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Uncovering the engagement of construction subcontractors on smart city digitalization in Malaysia

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ABSTRACT

Smart city is a relatively popular concept with different meaning and services provided based on the needs of the people around the globe. The implementation of smart city is no longer new as many countries including Malaysia have already started developing and digitalizing smart cities that incorporate various breakthrough technologies which seems to integrate seamlessly into the construction industry. In construction industry, subcontractors have often been overlooked in previous studies, despite their significant role in smart city development as their skills and expertise are valuable in the industry. This gap exists because research examining the preparedness of Malaysian subcontractors to engage in smart city digitalization remains scarce. Hence, the objective of this study is to examine the subcontractors' engagement in smart city digitalization in Malaysia by studying their perception and readiness in adapting the smart city digitalization concept in Malaysia. A quantitative methodological approach is selected to determine the engagement of smart city digitalization by subcontractors in Malaysia. A total of 105 valid respondents from the subcontractors replied to this study. The results showed significant positive inter-correlation and high impact between the perception and readiness on the engagement of subcontractors in Malaysia's smart city digitalization. Subcontractors recognize the importance of smart city digitalization; however, if their perceptions are negative, their willingness and readiness to participate in such initiatives may be significantly diminished. This highlights the critical role of stakeholder perception within the construction industry, thereby underscoring the value of this study, which addresses a gap in the literature by examining subcontractors which often neglected respondent in the research.

Keywords: Smart city, Digitalization, Subcontractor, Construction engagement.

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1. INTRODUCTION

Smart cities are the result of an inter-disciplinary effort to incorporate technology and infrastructure. Ong et al. (2024) mentioned that numerous industries involved in the development of smart cities have been reaping the benefits of this idea. One such industry is the construction industry. The construction industry is constantly evolving with now greatly moving towards a sustainable future for all. The implementation of smart cities is expected to accelerate the sustainable goals set by the United Nations. However, implementation requires the involvement of both policymakers and subcontractors who play a critical role in executing construction activities as subcontractors play a critical role in the development and digitalization of smart cities. They are commonly engaged in the construction industry to perform specialized tasks requiring specific expertise, as supported by Chin et al. (2014). However, the view of subcontractors on the smart city digitalization remains understudied, raising important questions on their engagement in smart city digitalization. Although subcontractors are central to smart city development, their readiness to adopt emerging technologies and services in the construction industry

has not been sufficiently examined.

Furthermore, subcontractors with technical expertise in digital technologies may have a positive perception of smart cities, as this aligns with their trade. In contrast, those in fields such as mechanical, electrical, and plumbing (M&E) may perceive smart city concepts differently due to the less direct relevance to their work. Some subcontractors may not even be aware of the smart city concept, believing it to be outside their scope of concern or beyond the stage where they are directly involved. Moreover, many subcontractors lack access to resources and training necessary for participation in smart city development, as they typically operate as small-scale firms specializing in specific tasks for main contractors. As a result, it remains unclear whether they are adequately prepared to participate in smart city development. Equally uncertain is the extent to which these challenges influence subcontractors' readiness for digitalization, and how significantly such factors affect their overall readiness levels. These research problems have brought up a set of research questions that will be answered through this study. Hence, there is a research gap in how the subcontractors are ready to be engaged in smart city digitalization.

2. LITERATIRE REVIEW

In the twenty-first century, there are demands for sustainable and environmentally friendly cities that have prompted those involved in the construction industry to take necessary measures to adapt. One of the biggest steps currently being applied is the integration of digital technologies into cities. As part of the fourth industrial revolution which involves technological breakthroughs in areas such as artificial intelligence, IoT and robotics, digital integration into the construction industry has become increasingly unavoidable (Anthopoulos, 2015). Digitalization of cities has already been tested in cities like Amsterdam, Barcelona and Oslo with some experts naming them as "smart cities". Although concerns remain regarding the extensive role of technology in urban development, evidence suggests that smart city initiatives are advancing in the right direction, contributing to a more sustainable future.

Smart cities are a relatively new concept, and numerous definitions of the term exist. Albino (2015) describes the term "smart city" as a nebulous idea that lacks consistent usage, since no single definition can capture its full scope. Although the phrase "smart city" is known to refer to a city's capabilities rather than a single component, a more precise description is necessary to identify the traits used for evaluation. Anthopoulos (2015) stated that Smart City is a phenomenon with diverse interpretations reflecting the vastness and complexities of its domain which encourage scholars to propose alternative methodologies and framework.

The digitalization of smart cities has become an emerging trend. Information and Communication Technologies (ICT) are widely applied for data transmission, collection, management, and analysis. Data-driven smart cities rely heavily on wireless networks and the Internet of Things (IoT), with big data analytics enabling the processing of information gathered from sensors and monitoring systems (Ong, 2023). To ensure security, personal information collected in smart cities is safeguarded through dedicated privacy and protection technologies. In cloud-based smart cities, the cost of physical ICT infrastructure, such as servers, can be reduced through the adoption of cloud computing services for data storage and management. Furthermore, both traditional machine learning and modern deep learning algorithms are used to predict and optimize urban systems. In addition, mobile crowdsensing—where mobile devices function as sensors—has emerged as an effective method for data collection in smart city environments.

Various studies have examined the applications and services driving the digitalization of smart cities. Among these, the application area recognized as having the greatest potential is transportation, which encompasses services such as car-park management, connected vehicles, traffic and transportation management, and smart vehicle charging infrastructure (Bagula et al., 2015; Bamwesigye and Hlavackova, 2019). The concept of connected vehicles is comparable to Bluetooth technology in smartphones, enabling data transfer between vehicles and surrounding infrastructure. Traffic and parking management systems are developed based on data collected through multiple forms of sensing and monitoring technologies deployed within the city. Similarly, infrastructure for charging electric vehicles emphasizes the strategic placement of charging stations to maximize accessibility and efficiency. According to Anagnostopoulos et al. (2015), the environment also represents a key application domain for smart city services. For instance, waste management can be more efficient by utilizing the IoT through advanced sensors and monitoring systems. These sensing technologies are also applied in monitoring noise levels, air quality, and pollution, further supporting sustainable urban development.

The rapid growth of technology is expected to further expand the applications and services used in the development of smart cities. However, the increasing adoption of advanced technologies in the construction industry may raise concern among subcontractors. Therefore, it is essential to assess subcontractors' perceptions and readiness for smart city digitalization to better understand how the construction industry is likely to respond. Despite their critical role in executing on-the-ground construction tasks, subcontractors often face significant barriers to effectively engaging with smart city digitalization concepts. These challenges include limited awareness of smart city concepts, inadequate exposure to emerging digital technologies (e.g., IoT, BIM, AI-based systems), and minimal access to structured digital training programs. This is because many subcontractors operate as small or medium-sized enterprises (SMEs), which often

lack the financial resources to invest in smart technologies, digital tools, or process automation. In addition, main contractors and developers may fail to communicate clear expectations or provide sufficient technical guidance, creating uncertainty about the subcontractor's role in smart city projects. As a result, this can lead to fragmented project implementation, inconsistent adoption of digital practices, and even resistance toward technology-driven workflows on site.

Therefore, the central issue this study seeks to address is the uncertainty surrounding subcontractors' perception and readiness to participate in smart city digitalization. While substantial research has examined digital transformation from the perspectives of policymakers, consultants, or main contractors, there remains a clear research gap regarding the extent to which subcontractors, who are integral to project execution are prepared and willing to adopt smart city technologies. Understanding their perceptions and readiness is essential for ensuring cohesive implementation, reducing friction in digital workflows, and fostering inclusive progress in smart city development across all levels of the construction supply chain.

The core issue this study aims to address is the readiness and perception gap among subcontractors whether they understand, support, and are prepared to participate in the digital transformation associated with smart city initiatives. Addressing this gap is crucial, as subcontractor alignment directly influences the success of technology-enabled urban development. Perception is one of the most essential psychological characteristics, reflecting how individuals interpret and respond to various internal and external factors. According to Żywiołek and Schiavone (2021), perception encompasses a wide range of concepts, both internal and external. Readiness, on the other hand refers to a psychological and behavioral condition of readiness to act. It can be defined in either a physical or psychological context. In a physical sense, readiness may describe an individual's fitness to face a challenge, whereas in a psychological context, it relates to cognitive and attitudinal preparedness (Ong et al., 2023). As such the research objective is developed for this study:

Research Objective: To investigate the engagement on smart city digitalization relating to the perception and readiness of the subcontractors in Malaysia.

3. METHODLOGY

According to Weiner (2009), readiness refers to a psychological and behavioral condition of readiness to act. Fowler (1998) mentioned that readiness can be defined in a physical or psychological context. In a physical sense, readiness refers to how fit and capable an individual is to face a task; for instance, a football player's preparedness for an upcoming game can be considered physical readiness. In contrast, psychological readiness reflects how mentally prepared an individual is to approach or respond to a challenge. According to Achmad et al. (2018), to measure readiness of smart city, the readiness of ICT must be assessed. The question arises on how ready are the subcontractors for smart city digitalization in Malaysia. To investigate this issue, a similar approach to that of Ong et al. (2023) will be adopted, whereby a readiness survey targeting industry professionals will be conducted using adapted questionnaires based on previously established and widely recognized theoretical frameworks. According to Ghazali et al. (2018), their citizen-centric study highlighted that Malaysia still faces significant challenges in achieving smart city readiness, primarily due to the limited implementation of smart city services and suboptimal user experiences. In order to understand smart city digitalization readiness from the perspective of Malaysian subcontractors, it is necessary to formulate relevant questions based on established models previously applied in the smart city context. As research exploring the construction industry's perspective in Malaysia remains limited, this study adapts the McVay readiness questionnaire which also adapted by Ong et al. (2023) to the smart city context, focusing on comparable factors such as comfort and self-management.

In this study, subcontractors were identified and selected based on their active involvement in urban development projects. However, responses were filtered to include only those currently engaged in building or infrastructure-related work to ensure relevance to smart city contexts. Subcontractors from various trades within the Malaysian construction industry were targeted, including electrical, mechanical and plumbing (MEP), civil works, ICT infrastructure. These trades were chosen as they are directly or indirectly impacted by smart city digitalization through the integration of digital systems (e.g., IoT, smart sensors, data platforms). Subcontractors in purely manual trades were excluded as their work currently has limited integration with digital technologies. Through this questionnaire a general perspective of subcontractors on readiness of smart city development can be interpreted by assessing their comfort and self-management. However, the goal of this research is to measure the engagement of subcontractor's readiness in smart city digitalization.

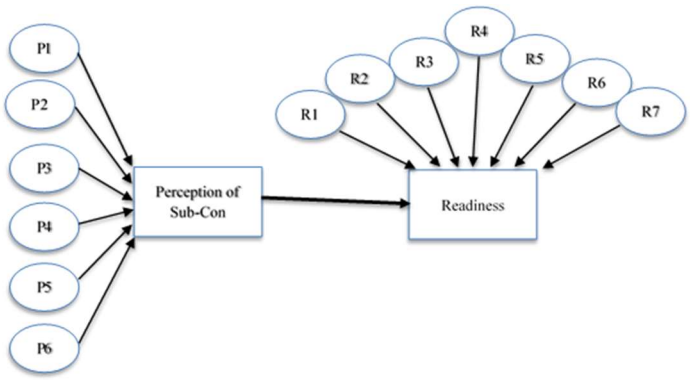


Fig. 1. Conceptual framework for the study

Table 1. Demographic profile

Demographic variable	Category	Frequency (n)	Percentage (%)	Cumulative percentage (%)
Gender	Male	95	90.0%	90.0%
	Female	10	10.0%	100.0%
Age group	20 or below	2	2.0%	2.0%
	21–25	40	38.0%	40.0%
	35–44	18	17.0%	57.0%
	45–54	9	9.0%	66.0%
	55–64	3	3.0%	69.0%
	65 and above	0	0.0%	69.0%
Education level	Secondary school	10	10.0%	10.0%
	Skills certificate/Diploma	35	33.0%	43.0%
	Bachelor's degree	54	51.0%	94.0%
	Master's degree	6	6.0%	100.0%
Years of experience	1–5	58	55.0%	55.0%
	6–10	21	20.0%	75.0%
	11–15	15	14.0%	89.0%
	16–20	5	4.70%	93.70%
	21–25	4	3.80%	97.50%
	26 and above	2	2.50%	100.0%

A conceptual framework is developed to guide this research by giving a foundation for research questions and hypotheses, creating links between variables to be researched, and offering a foundation for evaluating results as shown in Fig. 1.

The conceptual framework of this study proposes that subcontractors' perception of smart city digitalization which measured through awareness, perceived relevance, and perceived benefits has a direct and significant influence on their readiness to adopt digital technologies in construction (Table 2). Readiness is assessed across multiple dimensions including digital self-efficacy, comfort with tech use, organizational support, change readiness (Table 3). Therefore, the following hypotheses were developed:

H1a: Subcontractors' awareness of smart city digitalization positively influences their digital self-efficacy.

H1b: Subcontractors perceived benefits of smart city digitalization positively influence their comfort with adopting new technologies.

H2a: Subcontractors' organizational support positively influences their engagement readiness toward smart city digitalization initiatives.

H2b: Subcontractors with higher learning readiness are more likely to exhibit greater digital self-efficacy.

A quantitative research design was adopted in this study, and statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS). In this study, the respondents are subcontractor in construction field, a purposive sampling was adopted. A total of 114 respondents from the subcontractors replied to the questionnaire. However, 9 respondents were excluded due to incomplete data. In Table 1 shown that remain 105 valid usable data. From the total of 105 valid sampling data, 90% are male respondents and 10% are female respondents. A huge population in the age group of 21 – 25 years old representing 38% of the population, followed by 35 to 44 representing 17%, 45 to 54 representing 9%, 55 to 64 representing 3% and lastly age 20 or below representing 2% of the population. An additional choice for the age group 65 and above was given. However, no respondents from the population were from that particular age group. This group comprises more than half of the respondents are graduates with degree where 54 respondents representing 51% of the population have a Bachelor's degree followed by 6 respondents representing 6% having a Master's degree. 35 respondents representing 33% of the population have acquired either skills certificate or a diploma relevant to the industry whereas 10 respondents representing 10% of the population have only completed education until the secondary school level. Lastly for the work experience of the respondents. This question ascertains the experience they have within the construction industry as a subcontractor. Most of the respondents have gained 1 to 5 years of experience within the industry with 58 of them representing 55% of the population. 21 respondents representing 20% of the population have gained 6 to 10 years of experience in the field. This is followed by 15 respondents representing 14% that have 11 to 15 years of

Table 2. Survey questionnaire (Part A – Perception)

No.	Item
P1	I am aware of the concept of smart city digitalization. (Awareness)
P2	I understand how smart city technologies (e.g., IoT, BIM, sensors) relate to construction activities. (Awareness)
P3	I believe smart city digitalization is important for the future of the construction industry. (Perceive Relevance)
P4	I think smart city digitalization is relevant to the work subcontractors do on-site. (Perceive Relevance)
P5	I believe that adopting smart city technologies can improve construction project outcomes. (Perceive Benefits)
P6	I view smart city initiatives as an opportunity for subcontractors to enhance their competitiveness. (Perceive Benefits)

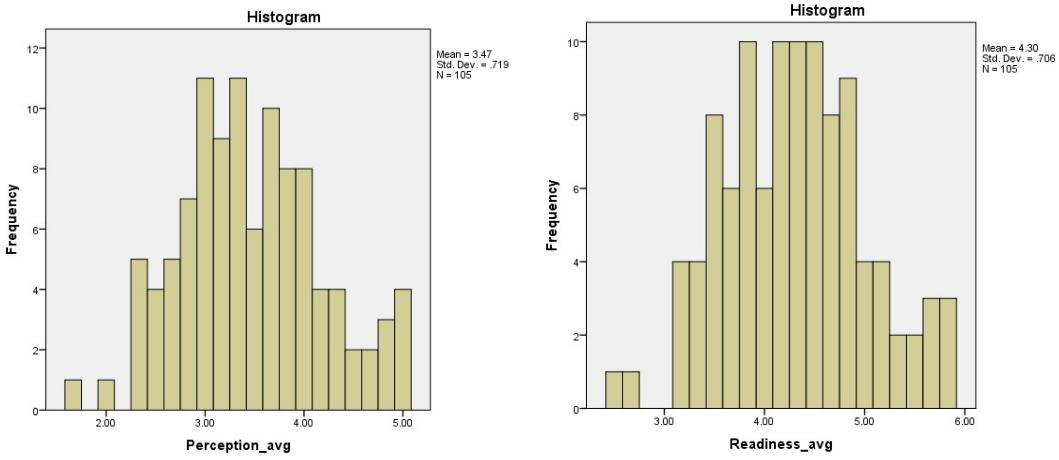
Table 3. Survey questionnaire (Part B – Readiness)

No.	Item
R1	I feel confident in my ability to learn and apply digital technologies related to smart cities. (Digital self-efficacy)
R2	I am comfortable using construction-related digital platforms or tools. (Comfort with tech use)
R3	I am open to changing the way I work if it helps align with smart city digital practices. (Change readiness)
R4	My company supports digital transformation and smart technology adoption. (Organizational support)
R5	I am willing to attend training or workshops to learn about smart city digitalization. (Learning readiness)
R6	I believe my team is capable of adapting to smart city digital technologies. (Team readiness perception)
R7	I am ready to take part in future construction projects that implement smart city technologies. (Engagement readiness)

experience, 5 respondents representing 4.7% that have 16 to 20 years of experience and 4 respondents representing 3.8% of the population gaining 21 to 25 years of experience. The least proportion of respondents come from the group with 26 years or/and above of work experience in which 2 respondents representing 2.5% of the population come from.

In the questionnaire, it comprised three sections: (1) respondent demographic information, (2) perception toward smart city digitalization, and (3) readiness to engage in smart city initiatives. To ensure construct validity, the perception construct was conceptualized based on relevant literature and adapted frameworks associated with digital transformation in construction and smart city contexts. The perception construct was measured using 6 items and it was measured through three core dimensions: awareness, referring to the respondent's understanding of smart city concepts, technologies, and objectives; perceived relevance, which captures the belief that smart city initiatives are important to the construction industry and directly applicable to their professional role; and perceived benefits, representing the belief that participating in smart city digitalization can provide professional or operational advantages, such as increased efficiency, competitiveness, or marketability (Table 2). Furthermore, the readiness construct was adapted from the McVay readiness model, as employed by Ong et al. (2023), and consisted of 7 items operationalized through four key components. Digital self-efficacy reflects the respondent's confidence in their ability to effectively engage with digital tools and technologies. Organizational support refers to the extent to which subcontractors perceive their companies as equipped and willing to adopt and invest in digital initiatives (Table 3). Comfort with technology use captures their willingness to learn, adopt, and integrate new digital tools into their daily work practices. Lastly, change readiness denotes their openness to embracing new systems, workflows, or standards that are aligned with the evolving demands of smart city development. These dimensions were incorporated into a structured questionnaire with six items measuring perception and seven items measuring readiness, each rated on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The initial version of the questionnaire was reviewed and validated by three academic experts and two industry professionals to ensure content relevance, language clarity, and practical appropriateness. The final items used in the survey are listed in Table 2 and 3.

Figs. 2(a) and 2(b) present the descriptive distributions for the independent variable (perception) and the dependent variable (readiness) in the context of subcontractor engagement in Malaysia's smart city digitalization. The histograms illustrate that both variables are moderately



(a) (b)

Fig. 2. (a) Descriptive of independent variable (left). (b) dependent variable (right)

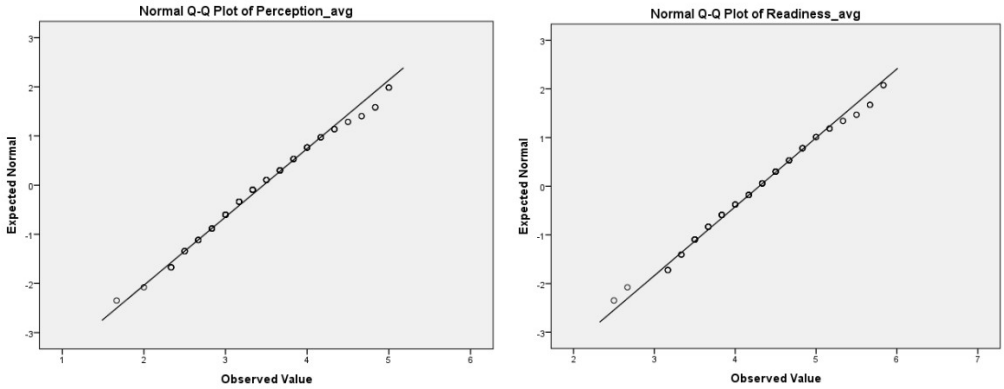


Fig 3. (a) Normality distribution for variable of perception (left). (b) Normality distribution for variable of readiness (right)

skewed toward agreement, with mean values of 3.47 for perception and 4.30 for readiness, and standard deviations of 0.719 and 0.706, respectively. These results indicate that, on average, respondents expressed a positive perception of smart city digitalization and a high level of readiness to be involved in such initiatives. To ensure the accuracy of the questionnaire, the instrument was first reviewed by a panel of three academic experts in construction management and digitalization, as well as two experienced practitioners from the construction industry. Based on their feedback, several items were rephrased for clarity and contextual relevance to subcontractors. A pilot study involving 15 subcontractors was subsequently conducted to evaluate the questionnaire's structure, language, and reliability. Based on pilot results, two ambiguous items were removed, and minor adjustments were made to improve comprehension.

Table 4. Reliability checking for the variables

Variables	Cronbach's alpha	N of items
Perception (P)	0.663	6
Readiness (R)	0.768	7

To assess the reliability of the data used in this study on subcontractor engagement in Malaysia's smart city digitalization, a reliability test was conducted using Cronbach's alpha. As shown in Table 4, both constructs achieved acceptable internal consistency, with Cronbach's alpha values of 0.663 for Perception and 0.768 for Readiness. Although the perception construct's alpha is slightly below the commonly cited threshold of 0.70, it remains within the acceptable range for exploratory studies and early-stage behavioral research, particularly within the social sciences. This is supported by prior studies, including Lamichhane (2021), who reported acceptable alpha values ranging from 0.62 to 0.71, and by Kallier (2017) and Lee and Kim (2015), who recognized values between 0.60 and 0.70 as acceptable indicators of reliability. Furthermore, the item total correlation values indicated satisfactory internal consistency, justifying the retention of all items within each construct.

Fig.3 (a) and (b) present the Normal Q–Q plots for the variables of perception and readiness, respectively. A normality test is used to visually assess whether the data follow a normal distribution, which is a key assumption for applying parametric statistical methods such as linear

Table 5. Coefficient of multicollinearity test

Model	Unstandardized coefficients[a]		Standardized coefficients	t	sig	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
Constant	2.468	0.289		8.538	0.000		
Perception	0.528	0.082	0.537	6.458	0.000	1.000	1.000

a. Dependent variable: Readiness

regression (Sreejesh, 2014). The plots indicate that the data points generally follow the expected trend, suggesting that the variables are approximately normally distributed. As the assumption of normality is satisfied, subsequent inferential analyses were conducted using parametric methods.

Multicollinearity is a concept where statistics will be applied to know the independent variable in a model is correlated with. The relationship between independent variables can be forecast by using multicollinearity. The mean of Variance inflation factor (VIF) value is the indicators of multicollinearity issue which proven by Hair et al. (2019). In this study, the result shows $1 < VIF < 10$. Therefore, no collinearity issue for the data collected is shown in Table 2.

After conducting the variables measurement testing, the data collected shows reliable, normal and valid to further performing inferential testing to investigate the correlation and the influences measurement to observe the impact of the independent variables towards the dependent variable. As such, Pearson correlation and regression analysis are performed for this study

4. RESULTS AND DISCUSSION

After conducting the data checking analysis and confirmed with the reliability, normality and collinearity test, further investigation is conducted to measure the inferential measurement. Inferential measurement enables to investigate the relation and influence of the independent variable of perception towards dependent variable of readiness on the engagement of subcontractors in Malaysia's smart city digitalization.

A. Inferential Measurement

Referring to the Table 6 indicates the result of correlation between the independent variable of perception towards dependent variable of readiness on the engagement of subcontractors in Malaysia's smart city digitalization.

The results indicate relationship between the independent variable, perception, and the dependent variable, readiness, in the context of subcontractor engagement in Malaysia's smart city digitalization, at the 99% confidence level ($p < 0.001$). These indicators reflect dimensions such as digital self-efficacy, comfort with new technologies, willingness to adapt workflows, and openness to learning, all key traits associated with readiness for digital transformation.

Importantly, Pearson's correlation analysis shows a moderate positive relationship between subcontractors' perception and readiness ($r = 0.537$, $p < 0.01$), which is statistically significant at the 99% confidence level. This suggests that subcontractors who have more favorable perceptions of smart city digitalization. For example, who perceive it as relevant, beneficial, or aligned with industry evolution are significantly more likely to report higher readiness levels. In other words, perception acts as a psychological enabler of readiness, highlighting the importance of awareness and attitudinal alignment in driving actual digital engagement.

These empirical results directly address the research gap identified in the introduction, which called for an investigation into how subcontractors are positioned in both cognitively and behaviorally, they are keen to participate in the growing landscape of smart city development. The evidence confirms that subcontractors are not merely passive actors, but are actively forming perceptions that shape their digital readiness. Moreover, this study contributes to the literature by quantifying the influence of perception, a variable often overlooked in readiness models applied to the construction sector, particularly for subcontractors in developing countries like Malaysia.

Table 7 shown the output of the regression analysis for the independent variable of perception towards dependent variable of readiness on the engagement of subcontractors in Malaysia's smart city digitalization. For the independent variable value, the probability of the t statistic showing 6.458 and statistical significantly at $p < 0.000$. therefore, null hypothesis is rejected. It is concluded that there is a statistically significant relationship between the independent variable of perception towards dependent variable of readiness on the engagement of subcontractors in Malaysia's smart city digitalization.

This study enables researchers to deepen their understanding of smart city digitalization acceptance among subcontractors within Malaysia's construction industry. This contribution aligns with the findings of Abanda et al. (2015), who highlighted the critical role of stakeholder buy-in for successful technology implementation in the built environment. While existing studies primarily explore digitalization acceptance by contractors and developers (Khosrowshahi and Arayici, 2012), this research uniquely emphasizes subcontractors, an often-overlooked stakeholder group in smart city contexts.

To examine the specific relationships between perception dimensions and readiness components, a Pearson's correlation analysis was conducted (Table 8). The results

Table 6. Correlation analysis for perception and readiness variables

Correlations			
		Perception_avg	Readiness_avg
Perception_avg	Pearson correlation	1	0.537**
	Sig. (2-tailed)		0
	N	105	105
Readiness_avg	Pearson correlation	0.537**	1
	Sig. (2-tailed)	0	
	N	105	105

** Correlation is significant at the 0.01 level (2-tailed).

Table 7. Regression analysis

Coefficients[a]					
Model		Unstandardized coefficients	Standardized coefficients	t	Sig.
		B	Beta		
1	Constant	2.468		8.538	0.000
	Perception_avg	0.528	0.537	6.458	0.000

[a] Dependent variable: readiness_avg

Table 8. Pearson's Correlation analysis for specified hypotheses

	Correlations		
Variables	Digital self-efficacy	Comfort with tech use	Engagement readiness
Awareness (H1a)	0.515**	0.442**	0.419**
Perceived benefits (H1b)	0.479**	0.534**	0.551**
Organizational support (H2a)	0.496**	0.500**	0.586**
Learning readiness (H2b)	0.520**	0.458**	0.504**

**Correlation is significant at the 0.01 level (2-tailed).

revealed several significant associations aligned with the proposed sub-hypotheses (H1a–H2b).

H1a predicted that subcontractors' awareness of smart city digitalization would positively influence their digital self-efficacy. A significant positive correlation was found ($r = 0.515^{**}$, $p < 0.01$), supporting the hypothesis. The strong correlation ($r = 0.515$) confirms that subcontractors with greater awareness of smart city concepts are more confident in their ability to learn and apply related digital tools.

H1b predicted that perceived benefits of smart city digitalization would positively influence comfort with technology. This was also supported, with a significant correlation ($r = 0.534^{**}$, $p < 0.01$). A significant association ($r = 0.534$) highlights that when subcontractors believe smart city adoption will yield tangible benefits, they are more comfortable using technology.

H2a proposed that organizational support would positively influence engagement readiness. The correlation was both significant and the strongest among all tested relationships ($r = 0.586^{**}$, $p < 0.01$). The highest observed correlation ($r = 0.586$) underscores the critical role of organizational backing in motivating subcontractors to participate in smart city projects.

H2b stated that learning readiness would be positively associated with digital self-efficacy. A significant positive relationship was observed ($r = 0.520^{**}$, $p < 0.01$). The strong link ($r = 0.520$) indicates that subcontractors who are willing to engage in training or workshops are more likely to feel confident in their digitalization abilities. Thus, investment in continuous learning opportunities might be a viable pathway to strengthening overall readiness.

From a methodological perspective, the study employs rigorous processes for assessing measurement model validity and reliability, mirroring standards set by Hair et al. (2019) on structural equation modelling in social sciences. This methodological rigor ensures the findings are both robust and reproducible, supporting the study's generalizability to other developing countries or industries exploring technological acceptance. For instance, the results can inform research on stakeholder engagement in similar technology-driven initiatives, such as smart manufacturing in developing economies.

Comparisons with related work further substantiate the study's contributions. For example, digital adoption studies in construction often focus on barriers such as cost or technology readiness (Gledson and Greenwood, 2017). In contrast, this research highlights the psychological and perceptual aspects influencing subcontractors' readiness, complementing prior insights while addressing a research gap. Moreover, the findings extend the digital adoption framework by emphasizing the interconnectedness of perception and readiness, paralleling studies in other sectors like healthcare technology (Dou, 2023).

The study's generalizability is also supported by its

methodological alignment with international best practices, such as the employment of robust statistical techniques and validated survey instruments. Consequently, these results provide a replicable blueprint for policymakers and industry leaders to foster smart city initiatives tailored to diverse stakeholder needs. Practical implications include the development of targeted strategies to enhance subcontractor engagement, such as workshops and training programs aimed at reshaping perceptions and increasing readiness for digital transformation. While this study provides useful insights into subcontractors' perception and readiness for smart city digitalization, it did not explore whether these responses differ across demographic subgroups such as age, education level, or years of experience. Conducting subgroup comparisons using statistical methods such as ANOVA or t-tests could reveal important variations in digital readiness and perception across different subcontractor profiles. This presents a valuable avenue for future research, particularly to inform targeted policy and training programs that cater to the needs of specific groups within the subcontractor population.

In short, this research bridges theoretical and empirical gaps by shedding light on subcontractors' perspectives in smart city digitalization. It not only complements existing literature but also offers actionable insights for fostering stakeholder engagement in Malaysia and beyond.

5. CONCLUSION AND RECOMMENDATION

This study explored the perception and readiness of subcontractors in Malaysia toward smart city digitalization within the construction industry. The findings indicate that subcontractors generally exhibit a high level of readiness to engage in smart city initiatives and perception serves as a critical factor influencing the readiness. Subcontractors who are more aware of smart city concepts, perceive them as relevant and recognize their benefits are significantly more inclined to adopt and support digital technologies in their professional practices.

These results highlight the vital role of perception as a psychological enabler of readiness. By strengthening awareness, relevance and perceived benefits among subcontractors, policymakers and industry leaders can enhance digital engagement across construction projects. The study underscores the need for continuous education, training and communication initiatives that align subcontractors' technical capacity with national smart city goals by improving perception as it could serve as an effective pathway to increase overall readiness and participation in smart city transformation.

This research contributes to the literature by addressing an often-overlooked group in smart city studies, subcontractors who play a crucial role in implementing digital solutions on-site. It enhances the understanding of their perceptions and readiness that helped to bridge the gap between policy-level strategies and ground-level execution. This method can ensure a more cohesive transition toward digitally enabled construction environments.

Nonetheless, this study has several limitations. The data relied on self-reported measures and was confined to a specific regional context, which may limit generalizability. Future research should expand the sample size, include diverse subcontractor categories and conduct subgroup analyses to explore variations across demographic. Longitudinal or mixed-method studies could further enrich understanding of how subcontractors' readiness evolves over time within the smart city development agenda.

DECLARATION OF COMPETING INTEREST

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

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