between organisational challenges and planned competency interventions and is empirically grounded with Exploratory Factor Analysis (EFA) and validated with Partial Least Squares Structural Equation Modelling (PLS-SEM) as per Figure 2.

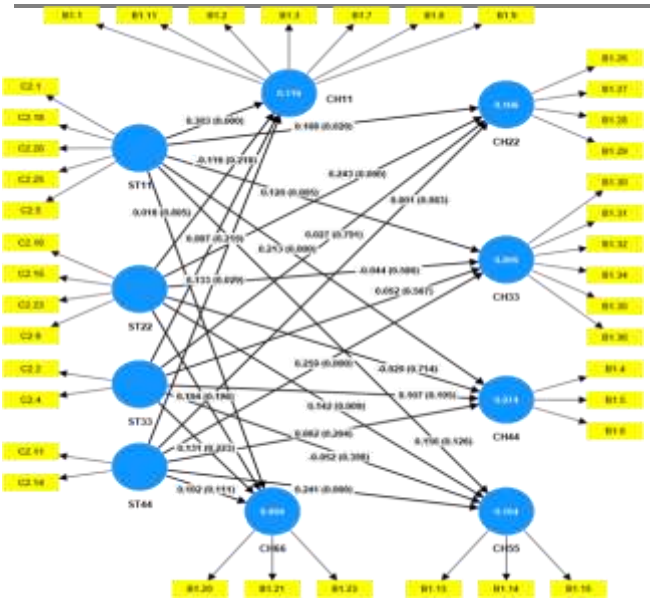

Figure 2. Specified technical competency enhancement framework for civil engineers towards successful public projects delivery in Malaysia structure model (Strategists Influence Challenges)

On the whole, the framework in Figure 3 posits the technical competency development as a strategic enabling factor to enhance technical decision-making, innovation, cost-effective timely and high quality delivery of public projects to support national development goals.

Strategies in Enhancing the Technical Competency for Civil Engineers Towards Successful Public Project Delivery in Malaysia			
ST11	**Structured Training and Practical Exposure**	C2.5	On-the-job real-time technical exposure
		C2.2	Mentorship & coaching by senior engineers
		C2.18	Participation in cross-functional project teams
		C2.1	Formal training programmes
ST22	**Organisational Culture and Knowledge Sharing**	C2.9	Organisational culture encouraging knowledge sharing
		C2.10	Organisational culture encouraging peer learning
		C2.23	Incentives for technical excellence
ST33	**Career Development and Competency Integration**	C2.11	Job rotation across phases/departments
		C2.14	Clearly defined career promotion pathways
		C2.25	Integration of technical competency in KPIs
ST44	**Digital and Performance Systems**	C2.20	Access to up-to-date digital tools, software, and modelling systems
		C2.4	On-the-job technical exposure
		C2.15	Regular performance reviews linked to training

Challenges That Lead to Inadequate Technical Competency Among Civil Engineers for Successful Public Project Delivery in Malaysia			
CH11	**Training and Development Gaps**	B1.1	Lack of CPD opportunities
		B1.2	Limited mentorship/knowledge transfer
		B1.3	Inadequate exposure to emerging technologies
		B1.7	Insufficient training budget
		B1.8	Absence of structured competency framework
		B1.9	Ineffective performance appraisal systems
		B1.11	Limited hands-on experience
		B1.36	Fragmented learning not tailored to professional paths
CH22	**Resource and Accessibility Issues**	B1.26	Lack of access to technical references
		B1.27	Lack of access to tools
		B1.28	Lack of access to databases
		B1.29	Inequitable access to training opportunities
CH33	**Organisational and Structural Barriers**	B1.30	Organisational restructuring disrupting skill continuity
		B1.31	Lack of alignment of job functions
		B1.32	Misalignment of individual competencies
		B1.34	Absence of technical leadership
		B1.35	Absence of technical champions
		B1.23	Lack of incentive mechanisms for career advancement
CH44	**Workload-Related Pressures**	B1.4	Heavy designated workload
		B1.5	Overload of administrative duties
		B1.6	Overload of non-technical duties
CH55	**Individual-Level Factors**	B1.13	Low intrinsic motivation
		B1.14	Low interest in skill improvement
		B1.15	Disengagement from skill development
CH66	**Decision-Making and Collaboration Constraints**	B1.20	Overdependence on senior staff
		B1.21	Poor interdisciplinary collaboration

Figure 3. Proposed technical competency enhancement framework for civil engineers towards successful public projects delivery in Malaysian (Strategists Influence Challenges)

CONCLUSION

Identification of the Challenges That Lead to Inadequate Technical Competency Among Civil Engineers for Successful Public Project Delivery in Malaysia

This study establishes various institutional challenges that still limit the technical capacity of civil engineers and hence the efficiency of public project delivery in Malaysia. Some of the major challenges include the pace of acquiring digital technologies like Building information Modelling (BIM) and the integrated project management system, which reduce the productivity, coordination, and transparency of complex public projects. Although the country and the world are focused on digital transformation, the use of traditional two-dimensional documents and manual monitoring is still a matter of necessity.

The findings also indicate a lack of sustainability competencies integration in the engineering practice. Despite the fact that Malaysia has also aligned its development agenda with the Sustainable Development Goals (SDG), the sustainability considerations are often attributed to the second place in the agenda because of the lack of training in the lifecycle analysis, environmental compliance, and energy efficiency. Also, the growing reliance on the multicultural work force poses a challenge to the management as most civil engineers have not been adequately trained in cross cultural coordination, which adds to the inefficiencies and safety hazard.

Moreover, the study has also pointed to the disjointedness in competency-based training and career development. Although professional accreditation can be delivered by other organisations (BEM and IEM), the development of competency is not coherent and is poorly connected with certification and career advancement. This restricts the willingness of engineers to respond to changing technical, digital and sustainability requirements.

All these gaps undermine the technical capability and hinder the achievement of time, cost, quality, and sustainability goals in the public projects. Competency development is therefore a systematic challenge that needs to be addressed through integrated approaches to assist in supporting the Construction 4.0 agenda of Malaysia and the long-term infrastructure development agenda.

Proposal of the Strategies in Enhancing the Technical Competency for Civil Engineers Towards Successful Public Project Delivery in Malaysia

This study identifies some of the strategic interventions to be adopted in reducing the technical competency gaps among civil engineers and enhancing the delivery of the public project in Malaysia. First of all, it highlights the need to introduce competency-based training and certification as part of the formal professional development opportunities. Through formal education being matched with the competency-based certification standards set by authoritative organisations like CIDB, BEM and IEM, a standardised framework of competencies can be advocated, hence providing career progression based on meritocratic and not tenure-based approaches.

Second, the results demonstrate the significance of digital up-skilling, specifically, Building information modelling (BIM), digital project simulation, and integrated project management platforms. The digital competency will be necessary to facilitate the development of collaboration and transparency, real-time monitoring, and the management of the cost and schedule performance of public projects in Malaysia as it advances to a Construction 4.0 paradigm.

Third, this study emphasizes the importance of incorporating sustainability competency into the engineering practice. The inclusion of life-cycle costing, energy-efficient design and green construction in training makes the civil engineer able to provide contributions to the national sustainability goals and the Sustainable Development Goals (SDG), and also increase the economic value of the infrastructure provided to the public in the long run.

Lastly, the study also highlights the necessity of developing cross-cultural and managerial skills to improve diversity in the workforce and increase communication, safety, and productivity in construction sites.

These are the strategies that are supported by the industry experts and are in line with the national priorities in the development and provide a realistic route towards enhancing the technical competency. The institutionalisation of these interventions will fill the remaining competency gaps and equip the Malaysian civil

engineers in the public sector with the tools needed to face future challenges in infrastructure provision, digitalisation and sustainability.

Theoretical Contributions

The study contributes to the competency theory of project management and civil engineering in a number of ways. First, it builds upon the existing competency theory by putting into context in the Malaysian public construction sector where project dynamics are determined by regulatory requirements, cultural diversity, and workforce characteristics. In contrast to the traditional competency models that were created in majorly Western or generic settings, the results show that technical competency needs to be localised to the institution and policy settings. This adds to the theoretical knowledge of how contextual issues affect competency requirements in the delivering of projects in the public sector. Second, the study develops the competency theory because it incorporates the idea of digitalisation and sustainability as the elements of technical competency, thus going beyond the conventional cost-time-quality framework of project success. The study transforms the understanding of technical competency to be an adaptive capacity incorporating innovation and long-term value creation by introducing competencies associated with Building Information Modelling (BIM), digital monitoring, simulation tools, and sustainable practices. This extension is in line with the global construction megatrends, such as Industry 4.0 and Sustainable Development Goals, and Malaysia Construction 4.0 agenda. Lastly, the study has methodological contribution as it shows a sound multi-methodology of study on competencies. When Relative Importance Index (RII), SPSS reliability, and Partial Least Squares Structural Equation Modelling (PLS-SEM), are used as a combination model; this offers a framework of replicable competency based studies later. All these contributions render the competency theory stronger using the grounding of the theory in context, conceptual expansion, and rigor of the methods.

Practical Contributions

The current study has major practical implications on the agencies, professional organizations and policymakers in the Malaysian construction industry. However, most importantly, it outlines a competency-based structure that can help the governmental agencies such as the Jabatan Kerja Raya (JKR) Malaysia and the Construction Industry Development Board (CIDB) to structure the training programs, coordinate the certification processes, and develop the policies based on clearly defined technical, digital, and managerial competency dimensions. This structure would help in ensuring a more consistent formulation of competencies among the civil engineers and hence strengthens the abilities of the public sector in ensuring timely, cost efficient, and sustainable infrastructure projects. Secondly, the framework proposed can strengthen professional institutions like the BEM and IEM in streamlining Continuous Professional Development (CPD) programmes by matching them to the current and future industry demands. Finally, the study provides evidence-based advice to policymakers to address the lack of competency in the system, as well as to improve the performance of the public projects. The institutionalisation of the standards of competency that include digital capability, sustainable construction, and national skills evaluation can help soothe the long-term issues of delays during project development, overruns, and quality deficiencies. The proposed framework, on the whole, can be seen as a theoretical step forward as well as a practical tool of integrating training, professional practise and policy to strengthen the ability of Malaysia to provide infrastructure.

Limitations

In spite of its contributions, the current study has several methodological and contextual limitations. First, the empirical study is limited to the Malaysian construction projects in the public sector hence it may not be able to be generalised to the private sector projects or other international settings. Differences in the regulatory environment, contractual rules, cultural conditions, and market dynamics might require adjustments of the competency framework offered, and only then it can be extended to a greater range. Second weakness is caused by the fact that the study mostly used survey data and expertise qualification. Despite being methodologically sound, such approaches might not be very effective in capturing dynamic and situational aspects of project delivery. Such complex skills as real-time decision-making, leadership in pressure, and interactions in multicultural teams are hard to test using a survey. More in-depth methodologies, like longitudinal case studies or fieldwork of ethnographic nature, might provide more detailed information about how technical competencies are applied in practice. Third constraint is the speed at which digital and sustainability competencies are

developed in line with the technological progress and changes in policies. Since the areas of BIM, artificial intelligence, data analytics, and high-end sustainability practices progress constantly, the suggested framework will be subjected to constant changes to stay topical, especially within the framework of the Construction 4.0 agenda in Malaysia. These shortcomings do not undermine the value of the study but it does reflect the future study opportunities on how to increase the applicability, generalisability and long-term applicability of the framework in the local and global construction-related contexts.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding this article.

Author Contribution

The contributions of each author are as follows: the first author conducted data collection, literature review and drafted and wrote scientific article, the second and third author conducted the writing review and advice.

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