Assessing the construction site supervisory attributes in effectuating mathematical theories and applications to construction operations

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Abstract

Purpose – Site supervision features largely influence the productivity status of construction operational processes. This study aims to use a case study containing mixed methods to test the site supervisory traits in applying mathematical theories to construction operations for directing supervisory capabilities under various operational characteristics.

Design/methodology/approach – A total of 62 construction site supervisors were trained as part of a new apprenticeship programme. Through literature reviews and expert consultations, grading criteria were designed with various degrees of descriptions and score ratings. The supervisory attributes were evaluated under seven competency element characteristics mapped with the relevant learning domains.

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Findings – The results demonstrate a detailed sectional view of performance ratings of supervisors under different characteristics of competency factors with the validity, reliability, applicability and generalisability assurance of the research findings using relevant statistical tests and expert evaluations.

Research limitations/implications – Though the research applications were engaged directly with the construction industry in the Sri Lankan setting, other developing countries and emerging industries can also employ equivalent tactics to attain similar outcomes in their industry-based operations.

Originality/value – The research findings have led to producing a new guide that makes significant impacts on deciding the capability levels in construction supervisory attributes while executing problem-solving applications in construction planning and operational processes. Accordingly, the findings push to open a gate to intake advanced cognitive attributes towards addressing the industry's knowledge gap on how the problem-solving-based apprenticeship protocols need to be linked with the supervision features.

Keywords Construction supervision, Mathematical applications, Performance evaluation, Productivity enhancement, Skill development, Training

Paper type Research paper

1. Introduction and background

By generating large-scale investment plans, the construction industry outcomes considerably impact the national economy in every nation (Hai and Tam, 2019). Noticeably, higher productivity levels of the construction processes unquestionably affect the financial stability and sustainable outcomes of the construction organisations (Serdar and Jasper, 2011). Additionally, recent studies show that the construction sector employs more people over a longer length of time than any other sector, undoubtedly making it the most human-intensive than machinery-intensive (Nwosu, 2018; Mistri *et al.*, 2019). Importantly, the abilities of human resources connected to planning, managing and applying tasks greatly impact the safety, quality and productivity results of industrialised processes (Mistri *et al.*, 2019). However, due to the incompetence of human resources working in various job positions in the construction sector, the industry has been facing a wide range of issues in relation to capital flows and enterprise competition in many emerging nations (Nwosu, 2018; Hai and Tam, 2019). Particularly, recent studies highlight the issues associated with overrunning costs and time, as well as poor safety, quality and quantity levels of operational processes and outputs in construction, as the notable result of incompetence of human resources (Kumara *et al.*, 2018; Hai and Tam, 2019; Mistri *et al.*, 2019). In particular, studies highlight that Australian (Hughes and David, 2014), Iranian (Parviz *et al.*, 2015), Nigerian (Nwosu, 2018), Vietnamese (Hai and Tam, 2019) and Sri Lankan (Manoharan *et al.*, 2021) construction industries have been experiencing these causes and results in recent years.

Taking on the cross-section of various human resources involved in construction operational processes in various phases, the labour resources are unquestionably significant compared to other human resources since the construction operational flows are directly converted by them into built products (Hai and Tam, 2019). Here, the supervision role plays a crucial part in directing various construction labour operations and handling various factors and characteristics that influence labour work practices (Brent and Leighton, 2013; Parviz *et al.*, 2015; TVECSL, 2017). Efficient supervision strategies can offer sustainable solutions in handling technical matters against constantly changing challenges related to technological advancement (Abimbola, 2016; Kumara *et al.*, 2018), as well as link operational flows to manage efficiency-related difficulties and create a major beneficial impact on the enhancement of work safety, quality and productivity (Hai and Tam, 2019). Moreover, the supervision approaches are crucial in deciding how well labour, materials and machinery are deftly connected within a system to process various construction operational flows towards avoiding disputes associated with unnecessary delays and expenses (Hai and Tam, 2019). When modern circumstances are considered in developing nations like Sri Lanka, the supervisory attributes, job roles and work patterns do not meet the expected standards to accomplish the industry's expectations and needs (Manoharan *et al.*, 2021).

Taking on the Sri Lankan context, construction initiatives are essential while examining the country's aspirations (Kumara *et al.*, 2018). Following the end of the protracted conflict of the "Elam war", the Sri Lankan construction sector saw tremendous expansion, drawing sizeable investments and employment opportunities connecting with various governmental and non-governmental bodies. As a result, the nation is currently undertaking a wide range of infrastructure development projects (Manoharan *et al.*, 2022). However, the above-highlighted aspects have been the major causes that resulted in construction enterprises facing productivity-related problems in numerous infrastructure development projects in Sri Lanka (Kumara *et al.*, 2018). Recent studies spotlight that the industry's requirements and the direction of the vocational training sector are drastically out of sync in the nation (Kumara *et al.*, 2018; Manoharan *et al.*, 2022). Another cause in this regard is the lack of emphasis on job-based training procedures in the direction of industrial policies and practices (Manoharan *et al.*, 2021). The above-stated fact of the current status of the Sri Lankan setting can mostly be common in developing nations, as per the consultations with the Sri Lankan construction experts who had sufficient work experience in other countries and recent studies (Nwosu, 2018; Kumara *et al.*, 2018; Hai and Tam, 2019).

It is critical to keep in mind that competence is the outcome of skills, knowledge and attitude because they are directly connected to the aspects of the demand of learning, job processes and responsibilities (TVECSL, 2017). The construction supervision competency characteristics associated with the execution of mathematical theories and applications to construction operations need to be chiefly upgraded, as per the industrial drawbacks and troubles highlighted by recent studies in the settings of various developing nations (Nwosu, 2018; Kumara *et al.*, 2018; Hai and Tam, 2019). In light of this crucial fact, this study underlines the requirement for advanced attributes in site supervisory procedures to solve real problems at worksites using mathematical, statistical, optimisation and value engineering-based approaches and conceptualisations within a sustainable mechanism in the industry sector. This crucial need has not been properly addressed in the training curricula by the vocational institutions currently functioning in such countries. In addition, this study highlights the industrial researchers' lack of focus on this fact. This study intends to fill this research gap using systematic apprenticeship components. Accordingly, this study contributes to addressing the knowledge gap on how the apprenticeship protocols and application approaches need to be connected with the track on testing construction supervisors' capabilities in this setting.

Taking on the above-spotlighted problem statement and gap analysis connected with the underscored aspects of the construction industrial context in numerous developing countries, this research approaches with the intention of examining the capabilities of construction site supervisory staff in executing mathematical theories, conceptualisations and applications to construction operational flows towards the enhancement of the effectiveness and productiveness of the industrial outcomes. A variety of supervisory practices and competency element factors connected to the study's goal are the main focus of this research, and the study outcomes can benefit industrialists by addressing this knowledge gap, leading to opening a gate to receiving advanced cognitive attributes for the industrialised processes along with the needed comparisons, predictions and comprehensions on which levels of potential competencies should be conceptually and practically taken into account of supervision characteristics. This can be essential for the development of more advanced engineering, technical, managerial and scientific approaches and procedures connected to the constructiveness of industrial operational flows and other benefits associated with profitable and sustainable industrial outputs.

Within the problem background, scope and significance of the study as indicated in the preceding paragraphs, the rest of the paper is structured as follows: Section 2 contains the discussion of literature analysis in relation to productive tools to examine the construction supervision practices, significant site supervisory abilities affecting the effectiveness of construction activities, highlighting the overview of the gaps, limitations and flaws in the past study findings and the significance of the adaptability of the current industry practices to the application of suitable training guiding tools. Section 3 illustrates the methods used to achieve the study's aims through comprehensive approaches. Section 4 describes the performance ratings with the standard levels of site supervisors in the linked competency components and characteristics using relevant analysis and results. Additionally, Section 5 also discusses the findings, making the necessary comparisons with previous studies from the contexts of various developing nations to the key findings, as well as outlining the contributing elements highlighting the validity, generalisability and applicability of the findings. Finally, Section 6 summarises the study's findings, emphasising how the findings connect to multiple implications, contributions, limitations and recommendations.

2. Literature review

2.1 Productive tools to examine the construction supervision practices and the effectiveness of construction operational flows

More than three decades ago, within the scope of producing construction supervisors with a variety of work qualities, a manpower-utilising model was introduced by Uwakweh and Maloney (1991). This model emphasises the importance of cooperation skills in supervisory tactics as well as the proper path to travel when carrying out duties and using the equipment. In the recent scenario, more digitalised apprenticeship models have been introduced by several researchers to promote and simplify competency assessment and enhancement practices on work sites, for instance, the application of virtual reality videography techniques emphasised by Idris *et al.* (2017). On the other hand, useful practical training tools and systems that specifically target enhancing the effectiveness and productivity of construction operations have been presented by Manoharan *et al.* (2021, 2023) recently. These include a labour apprenticeship guiding tool, a site supervisory apprenticeship guiding model and a productive new template for testing the job performance of labourers in construction. These tools and systems enhance the importance of construction site supervisory staff in applying useful procedures on construction work processes, as well as generating ways for adding advanced characteristics to the job roles of construction supervisory staff.

2.2 Significant site supervisory abilities affecting the effectiveness of construction activities

Strong communication between construction site supervisory staff and labourers is required for higher worker motivation levels as well as better standards of job outputs (Nwosu, 2018). Site supervision strategies are the primary impetuses behind the execution of labour apprenticeship elements at construction project sites (Manoharan *et al.*, 2021). Strong communication, decision-making, leadership, planning and manipulation abilities of construction supervisory staff enable higher levels of quality, quantity and safety of work outputs (Brent and Leighton, 2013). Notably, leadership plays the most significant part in the site management tactics employed by construction supervisors, according to a study of 84 Qatari construction businesses conducted by Jarkas *et al.* (2012). On the other hand, based on a study conducted by Mistri *et al.* (2019) on a large number of Indian construction projects, one of the significant performance indicators that significantly affect construction work efficiency has been recognised as the planning abilities of site supervisory staff. In order to avoid unnecessary expenses and delays in executing project tasks, effective project planning techniques boost the efficiency of resource management practices (Manoharan *et al.*, 2022). Effective site coordination and management are necessary when combining various resources in construction activities, especially to maximise the resource utilisation factor (Serdar and Jasper, 2011). Studies emphasise the use of project management software to enhance the site communication and coordination approaches, especially to optimise the project duration, cost, quality and timeliness of work to improve project performance

(Liberatore *et al.*, 2001; Vukomanović *et al.*, 2012; Manorathna, 2013). Vukomanović *et al.* (2012) divide the project management software tools into three categories, where the first one has limited functions for project management practices associated with scheduling techniques, e.g. Microsoft Project. The second type is a complex project portfolio management system that seeks to integrate all project management tasks with enterprise resource planning (ERP), eg. Primavera. The last one is the project management system, which aims to combine project management procedures with on-site management and best practices. Importantly, the use of Microsoft Project and Primavera software tools may result in productive outcomes in the processes associated with critical path analysis, resource scheduling, levelling and earned value analysis for planning and controlling (Liberatore *et al.*, 2001; Vukomanović *et al.*, 2012; Manorathna, 2013). In particular, Liberatore *et al.* (2001) highlight that modern planning and control approaches should be integrated into project management software to have the greatest impact on practice.

Moreover, the weak cognitive abilities of the site supervisory staff in applying quality control procedures were discovered to be a key influencing factor on construction productivity in a range of building projects in Australia (Hughes and David, 2014). By enhancing quality control systems, project activities can be made safer and the likelihood of expensive faults can be decreased (Hughes and David, 2014). Another significant barrier to contractors' efforts to improve efficiency in Australian building projects was the lack of cognitive domains in site supervisors' understanding of health and safety legislation (Hughes and David, 2014). Similar issues with construction oversight have also been found to impede a large number of construction projects in Nigeria (Nwosu, 2018). Additionally, Indonesian construction supervisors should develop their cognitive skills when doing market research and surveys, according to Adi and Ni'am (2012). A rising corpus of research highlights the need of developing construction supervisors' research skills to enable quick identification of concerns at project sites (Brent and Leighton, 2013; Manoharan *et al.*, 2020).

Several studies have made an effort to improve site oversight methods. Taking into account the environment for construction in numerous developing nations like Sri Lanka, the site supervisors' cognitive skills in terms of mathematical modelling and problem-solving aspects were found at a very weak level, as per the important aspects highlighted by TVECSL (2017). Further, the meetings with the technical assessors, academicians and mathematical experts employed in the tertiary education sector of Sri Lanka stated that site management authorities need to have special attention to the use of algebraic, trigonometric and linear programming functions in real work applications. Supporting and replicating this statement, "applying the needed mathematical conceptualisation to solve real challenges of construction project site tasks" has been highlighted by Manoharan *et al.* (2020) as one of the essential 20 programme outcomes that need to be considered in the basis of advanced site supervisory apprenticeship programmes. Noticeably, Manoharan *et al.* (2020) added a strong reinforcement layer to the base of fundamental characteristics of site supervisory job roles replicating what the industry sector anticipates in the next normal stages.

2.3 Overview of the gaps, limitations and flaws in the past study findings

In spite of the fact that this study's academic review reveals that a number of past studies have widely identified a range of key site supervisory competency elements that impact the efficiency of construction work processes and outputs in various directions, only a few of them have offered apprenticeship tools to the application of work efficiency enhancement practices at construction sites. However, there are significant limits when employing such apprenticeship tools in accordance with industrial requirements and characteristics. Despite barely addressing the topic of productivity development, the major flaws of those apprenticeship tools are their absence of specialised competency characteristics and performance evaluation processes. The primary causes of this constraint are mainly connected with the inability of construction businesses in numerous developing countries in adapting to the usage of advanced technologies and ensuring the required fund and other resource availabilities. Despite the construction sector of industrialised nations has adopted the use of the digitalised models provided by Idris *et al.* (2017), the significant flaw in the application of such models is that they disregard techniques for improving the efficiency and safety of construction activities.

Overall, the review of these academic findings suggests that there are still a lot of knowledge gaps that need to be filled for sustaining the reinforcement approaches on the effectiveness of site operational flows. Primarily, this study spotlights that the industry has trouble in predicting the capacity levels of site supervision characteristics in theoretical and practical applications due to knowledge gaps in the formation of application protocols and systems required to test the capabilities of site supervisory workers and evaluate their job efficiency.

2.4 The significance of the adaptability of the current industry practices to the application of the guiding tool of Manoharan et al. *(2021)*

Manoharan *et al.* (2021) have provided a paradigm for developing new construction supervisory apprenticeships that methodically address the challenges of the industry as it changes in more detail. Interestingly, the execution of mathematical theories and applications has been emphasised among the competency units produced in the tool of Manoharan *et al.* (2021). More importantly, seven competency elements (CEs) have been accentuated for the application of mathematical functions among the sixty-four in total presented by the tools of Manoharan *et al.* (2021). As stated by Manoharan *et al.* (2021), such competency elements provide a perfect package/unit of competencies to upgrade the construction site supervisory attributes in effectuating mathematical theories and applications to construction operations. As presented in Table 1, the site supervisory apprenticeship guiding tool of Manoharan *et al.* (2021) has additionally offered the weight distribution of the CEs of mathematical applications in accordance with the domains of Bloom's taxonomy, and this displays the means of developing competency evaluation techniques and offers a distinct sectional view of the CEs. Notably, the Delphi survey technique was used by Manoharan *et al.* (2021) to determine the weights assigned to each CE, whereas such weights were distributed among the learning domains through a series of consultations/discussions with academic experts. Importantly, this weight distribution was performed in the opposite direction as well in order to align the distributed weights well.

In addition to the above, Table 2 shows how such CEs are well-mapped with the relevant site supervisory apprenticeship programme outcomes (POs) of Manoharan *et al.* (2020), as per the descriptions mentioned below.

(1) Intended Outcome Level 1 (IOL1): The apprenticeship contents give an overview of the desired result.

(2) Intended Outcome Level 2 (IOL2): The apprenticeship contents lay the primary reinforcement layer on the learning process directed to the desired result.

(3) Intended Outcome Level 3 (IOL3): The apprenticeship contents lay a secondary reinforcement layer on the learning process directed to the desired outcome.

During the process of determining the mapping levels between the CEs and POs, the supervision capabilities, the industry's next-normal characteristics and practical factors were all carefully taken into account. The mapping findings of the complete competency unit (CU) under the POs were established in accordance with the following statements given the intended outcome levels that emerged between the CEs and POs.

(1) The mapping outcome indicates that the relevant PO's attributes are matched with the characteristics of the CU at the introduced (I)/emphasised (E)/reinforced (R)/advanced (A) level.

Table 1. Mapping and weight distribution of relevant competency elements (CEs) with respect to learning domains presented in the site supervisory apprenticeship guide model of Manoharan *et al.* (2021)

Competency elements (CEs)/ Competency unit (CU)	Weight (%)	Domain levels of Bloom's taxonomy: Cognitive levels (CL) CL1	CL2	CL3	CL4	Psychomotor levels (PL) PL1	PL2	PL3	PL4	PL5	PL6	PL7	Affective levels (AL) AL1	AL2	AL3	AL4	AL5
CE1: Using trigonometric functions in modelling and problem-solving applications for industrial tasks	15	4	7			2	2										
CE2: Applying the algebraic functions in modelling and problem-solving applications for industrial tasks	15	4	7			2	2										
CE3: Using statistical approaches in problem-solving applications for industrial tasks	15	2	4	3		2	2						2				
CE4: Applying cycle time approaches in problem-solving applications for industrial tasks	10	2	2			2	2						2				
CE5: Using linear programming models in problem-solving applications for industrial tasks	10	2	1	1		2	2						2				
CE6: Using fundamental optimisation techniques in problem-solving applications for industrial tasks	15	3	3	2		2	3						2				
CE7: Using value engineering techniques to solve real problems in construction activities	20	3	6	4		3	2						2				
Competency Unit (CU)	*100*	*20*	*30*	*10*	*0*	*15*	*15*	*0*	*0*	*0*	*0*	*0*	*10*	*0*	*0*	*0*	*0*

Note(s): The mapping and weight distribution of CEs mentioned in Table 1 were produced by Manoharan *et al.* (2021)
Domain Levels of Bloom's Taxonomy: CL1 - Remembering and Understanding; CL2 - Applying; CL3 - Analysing and Evaluating; CL4 - Creating; PL1 - Perception; PL2 - Set; PL3 - Guided Response; PL4 - Mechanism; PL5 - Complex Over Response; PL6 - Adaptation; PL7 - Origination; AL1 - Receiving Phenomena; AL2 - Responding to Phenomena; AL3 - Valuing; AL4 - Organization; AL5 - Characterisation

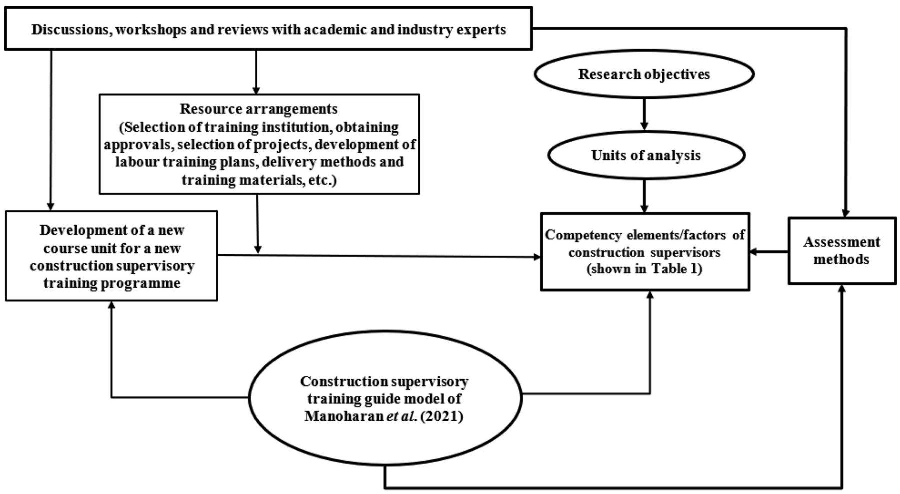
Table 2.
Levels of mapping of the competency elements (CEs) of Manoharan et al. (2021) connected to the relevant site supervisory apprenticeship programme outcomes (POs) of Manoharan et al. (2020)

Competency elements (CEs)/Competency unit (CU)	Site supervisory apprenticeship programme outcomes (POs) of Manoharan et al. (2020) A	B	C	D
CE1	–	IOL1	IOL2	IOL1
CE2	–	IOL2	IOL2	IOL2
CE3	–	IOL2	IOL2	IOL2
CE4	IOL2	IOL1	IOL3	–
CE5	IOL2	IOL1	IOL3	–
CE6	IOL2	IOL1	IOL3	IOL1
CE7	IOL2	IOL1	IOL3	IOL1
Competency Unit (CU)	*E*	*I*	*R*	*E*

Note(s): The mapping levels of CEs and POs mentioned in Table 2 were produced by Manoharan *et al.* (2021)
Site Supervisory Apprenticeship Programme Outcomes (POs) of Manoharan *et al.* (2020)
A: Demonstrating the abilities of planning, managing and controlling the resources in the site activities effectively
B: Following self-learning approaches on modern concepts and advanced technologies related to construction site activities
C: Following the proactive approaches associated with mathematical applications in site operations
D: Assisting in field investigations, industrial surveys and data analysis associated with the feasibilities of construction site practices

3. Methodology

Figure 1 depicts the layout of the research methodology to achieve the research objectives. With the involvement of academic and construction industry experts, consisting of senior academicians, academic directors, project leaders, organisational directors, managers and site engineers, a series of discussions, interviews, reviews and workshops were carried out throughout the process shown in the layout (Figure 1) with a focus on the changing characteristics of construction operational and site management practices in the industry's next normal circumstances. Problem-focused consultative approaches were used at all stages of the research process, particularly for identifying problems and sketching solution



Source(s): Authors' own work

Figure 1.
Layout of the research methodology

mechanisms. It is significant to note that the research strategy was based on the site supervisory training manual of Manoharan *et al.* (2021), as expert interviews and evaluations supported the use of this apprenticeship manual while considering the intention of the present research and other important factors.

3.1 Developing a new competency unit for a site supervisory apprenticeship programme

Considering the competency components described in the guiding tool of Manoharan *et al.* (2021), an advanced occupational and vocationally specific site supervisory apprenticeship was methodically constructed to attain the diploma-stage qualification of the Sri Lankan National Vocational Qualification Framework (NVQF). The candidates were selected for the apprenticeship programme fulfilling the requirements of the entry criteria for the qualification level 5 of NVQF.

A number of processes were followed during the apprenticeship development activities while considering fresh characteristics in the opportunities and challenges facing the industry in the new normal conditions. The institution for the delivery of the proposed site supervisory apprenticeship was chosen through a series of expert consultations utilising the SWOT testing approach. Noticeably, the institutional directors and academic heads from various institutions and departments were involved in this SWOT analysis process. After finalising the apprenticeship institution, a series of consultations were held among different groups of members in various committees associated with curriculum designing, academic development and planning, institutional ethics, quality assurance and finance. The relevant approvals were obtained from such committees for the commencement of the proposed site supervisory apprenticeship programme. In order to make the path for sustaining the methodical apprenticeship delivery in the chosen institution, the establishment of a Board of Study, the nomination of academic resources, budgetary allocations and other key resource allocations were formed. Notably, the proposed site supervisory apprenticeship included a specific course unit that incorporated a number of job-integrated academic approaches to add efficacious mathematical functional attributes to supervision abilities based on the primary objectives of the current research. Notably, each of the components stated in Tables 1 and 2 was addressed in the relevant course unit.

More importantly, the components of such a specific course unit were reviewed by an expert panel of six academic and industrial specialists, who were well-expertise in mathematical functions and applications. The review process specifically focused on academic credit weight, course objectives, intended outcomes, learning contents, teaching, learning and evaluation methods, weights of assessment components and the types of required resources, within a consideration of the applicability and practicality of those components with the aspect shown in Tables 1 and 2.

3.2 Academic delivery of the competency unit

The method of snowball sampling was employed to locate site supervisory workers since this method provides proactive strategies in situations where it is challenging to gather samples with the required attributes. The sample was initially expanded through a small group of well-known construction site supervisors in order to identify more supervisors who could be interested in applying to the designed apprenticeship elements. According to the guidelines outlined in the developed by-laws of the programme, 62 construction site supervisors were ultimately selected based on the scores obtained during the selection interviews for their qualifications. The interviewing panel was composed of seven academic experts with backgrounds in construction engineering to evaluate the candidates' vocational qualifications, subject knowledge, attitude, interest, self-discipline, communication abilities, job experience and the capacity to apply contemporary practices. The majority of the selected site supervisory employees have been involved in building project site works (40%), while the ratio between the selected supervisors involved in building, road and water supply project site works was around 8:7:3. Noticeably, 30% of the chosen supervisors had experience ranging from six to ten years, with all of them having at least one year's worth of expertise in the construction sector. Each province of Sri Lanka was strongly represented among the construction supervisors who were chosen. All the chosen site supervisors received the apprenticeship components in accordance with the recommendations made in the apprenticeship manual of Manoharan *et al.* (2021).

3.3 Evaluation of the site supervisors' competencies

Following consultations with academic specialists to evaluate the CEs, a complete grading guide was created, as illustrated in Table 3. The developed grading guide makes sure that the distributed weights of CEs related to the domains of Bloom's taxonomy listed in Table 1 are satisfied. When developing the grading guide, the mapping of those CEs with the POs of Manoharan *et al.* (2020) (indicated in Table 2) was also taken into account. In this course unit, 60% of the apprenticeship was devoted to enhancing the cognitive skills (knowledge) of site supervisors, especially in the evaluation of how they characterise terms and approach problems. Further, 30% of the apprenticeship contents were intended to evaluate the supervisors' manual abilities with an emphasis on the relevance of demonstrated behaviour and turning learnt aspects into responses and actions. In order to advance active engagement in evaluations, the remaining 10% of the apprenticeship content concentrates on the supervisory attitudes and exploits their thoughts and emotions. The site supervisors who were the direct operators of the research applications had levels of cognitive, psychomotor and emotional attributes with a ratio of 6:3:1. Each site supervisor was evaluated for each CE under each area and given a score that was within the range presented in Table 3. The performance scores were then produced using the weights given to the CEs across all of the domains, as indicated in Table 1. The developed grading guide shown in Table 3 was validated by a panel of reviewers described in Section 3.1 through an evaluation of its applicability.

Descriptions/Standards	Meets standards	Score range
E (Exemplary/Superior)	E1 (Slightly above)	95–100
	E2 (Same level)	90–94
	E3 (Slightly below)	85–89
A (Accomplished/Proficient)	A1 (Slightly above)	80–84
	A2 (Same level)	75–79
	A3 (Slightly below)	70–74
D (Developing/Fair)	D1 (Slightly above)	65–69
	D2 (Same level)	60–64
	D3 (Slightly below)	55–59
B (Beginning/Attempted)	B1 (Slightly above)	50–54
	B2 (Same level)	45–49
	B3 (Slightly below)	40–44
I (Inadequate)	I1 (Weak)	30–39
	I2 (Very Weak)	20–29
	I3 (Unacceptable)	0–19

Source(s): Authors' own work

Table 3.
Competency grading guide with the descriptions and score ratings

3.4 Validating the research tools and outputs

An evaluation procedure encompassing observations and evidence-based discussions was accomplished by an expert panel consisting of nine members with an emphasis on the research plans and tools used, as per the above-described parts. The panel's notable composition encompassed four academic experts who have a doctorate in construction engineering, three industry professionals with certifications in chartered construction engineering and two institutional directors with vast administrative experience. Importantly, the system developed for documentary evidence was evaluated by the panel to assure the construct validity of the research applications. Further, the internal validation of the research findings was assessed by the panel's observations on the patterns of variance in each CE considering various project types. Moreover, the panel evaluated the applicability and generalisability of the proposed applications on the efficiency and productivity enhancement to assess the external validity of the research outputs. The relevant instructions established by Yin (2002) for application-based case study methods were followed for this.

4. Analysis and results

Figure 2 shows the variations in the standard levels of construction site supervisors for the different characteristics of competency factors. Taking into consideration the site supervisors' competencies in using trigonometric functions in modelling and problem-solving applications for industrial tasks (CE1), just above half of the site supervisors were found to be having at least proficient-level competencies, whereas the majority of the other supervisors were identified in the fair stage, and only a few were found at the attempted level. When it comes to site supervisory abilities to apply the algebraic functions in modelling and problem-solving applications for industrial tasks (CE2), the results were found to be almost similar to CE1 within marginal differences. Noticeably, around 10–15% of supervisors were at superior level in those two competency elements. When it takes on the supervisory abilities in the usage of statistical approaches in problem-solving applications (CE3), a quarter of the supervisors showed their accomplished-level competencies, but none of them was at an exemplary level. Considering the remaining supervisors, a 3:2 ratio was reported between the supervisors standing at the developing and beginning stages in the characteristics of CE3. It can be conspicuously observable that the supervisors had much better performance levels in applying cycle time approaches (CE4), linear programming models (CE5) and fundamental optimisation techniques (CE6) in problem-solving applications of industrial tasks compared to the above-discussed three competency elements (CE1, CE2 and CE3). The characteristics associated with CE4, CE5 and CE6 essentially contain conceptual, technical and practical related attributes, whereas the characteristics related to CE1, CE2 and CE3 have analytical and logical based attributes at a substantial level. This can be pointed up as the major reason behind this. Prominently, a significant percentage of site supervisors were at an exemplary level in CE4 (41%), CE5 (34%) and CE6 (39%), whereas the majority of the others were at an accomplished level, only a few were found at the developing stage, and none of the supervisors was found to be at the beginning or below levels in those competency elements. In particular, a ratio of 2:2:1 was undoubtedly reported between the supervisors standing at superior, accomplished and developing levels in the characteristics of applying cycle time approaches (CE4). On the other hand, it is noticeable that nearly 55% of the supervisors had proficient level competencies in the characteristics of applying linear programming models (CE5) and fundamental optimisation techniques (CE6), whereas only 10% and 5% of the supervisors were identified that having fair level competencies in those two competency elements, respectively. When it comes to the last competency element in the list, which is using value engineering strategies for resolving real-world construction issues (CE7), the results were predominantly similar to CE3 (using statistical approaches in problem-solving

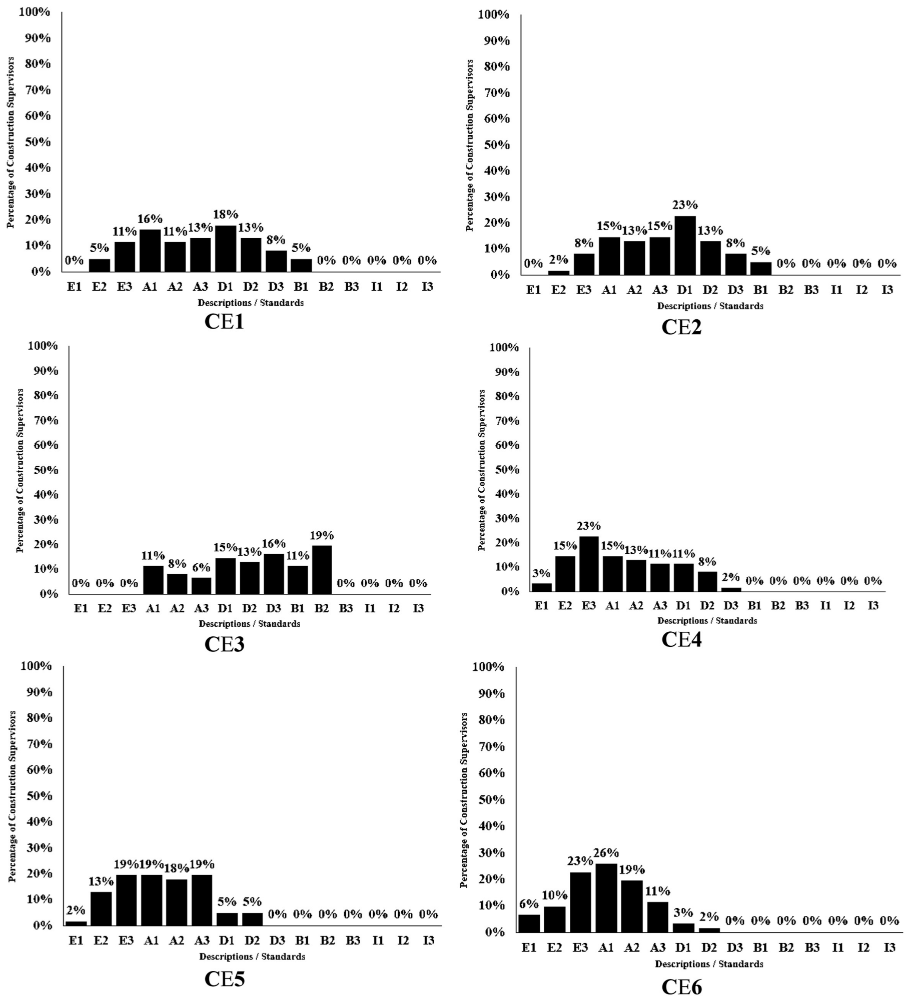
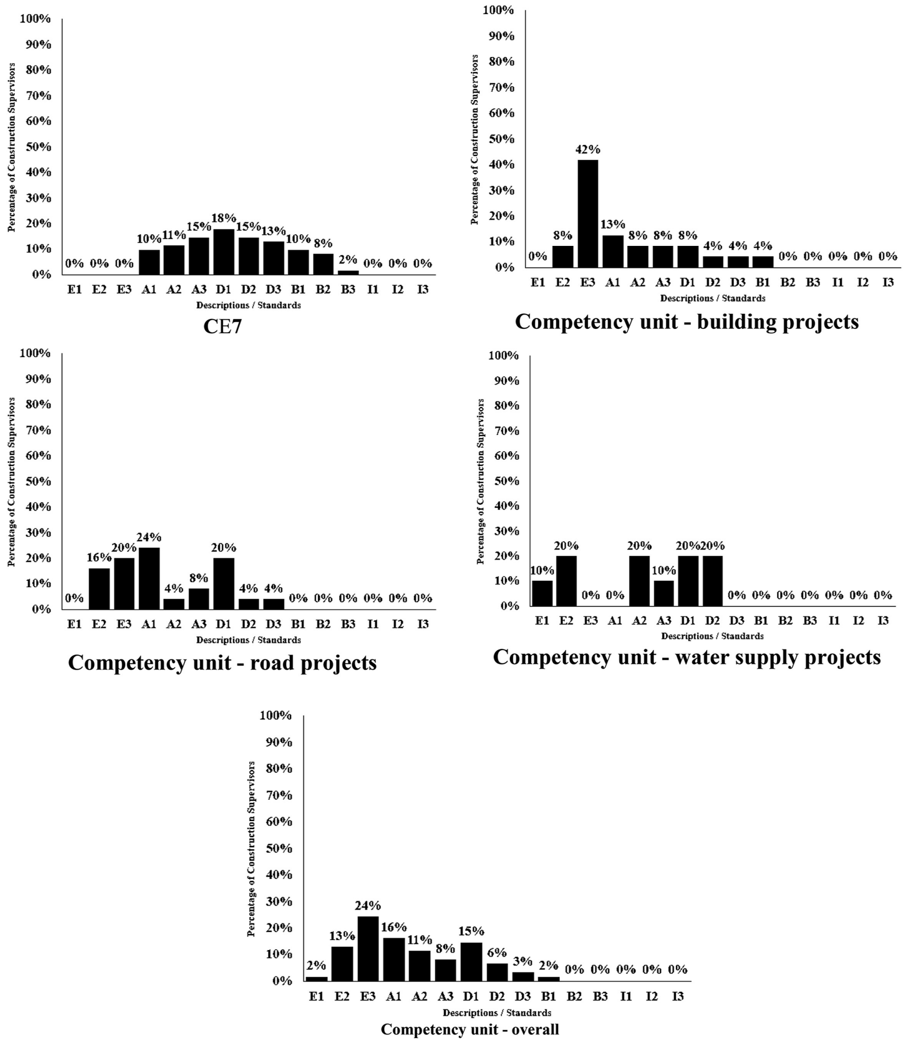


Figure 2.
The variations in the standard levels of construction site supervisors for the different characteristics of competencies

(*continued*)



Source(s): Authors' own work

Figure 2.

applications). Remarkably, nearly 55% of the site supervisors had proficient-level competencies, and none of them was at an exemplary level in those two competency elements (CE3 and CE7). But, only the differences in the results of CE3 and CE7 were in the percentages of supervisors found to be at proficient and fair levels. In CE3, such percentages were identified as 25% and 30% among those two levels, respectively, whereas those percentages were 35% and 20% in CE7.

In the overall category for the competency unit, 39% of the site supervisors received excellent or superior ratings, and 35% of the supervisors performed at an accomplished level, whereas a quarter of the supervisory staff was at the fair level. The results also show that supervisors overseeing building projects fared slightly better than supervisors overseeing other types of construction projects in applying mathematical theories and functions to work tasks. Prominently, half of the supervisors employed in building projects were exemplary in executing mathematical theories and applications, whereas 36% and 30% of the site supervisory workers were found at superior rating level in the road and water supply projects, respectively. This is also replicated by the ratio between the supervisors who were higher than the accomplished level standards and lower than the same level in applying mathematical theories and functions to work tasks. Notably, that ratio was around 4:1, 7:3 and 3:2 in building, road and water supply projects, respectively.

Table 4 lists the performance ratings that construction supervisors attained for each competency factor, and Figure 3 depicts the curves of the frequency distribution of such performance ratings. Overall, the mean values of the performance rating scores were significantly lower in CE3 (70) and CE7 (72) compared to other competency factors. Meanwhile, the mean scores were comparatively much higher in CE4 (84), CE5 (85) and CE6 (87). Further, it is noticeable that the mean scores of CE1 and CE2 were almost the same as the mean score rating of the overall competency unit, which is closer to 78.5.

5. Discussion

As per the results and analysis shown above, no glaring differences were found in the mean score ratings between the various project types, and these quantitative results replicate that the offered training materials are very transferable to the supervisory procedures utilised in all different types of construction project works. An important outcome of the results is that the data was used to develop a modern generalised guide to decide what levels of capabilities can be considered in construction site supervisory attributes (See Table 5). The results produced in Table 5 add advanced cognitive qualities for industrialised processes to perform necessary comparisons, forecasts and comprehensions on which degrees of potential competencies should be conceptually and practically taken into account of supervision characteristics, and this can be a significant addition to the literature highlighting theoretical and practical implications of this study. This could significantly enhance the planning processes related to performance management and resource utilisations in operational management in terms of improvements in technical competence, quality, productivity, safety and sustainability of the work outputs.

Moreover, the design logics, data gathering and analysing methods used in this case study were all instantly apparent. For the data analysis, the mixed approaches of qualitative and quantitative techniques were systematically applied, as per the characteristics of the objectives in different stages. In accordance with the instructions for application-based case study methods established by Yin (2002), the construct validity of the current research applications was blatantly obvious. It unambiguously demonstrates how haphazardly the case study's units of analysis are related. The illustration of patterns of variance in each CE while taking into account various project types has assured the internal validation of the research findings. Obviously, the findings of the expert reviews and data analysis demonstrated the applicability, generalisability and reliability of the suggested approaches for evaluating the efficacy and productivity of project activities. This guarantees the proposed mechanism's external validation and the quality of the outputs.

The results discussed-above show that this research has addressed the productivity assessment and performance testing difficulties brought up by past investigations (TVECSL, 2017; Nwosu, 2018; Kumara *et al.*, 2018; Hai and Tam, 2019; Manoharan *et al.*, 2020) to some extent. As per the results of the present research, the apprenticeship outcomes of advanced construction site supervisory practices provided by Manoharan *et al.* (2020) and the outcomes of the apprenticeship-based workforce efficiency enhancement systems given by Manoharan

Table 4. Performance ratings of construction site supervisors for each competency factor

Competency elements (CEs)/Competency unit (CU)	Building project work			Road project work			Water supply project work			Overall		
	MN	SD	CV	MN	SD	CV	MN	SD	CV	MN	SD	CV
CE1	80.63	6.55	0.08	78.88	7.81	0.10	76.55	8.28	0.11	79.21	8.78	0.11
CE2	81.26	8.46	0.10	76.92	5.64	0.07	78.35	7.55	0.10	78.96	6.47	0.08
CE3	70.87	6.23	0.09	68.75	6.95	0.10	69.52	7.36	0.11	69.82	6.88	0.10
CE4	85.69	9.45	0.11	82.92	7.82	0.09	83.87	6.45	0.08	84.25	7.55	0.09
CE5	86.77	9.26	0.11	83.52	7.36	0.09	82.44	6.38	0.08	84.67	6.55	0.08
CE6	85.46	7.56	0.09	87.96	6.71	0.08	84.88	6.27	0.07	86.67	7.38	0.09
CE7	70.05	5.22	0.07	75.74	7.57	0.10	69.95	5.48	0.08	71.95	6.11	0.08
Overall Competency Unit (CU)	*78.99*	*11.31*	*0.14*	*78.67*	*10.43*	*0.13*	*77.03*	*10.69*	*0.14*	*78.47*	*10.77*	*0.14*

Note(s): MN: Mean; SD: Standard Deviation; CV: Coefficient of Variation
Source(s): Authors' own work

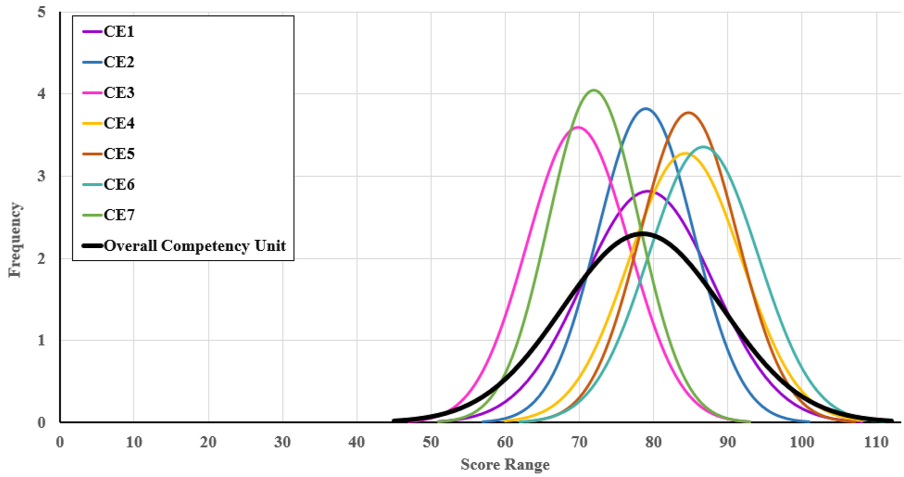


Figure 3. Frequency distribution of the performance ratings of construction site supervisors for each competency factor

Source(s): Authors' own work

Table 5. The cross-section of the developed guide to decide what levels of capabilities can be taken into account in construction site supervisory attributes

Competency elements (CEs)/ Competency unit (CU)	Building project work	Road project work	Water supply project work	Overall
CE1	A1	A2	A2	A2
CE2	A1	A2	A2	A2
CE3	A3	D1	A3	A3
CE4	E3	A1	A1	A1
CE5	E3	A1	A1	A1
CE6	E3	E3	A1	E3
CE7	A3	A2	A3	A3
Overall Competency Unit (CU)	*A2*	*A2*	*A2*	*A2*

Source(s): Authors' own work

et al. (2023) will soon be properly achieved by industry practices in emerging countries. The findings indicated above further push the construction firms in emerging nations for the timely initiation of the application of the digitalised tools and techniques suggested by Idris *et al.* (2017) and Hai *et al.* (2018) for boosting worker apprenticeship and skill evaluation methodologies. Furthermore, a thorough analysis of the peculiarities of site supervision procedures in various settings of developing countries and emerging industry sectors serve as a jumping-off point for the standard and description levels provided in Table 5.

6. Conclusion

The research has shown effective mechanisms to encourage construction site supervisory workers to attain a maximised level of work efficiency and productivity in construction tasks by enhancing their attributes in the application of mathematical concepts and functions. The current study emphasises the need to restructure the construction supervision characteristics associated with the knowledge gap in terms of identifying what supervisory traits are essential, what causes are associated with the influences of supervisory traits on project efficiency, how such influences disrupt the flows of project effectiveness and what types of actions need to be implemented. The research findings are expected to make significant impacts on the work roles of construction site supervisors and their career enhancement opportunities. In particular, the study outcomes add new dimensions to the characteristics connected with the site supervisory job processes, responsibilities and learning demand. These outcomes will have a significant impact on both the industrial and tertiary education sectors, as they will encourage changes in project planning, resource and operational management practices by enhancing problem-solving approaches in industrial process flows, as well as changes in existing training curricula and the introduction of new vocational apprenticeships to address the varying needs associated with next normal features. Accordingly, the findings may further importantly influence how the industry sector perceives practices for upskilling and reskilling employees and how the needful protocols should be developed and put into practice to comprehend what competency traits can be applied in site supervision features practically and conceptually linked to the improvement of quality, quantity and safety standards of process flows. These aspects replicate the theoretical and practical contributions/implications of the current study well.

Because of the additional implications that these additions or changes in supervision outcomes may have on the job characteristics of engineers and project managers, it is critical to ensure the sustainability of project participants' workflows and job outputs. As a result, the working connection between various job positions improves, ensuring the construction industry's long-term stability. Furthermore, the research findings may aid in the transition of supervisory personnel from temporary to permanent employment in many construction firms. As a result, this study assists local businesses in reducing their reliance on foreign workers and improving the quality of work on construction sites, so enhancing the industry's self-sufficiency and economic structure.

Despite a wide range of project tasks, resource availability, financial capabilities, work ethics and organisational regulations being followed up in the chosen construction projects where the applications of this research were processed, the reliability assessment outcomes showed only slight differences in the overall results between the different project types. This ensures that the study applications will be useful to a range of construction-related businesses. The site supervisory personnel, whose competence level ranges from technician level to managerial level, are the only individuals who are eligible to apply with the applications of this research. Even if the research applications were directly executed in the construction sector of Sri Lanka, similar strategies can be taken by other emerging countries to obtain comparable outcomes in their project operations. Other emerging industrial sectors may also use the study results to impact their workflow processes in order to strengthen their guiding principles and operational methods for their human resources. The overall study has established a foundation layer for understanding how the importance of site supervisory competencies associated with mathematical theories and applications to the productivity growth of the industry. This research suggests employing quantitative methodologies in future research to test productivity growth, as a result of the applications of the current research. This research further suggests that future research should concentrate on testing relevant other competency-based characteristics and working procedures of the site supervisory and other various trade categories under varied conditions. This could lead to better scientifically and practically generalisable outcomes based on the findings of the current research.

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