Cyber-physical systems for facilities management: a Delphi study on the propelling measures

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Abstract

Purpose – Through its advanced computational capabilities, cyber–physical systems (CPS) proffer solutions to some of the cultural challenges plaguing the effective delivery of facilities management (FM) mandates. This study aims to explore the drivers for the uptake of CPS for FM functions using a qualitative approach – the Delphi technique.

Design/methodology/approach – Using the Delphi technique, the study selected experts through a well-defined process entailing a pre-determined set of criteria. The experts gave their opinions in two iterations which were subjected to statistical analyses such as the measure of central tendency and interquartile deviation in ascertaining consensus among the experts and the Mann–Whitney U test in establishing if there is a difference in the opinions given by the experts.

Findings – The study's findings show that six of the identified drivers of the uptake of CPS for FM were attributed to be of very high significance, while 12 were of high significance. Furthermore, it was revealed that there is no significant statistical difference in the opinions given by experts in professional practice and academia.

Practical implications – The study's outcome provides the requisite insight into the propelling measures for the uptake of CPS for FM by organisations and, by extension, aiding digital transformation for effective FM delivery.

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Originality/value – To the best of the authors' knowledge, evidence from the literature suggests that no study has showcased the drivers of the incorporation of CPS for FM. Hence, this study fills this gap in knowledge by unravelling the significant propelling measures of the integration of CPS for FM functions.

Keywords Cyber–physical systems, Delphi study, Digitalisation, Drivers, Facilities management

Paper type Research paper

Introduction

Facilities management (FM) incorporates processes in an organisation to develop and maintain agreed services that aid and upscale the efficiency of the organisation's main activities (British Institute of Facilities Management [BIFM], 2019). Also, it is a process that enables the delivery of a sustainable enterprise within the ambits of managing an organisation's lifecycle with the aim of improvement in productivity and business support (Kamarazaly *et al.*, 2013). FM is attributed to the strategic assignment for the purpose of attaining a balance in business concerns, service management and technical processes (Jawdeh, 2013). The aforementioned description of FM portrays it as a vital strategic element in accomplishing the core objectives of any organisation. This is so due to its functions in the lifecycle of any business concern, which reflects a tactical value associated with delivery systems and assessment of facility utilisation. Hence, it can be noted that FM spans a wide spectrum of service solutions, including sustainability, maintenance, productivity, hospitality and safety (Kok *et al.*, 2011).

Inefficiencies and inadequacies hamper the delivery of FM tasks due to obsolete methods and systems, thereby negatively impacting performance (Atkin and Bildsten, 2017; Hoxha *et al.*, 2021; Ikuabe *et al.*, 2022). These problems bedevilling FM functions have a retarding ripple effect in attaining an organisation's objectives (Ikuabe *et al.*, 2023). Some of the attendant challenges include delays in covering the history of facility maintenance, poor collection of facility data, extension in processing time, abysmal quality control, non-conformance to standards, etc. (Aldowayan *et al.*, 2020; Ikuabe *et al.*, 2020a; Nidhi and Ali, 2020; Njuangang *et al.*, 2018). Furthermore, a major setback to the effective delivery of FM functions is not adhering to the transition of the espousal of innovative technologies (Aghimien *et al.*, 2022; Hudson, 2004; Ikuabe *et al.*, 2020b). With the superfluity of hurdles confronting the delivery of FM duties, it is imperative that innovative and modern systems, such as digital technologies, should be integrated into FM frameworks. The building industry is mandated to infuse systems resulting from innovative technologies to achieve longevity in building operation success and functionalities (Aghimien *et al.*, 2021; Islam *et al.*, 2019). Hence, deploying innovative systems is vital to proffer solutions to some of the challenges confronting the delivery of FM duties. New innovative systems would provide better outcomes in the light of optimised delivery, quick execution of tasks, efficient cost management and quality delivery system. One new innovative system with these attributes is cyber–physical systems (CPS).

CPS are computing systems whose functional ability is premised on the integration of advanced capabilities of computational structure and physical processes (Akanmu *et al.*, 2013; Ikuabe *et al.*, 2020c; Yuan *et al.*, 2016). Also, it is a complex, multidisciplinary, physically-alert upscaled engineering system whose operability is vested in the fusion of the physical structure and computing technology embedded for transformative systems utilisation. The system presents a scenario for resolving problems in real-time by providing an interrelationship with several technologies, such as wireless sensor networks, dispersed systems, real-time systems and control systems (Fitzgerald *et al.*, 2015; Lee, 2015). For engaging in FM tasks, CPS presents a framework that aids the coordination and monitoring of the elements of a facility enabled by real-time functions due to the synergized working ability between the physical facility and the virtual component (Akanmu and Anumba, 2015; Terreno *et al.*, 2020). As earlier stated, FM is multidisciplinary and transdisciplinary, whose deliverability is significantly influenced by human coordination, which is susceptible to managerial dysfunctions. Hence, incorporating CPS into FM tasks would help forestall some of these ostensible challenges.

Based on the outlined challenges faced in the delivery of efficient FM mandates and the potential benefits presented from the uptake of innovative technology such as CPS, this study is geared towards assessing the significant drivers for the espousal of the system for FM functions. The outcome of the study intends to fill the knowledge gap as, to the best of the authors' knowledge, no study has focused on the enabling measures for the incorporation of CPS for FM duties. Also, the study's findings would present a solid theoretical base for future studies on including digital technologies to deliver FM functions effectively. The follow-up sections of the paper include a review of extant literature, the methodological section, the outcome of the Delphi survey conducted, discussion of findings and conclusion and recommendations.

Drivers of the uptake of cyber–physical systems for facilities management

The delivery of FM functions is posed by a wide range of challenges, some of which includes the rise in the cost of energy, delay in detecting breakdown of building systems, mismanagement of facility space, irregular maintenance records and dissatisfaction of building occupants (Han *et al.*, 2012; Ikuabe *et al.*, 2023). A range of FM systems is attributed to passive guidelines, which are pre-programmed, whereas they need to be framed to accommodate complicated, changing and flexible scenarios comprehensively. In proffering solutions to some of these FM problems, systems have been proposed that would help the effective and efficient capture and assessment of the collective delivery of FM tasks to the benefit of the organisation. Terreno *et al.* (2020) affirmed that the uptake of innovative systems for coordinating and monitoring FM processes could help upscale its delivery mandate. A CPS approach for the delivery of FM tasks would improve the monitoring and coordination of the facility's elements by using real-time functionalities resulting from the fusion of physical and virtual platforms driven by networks and technologies (Akanmu and Anumba, 2015). The acquired data by the sensor technology covers detecting facility breakdown, monitoring energy use, reporting on potential system failure, safety surveillance and space management, etc. Also, a CPS-driven FM promulgates elements of facilities for conducting cognitive functions, hence, facilitating the recognition of the physical scenario enabled by a high level of intelligence (Wu *et al.*, 2014).

The conversation of resource allocation by organisations is important due to the significant implications of the choices made on resources reflecting on the growth or survival of the business concern. Due to the ever-increasing competition in the business environment, organisations make strategic decisions on what is best to invest in to help elevate their market capacity (Erdoğmuş and Esen, 2011). The need for an improvement in a system's efficiency and the increased level of consumer demands will propel the economic competition geared towards creating innovative approaches and technologies (Jahromi and Kundur, 2020). Also, the increasing competitiveness of the business landscape and the rapid accessibility of cost-effective sensing and other technological infrastructure is a major incentives for the uptake of emerging digital technologies (Lee *et al.*, 2005). Furthermore, the call for the improvement in the reliability of delivery of any mandate through the uptake of innovative technology is a motivating factor for using CPS for FM. This is attained through the high levels of connectivity facilitated by the seamless human-machine interaction (Parasuraman and Colby, 2014). Moreover, the learning capability of personnel plays a vital role in the drive to infuse innovative systems for service delivery (Serdyukov, 2017). This is vital as the human dimension in setting up the system to use and the subsequent management and making sense of the data and other dimensions are important.

Hakansson *et al.* (2015) noted that the concept of using CPS is being pushed by several factors, including the revolution experienced in wireless communication, the high-end increased capacity of low-cost sensors and the proliferation of internet bandwidth, among others. All these speak to the technological infrastructure necessitated for the application and use of any innovative technology. Howard *et al.* (2017) stated that the espousal of digital technologies is expedited by providing the requisite infrastructure for the setup and application of the system. Also, an important measure is a willingness by the top management of the organisation to key into the realities of the uptake of such a system for the improvement of service delivery. As an organisational structure is made up of responsibilities and roles that are put in place to aid in the accomplishment of objectives (Agbim, 2013), the top management hierarchy, which is saddled with the responsibility of taking very significant roles, plays a key role in the determination of choice to use digital technologies for service delivery of the organisation. While the intellectual resource to be provided for the use and management of the innovation seeks to ensure that the system is continuously put to best use, thereby playing a significant role in the uptake (Talukder and Quazi, 2011). Also, system security plays a significant role in the choice of the espousal of innovative technologies. Tomlinson *et al.* (2022) stated that the provision of a root of trust, implementation of cryptographic algorithms and guarding against physical attacks by secure hardware is a prominent element in the pursuit of the application of digital technologies for service delivery.

The role of market demands as a driver for the espousal of innovative systems such as CPS must be considered. Hastings and Sethumadhavan (2020) outlined that because organisations need more knowledge in considering a business model for securing the uptake of innovative systems, a framework to help establish the potential derivatives from these innovations would help propagate the need for their uptake by organisations. This is very true with adopting CPS for FM as most organisations need the requisite know-how of the deliverables of using the system. Similarly, Potter (2020, p.4) stated that "key stakeholders are placing increased pressure on companies to demonstrate with evidence how they invest in and use security technology to protect digital assets". Furthermore, the training and support provided to facilities managers to help bolster their technical competence in using digital technologies can boost the utilisation of these systems. Odumeru (2013) affirmed that providing the requisite knowledge to the handlers and users of digital technologies helps improve the call for the application of these high-end systems. Ideally, without being equipped with the knowledge of the application of these systems, end users would form a stumbling block towards the acceptance of the system.

Due to the demands of FM in the continuous updating of the working conditions of elements of the facility, there is constant pressure on the operational and service delivery of the system (Palem, 2013). The use of CPS for FM functions can aid the advancement of financial and predictive strategies, which is an improvement from conventional FM systems. Odumeru (2013) stated that when comparative advantage is guaranteed from the utilisation of an innovative system as against the traditional mode of service delivery, it helps propagate the need for the espousal for the system. The application of CPS in the delivery of FM mandates presents considerable effective management abilities as the high computational deliverability of the system can aid in abating total failure in the elements of the facility. Furthermore, the interoperability and data integration between the innovative system and the elements of the facility helps proliferate the utilisation of digital technologies such as CPS in the delivery of FM tasks. According to Shen *et al.* (2016), in complex facilities, it is important that an elemental-level assessment is conducted as against a whole assessment of the facility. Hence, the integration of data at an aggregate scale for facility analysis would be vital in driving the application of innovative technologies such as CPS. Table 1 summarises the drivers of the espousal of CPS for FM.

Table 1.
Drivers of the uptake of CPS for FM

Drivers	Authors
Compatibility with work procedures	Jaafar *et al.* (2007)
Compatibility with previous system	Jaafar *et al.* (2007)
Speed and reliability of system	Gupta *et al.* (2008)
Comparison with previous system	Odumeru (2013)
Training and support	Odumeru (2013), Serdyukov (2017)
Flexibility of learning	Parasuraman and Colby (2014), Serdyukov (2017)
Learning capability of personnel	Froese (2010), Serdyukov (2017)
Convenience	Merschbrock and Nordahl-Rolfsen (2016)
Interactivness	Jaafar *et al.* (2007)
Technology infrastructure	Howard *et al.* (2017)
Resource allocation	Erdoğmuş and Esen (2011)
User satisfaction	Parasuraman and Colby (2014)
System security	Watson (2018), Parn and Edwards (2019)
System stability	Jaafar *et al.* (2007)
Top management willingness	Lee *et al.* (2015), Oliveira *et al.* (2014)
Financial resource	Erdoğmuş and Esen (2011)
Intellectual resource	Talukder and Quazi (2011)

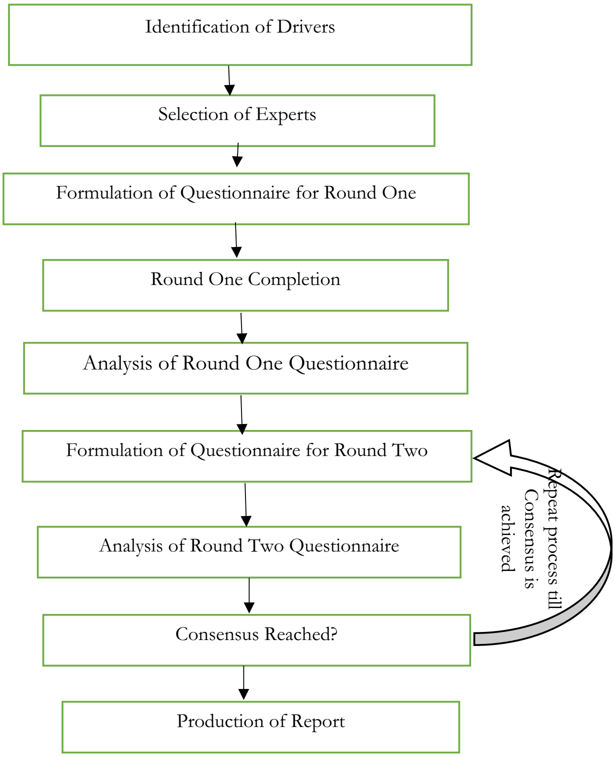
Source: Author's compilation

Research methodology

The aim of the study is to assess the driving factors of the uptake of CPS for FM using a Delphi approach. A constructive perspective was the philosophical view used for the study due to its qualitative nature. This approach presents the formulation of a worldview with peculiar knowledge and understanding conceptualised from experiences and a review of these experiences (Adom *et al.*, 2016; Mahamadu *et al.*, 2019). According to Chan *et al.* (2001) and Grisham (2008), the Delphi method is a type of qualitative methodological approach whose application is aimed at attaining a consensus among a group of experts forming a panel on a particular subject of interest. Moreover, the method is recommended to advance models, frameworks and research concepts. Several studies in the construction, built environment, FM and engineering sphere have used the Delphi method as an approach to research methodology (Aghimien *et al.*, 2020; Ikuabe *et al.*, 2023; Tengan and Aigbavboa, 2018). For this study, a Delphi technique is used to validate the drivers of adopting CPS for FM using the opinions provided by a panel of experts. This was actualised after a sequence of rounds in projecting the culmination of the views presented by the experts, which outlines a convergence of opinions of the panel of experts (Aigbavboa, 2013). Figure 1 outlines the framework of the Delphi study engaged for this research.

Selection of Delphi experts

The selection of the experts to make up the panel of the Delphi study is the aftermath of the establishment of the objectives of the research. The selection of the experts making up a Delphi panel is one pronounced area of unclarity in the Delphi process (Armstrong *et al.*, 2005; Rowe and Wright, 1999). In the current study, a well-defined process that established the yardstick that aided the selection of the experts to make up the panel of the Delphi study was put in place. Past studies have conformed with adopting a systematic process in selecting panel members for a Delphi study (Chan *et al.*, 2001; Ikuabe *et al.*, 2023). However, other studies have opted for a more relaxed and flexible process in selecting panel experts, albeit defining the selection criteria (Somiah *et al.*, 2020; Hallowell and Gambatese, 2010).



Source: Adapted from Aigbavboa (2013)

Figure 1.
Framework for the Delphi study

In the current study, the selected approach assesses the stipulated predetermined criteria in collaboration with the demographic details of the potential panel expert, with the affirmation of the attainment of 50% of the outlined criteria. This view of panel member selection aligns with previous studies (Aghimien *et al.*, 2020; Ikuabe *et al.*, 2023). The stipulated requirements for this study are the possession of a minimum academic qualification of a bachelor's degree in FM, engineering, construction or architecture (Evans and Farrell, 2021); the possession of a minimum of professional experience in the aforementioned professional domains (Aghimien *et al.*, 2020); a well-established knowledge in the use of digital technologies for FM or construction management (Ikuabe *et al.*, 2023); and a current employee of FM or construction establishment or having membership of the faculty of a university (Chan *et al.*, 2001).

Past studies have shown that there is no convergence in opinions on the sample size for a Delphi study (Williams and Webb, 1994; Ameyaw *et al.*, 2016). Hence, this study conducted a recruitment process for the panel experts by sending out an invitation to 32 potential panel members using email as the contact mode. The initial invite to partake in the Delphi process entailed a comprehensive explanation of the idea behind a Delphi technique, a well-detailed outlay of the process involved and the study's objective. A total of 32 potential panellists were sent invites, while 18 showed interest in partaking in the Delphi study. Consequently, the Delphi questionnaire was sent to these 18 experts to serve as the first round of the Delphi process. At the end of the round of the Delphi process, only 11 experts returned their questionnaire, which was appropriately completed. These 11 panellists also engaged in the entire process of the Delphi study by engaging in all the rounds of the study. A representation of the background information of the experts making up the Delphi panel is presented in Table 2.

Delphi iterations

Past studies have shown that there is a convergence of opinion on the number of rounds required for conducting a Delphi study (Critcher and Gladstone, 1998; Aigbavboa, 2013). Nevertheless, for most studies in the field of FM, engineering, architecture and construction, a consensus is usually met in two or three iterations or rounds (Ameyaw *et al.*, 2016; Ikuabe *et al.*, 2023). Two rounds were conducted for the current before consensus was achieved. Either round was engaged for one month, which provided ample time for the panellists to make quality contributions to the Delphi study. The research instrument for the first round was propounded by the outcome of the review of relevant literature on the subject under focus, while that of the second round was formulated on the opinions provided in the first round by the experts. Therefore, the Delphi questionnaire of the second round was an output of the brainstorming engagement from the panellists from the initial round. In the first round of the Delphi process, the questionnaire was comprised of open-ended questions, which availed the experts to proffer suggestions and ideas that were not initially captured by the research instrument. Therefore, this culminated in the formation of the questionnaire for the second round of the Delphi process. In each round, the experts' opinions were

Demographic designation	No. of experts	Percentage
Academic qualification		
Bachelor's degree	4	36.36
Master's degree	3	27.28
Doctor of philosophy	4	36.36
Total	11	100.00
Area of specialisation		
FM	4	36.36
Construction management	4	36.36
Building construction	2	18.19
Information technology	1	9.09
Total	11	100.00
Years of experience		
1–5 years	1	9.09
6–10 years	3	27.28
11–15 years	5	45.45
16–20 years	1	9.09
Over 20 years	1	9.09
Total	11	100.00
Employment agency		
Consultancy	3	27.27
Contractor	3	27.27
Government	5	45.46
Total	11	100.00

Source: Author's compilation

Table 2. Background information of experts

analysed to ascertain the consensus range in their responses. The second round entailed providing the experts with a closed-ended questionnaire, which presented the opportunity for the panellists to rate the analysis's outcome from the Delphi study's first round. Thereafter, the retrieved responses from the second round were also analysed to ascertain whether consensus was achieved on the reviewed issues.

Achieving consensus

The attainment of consensus from opinions provided on a subject matter is a tough task. No generally outlined rule stipulates how consensus can be achieved in a Delphi study. Holey *et al.* (2007) and Chan *et al.* (2001) noted that as consensus is the same as agreement, it is achieved through the communal protrusion of discernments, aligning with the subjective perception of central tendency or agreement of the views provided by the panellists in the rounds making up the Delphi study. Previous studies have used several statistical techniques in determining the consensus of a Delphi process. Rayens and Hahn (2000) used the mean item score and standard deviation, which stipulated that a decreasing return of the standard deviation in progressive rounds amounted to a high likelihood of consensus. Also, McKenna (1994) affirmed the consensus of a Delphi process using frequency distribution using a criterion of 51%. Similarly, other studies have deployed techniques such as inter-quartile deviation (IQD) in establishing a consensus of a Delphi study (Aigbavboa, 2013; Somiah *et al.*, 2020; Ikuabe *et al.*, 2023). In this study, the combined use of IQD, mean item score and standard deviation was used for the determination of consensus in the ensuing rounds of the Delphi study. The IQD entails producing the absolute difference between the 75th and 25th percentiles. A percentile represents a value of a test that is not referenced. Within the bandwidth of any formation, there is the 25th percentile, referred to as the first percentile (Q1), the 50th percentile, referred to as the second percentile (Q2), also known as the median; and the 75th percentile, referred to as the third percentile (Q3). According to Aigbavboa (2013), an IQD with a small value indicates a high extent of consensus, while an IQD with a high value indicates a low extent of consensus. The scales for determining consensus for the current study are outlined in Table 3. It indicates that a strong consensus is achieved when the resulting median is within the range of 9–10, while the mean has a resulting value of 8–10, and the IQD has a value ≤ 1.

Determining reliability and validity of the Delphi process

A Delphi process's reliable output can be guaranteed by ascertaining the validity and reliability of the data set for the study. However, resolving a reliable and valid Delphi process is a significant challenge for any Delphi study (Ameyaw *et al.*, 2016). "Reliability is the extent to which a procedure produces similar results under constant conditions at all times" (Els and Delarey, 2006 p. 52). Because Delphi studies are classified as a qualitative method of research, it then becomes difficult to establish the reliability and validity of the process as the results are hinged on intuitive reflection of the panellists' knowledge and

Status of consensus	Median	Mean	Interquartile deviation (IQD)
Weak consensus	≤ 6.99	≤ 5.99	≥ 2.1 ≤ 3 and ≤ 59% (5.99)
Good consensus	7–8.99	6–7.99	≥ 1.1 ≤ 2 and ≥ 60% ≤ 79% (6–7.99)
Strong consensus	9–10	8–10	≤ 1 and ≥ 80% (8–10)

Source: Author's compilation

Table 3.
Scale for consensus categorisation

perception of the subject under focus (Creswell, 2009; Aigbavboa, 2013). Nonetheless, the challenge can be overcome through a well-defined and detailed description of the process to the potential panellists and by presenting a simple understanding of the objective of the process (Yousuf, 2007). Against this backdrop, this study clearly explained the study's intent to experts making up the panel for the Delphi process. This was achieved through a detailed presentation of the identified drivers of the incorporation of CPS for FM. Moreover, a detailed guide on completing the Delphi questionnaire was shown to the experts of the Delphi study. According to Aigbavboa (2013), the expert selection process of a Delphi study also serves as a validity check for a Delphi study. Therefore, conscientious efforts were devoted to the process of expert selection for the Delphi study while also ensuring the suitability for the purpose of the study.

Findings

Delphi round one result

The initial round of the Delphi study gathered responses from the experts making up the panel on the drivers of the uptake of CPS for FM. There was a window for the inclusion of measures not captured in the survey by the experts. The study used a ten-point Likert scale having a coverage between very low significance to very high significance. The result of the first round of the Delphi study is presented in Table 4; it shows the findings of the mean, median, standard deviation, IQD and Mann–Whitney U test conducted. In trying to establish if there is a convergence in the opinions provided by the experts based on their affiliation with respect to professional practice and academic institutions, the Mann–Whitney U test was used. According to Pallant (2005), a measure with a divergence in views from the respondents will have a p-value ≤ 0.05, while a measure with convergence in views from the respondents will have a p-value > 0.05. The findings of the study show that all the identified

Drivers	Median	Mean	SD	IQD	Mann–Whitney Z	p-value
Compatibility with work procedures	7	8.66	1.09	1.00	−1.556	0.072
Compatibility with previous system	6	7.32	0.67	2.00	−0.237	0.232
Speed and reliability of system	7	8.38	0.43	1.50	−0.736	0.421
Comparison with previous system	6	7.87	1.38	0.50	−1.333	0.339
Training and support	7	8.11	0.84	1.50	−1.728	0.521
System's learning flexibility	6	7.22	0.22	2.00	−0.493	0.293
Learning capability of personnel	8	7.24	0.39	1.50	−0.335	0.717
Convenience of the system's use	7	8.84	1.05	1.50	−0.781	0.062
Interactiveness of the system	7	7.28	0.63	2.00	−1.253	0.374
Technology infrastructure	8	8.19	0.72	1.50	−0.397	0.552
Resource for procurement of system	6	7.28	0.18	1.00	−1.736	0.621
User satisfaction	7	7.99	0.95	1.50	−1.293	0.488
System security	8	8.01	0.42	2.00	−0.648	0.087
System stability	7	7.84	0.77	1.50	−1.275	0.783
Top management willingness	6	8.41	0.34	1.50	−0.382	0.392
Maintenance costing	8	8.07	1.24	1.50	−1.224	0.071
Financial resource	8	7.92	0.27	0.50	−1.002	0.437
Intellectual resource	6	6.87	1.83	1.00	−1.638	0.561
Cronbach alpha			0.779			

Notes: SD = standard deviation; IQD = interquartile deviation
Source: Author's compilation

Table 4. Delphi round 1 results

drivers have a p-value > 0.05, therefore indicating that there is no statistically significant difference in the responses provided by the two groups of respondents. Furthermore, the validity and reliability of the research instrument were ascertained with the use of the Cronbach Alpha test; this gave a value of 0.779, which portrays a commendable validity and reliability of the research instrument for the Delphi study as the value tends towards 1.00 (George and Mallery, 2000). Moreover, in the first round of the Delphi study, there was no formidable consensus attained among the identified drivers; the result of the IQD obtained from the findings shows they were within the range of 1.00 and 2.00.

Delphi round two result

Table 5 presents the findings of the second round of the Delphi study involving the experts that participated in the first round of the process. The results indicate that the validity and reliability of the research instrument at this round is given as 0.827 gotten with the Cronbach alpha test. The result of the Mann–Whitney U test shows no significant difference in the views provided by the two groups of respondents based on their affiliation, i.e. professional practice and academic institutions. Furthermore, the results show that the experts considered six of the drivers to be of very high significance (VHS: 9.00–10.00). These are speed and reliability of system (*Mean = 9.45; IQD = 1.00*); technology infrastructure (*Mean = 9.00; IQD = 0.50*); user satisfaction (*Mean = 9.27*; *IQD = 0.50*); system security (*Mean = 9.22*; *IQD = 1.00*); system stability (*Mean = 9.29*; *IQD = 1.00*); and financial resource (*Mean = 9.36*; *IQD = 0.00*). Furthermore, 12 of the drivers were shown to be of high significance (HS: 7.99–8.00). These are compatibility with work procedures (*Mean = 9.00*; *IQD = 0.00*); compatibility with previous system (*Mean = 8.55*; *IQD = 1.00*); comparison with previous system (*Mean = 8.82*; *IQD = 0.00*); training and support (*Mean = 9.18*; *IQD = 0.50*); system's learning flexibility (*Mean = 8.73*;

Drivers	Median	Mean	SD	IQD	Mann–Whitney Z	Mann–Whitney p-value
Compatibility with work procedures	8	9.00	0.54	0.00	−1.283	0.472
Compatibility with previous system	8	8.55	1.13	1.00	−1.694	0.339
Speed and reliability of system	9	9.45	0.52	1.00	−1.003	0.061
Comparison with previous system	8	8.82	1.08	0.00	−1.841	0.519
Training and support	8	9.18	0.60	0.50	−0.329	0.394
System's learning flexibility	7	8.73	0.90	1.00	−0.721	0.078
Learning capability of personnel	8	9.09	0.70	0.50	−0.692	0.617
Convenience of the system's use	8	9.00	1.10	1.00	−0.429	0.069
Interactiveness of the system	8	8.82	0.98	1.00	−1.558	0.722
Technology infrastructure	9	9.00	0.98	0.50	−0.371	0.271
Resource for procurement of system	8	9.18	0.40	0.00	−0.227	0.119
User satisfaction	9	9.27	0.47	0.50	−1.642	0.231
System security	9	9.22	0.65	1.00	−0.937	0.428
System stability	9	9.29	0.65	1.00	−0.388	0.339
Top management willingness	8	9.09	0.83	0.50	−1.749	0.173
Maintenance costing	8	9.00	0.92	0.00	−0.492	0.082
Financial resource	9	9.36	0.67	0.00	−1.227	0.739
Intellectual resource	8	8.64	0.92	0.00	−0.933	0.293
Cronbach alpha			0.827			

Notes: SD = standard deviation; IQD = interquartile deviation
Source: Author's compilation

Table 5.
Delphi round 2 results

IQD = *1.00*); learning capability of personnel (*Mean* = *9.09*; *IQD* = *0.50*); convenience of the system's use (*Mean* = *9.00*; *IQD* = *1.00*); interactiveness of the system (*Mean* = *8.82*; *IQD* = *1.00*); resource for procurement of system (*Mean* = *9.18*; *IQD* = *0.00*); top management willingness (*Mean* = *9.09*; *IQD* = *0.50*); maintenance costing (*Mean* = *9.00*; *IQD* = *0.00*); and intellectual resource (*Mean* = *8.64*; *IQD* = *0.00*). Also, the findings showed that none of the drivers identified for the study was of no significance in the espousal of CPS for FM. Given the scale provided in Table 3, all the drivers achieved consensus based on the opinions that the experts provided for the Delphi study. Also, the validity and reliability test conducted for the research instrument yielded an alpha value of 0.827, which portrayed good reliability.

Discussion of findings

The study's objective was to evaluate the drivers of the espousal of CPS for FM. A Delphi approach was used for the study, and the result from the process showed that six of the identified drivers were of very high significance, while 12 were of high significance. Furthermore, a consensus was attained regarding the opinions provided by the panellists on the identified drivers. The financial capability of any organisation serves as a bedrock for inculcating technological systems and innovations for its process deliveries and activities. Findings from this study highlight that an organisation's resource allocation outlay is a major influencing factor for adopting CPS for FM. The financial capability is of great importance to technology adoption as the entire chain of purchase, installation, usage, to maintenance is firmly placed on the financial strength of the organisation in engaging in these activities (Erdoğmuş and Esen, 2011). This finding opens a new chapter of thoughts in the light of stating that it is not enough for the organisation's willingness to pull through the adoption of technological innovations such as CPS; also, the financial capacity of the organisation is a huge determining factor. Also, findings showed that the willingness of the top management hierarchy of the organisation has a huge stake in deploying innovative systems and procedures. The top management of any organisation must be adequately informed of the benefits and advantages of using digital platforms for process deliveries (Walter, 2006; Lee *et al.*, 2005; Oliveira *et al.*, 2014). The top management of the organisation determines the strategic decisions to ensure that an organisation is well placed in the business environment by seeking to attain a competitive advantage over competitors. Hence, the top management board must be acquainted with up-to-date digital and technological dimensions that pertain to the field of concern. Similarly, Davis and Songer (2008) opined that without the conviction and support of the top management hierarchy of any organisation, the espousal of innovative technologies could be hindered. Moreover, system stability appeared to significantly influence the decision to adopt CPS for FM. This is corroborated by Lin *et al.* (2007), who stated that the ability of innovative technology to prove its stability in delivering optimised outcomes is a significant contributing factor in its espousal. Hence, the system's delivery attributes must be aligned with the core features of stability during task engagements. Moreover, the importance of intellectual resources at the disposal of the organisation for the implementation of new technology cannot be overemphasised, as the human resource for the management of the technology is fundamental (Talukder and Quazi, 2011). Furthermore, the call for the improvement in the reliability of delivery of any mandate through the uptake of innovative technology is a motivating factor for using CPS for FM. This is attained through the high levels of connectivity facilitated by the seamless human-machine interaction (Parasuraman and Colby, 2014). Moreover, the learning capability of personnel plays a vital role in the drive to infuse innovative systems for service delivery (Serdyukov, 2017). This is vital as the human dimension in setting up the system to use and the subsequent management and making sense of the data and other dimensions are important.

Conclusion and recommendations

The study used a Delphi approach to assessing the enabling measures for adopting CPS for FM. A thorough review of extant literature yielded eighteen drivers and was subsequently presented to the experts making up the Delphi panel for their opinions. The Delphi study entailed two iterations which were attributed to the attainment of consensus on the drivers in the second round of the process. Results from the study showed that the drivers that were deemed to be of very high significance are speed and reliability of the system, technology infrastructure, user satisfaction, system security, system stability and financial resource. Based on the findings of this study, it is important to note that the advancement of digital technologies, such as CPS, is driven by quite several factors, which includes the financial resource at the disposal of the organisation. Also, the cost input for the utilisation, management and maintenance of the technology is important. Furthermore, the infrastructure needed to use the innovative technology is a significant determinant of the use of the system. As all technologies can only thrive with the provision of the requisite infrastructure, it becomes imperative that the infrastructure needs for its implementation be addressed. Moreover, a guarantee of improving the functionalities of task or function deliveries for FM by using CPS is a significant enabling measure, as revealed by the study's findings. Due to the cutting-edge computational capabilities provided by the use of CPS, the delivery of FM mandates is guaranteed with high system security, speed and reliability and system stability.

The outcome of this study contributes to the body of knowledge as it showcases the significant measures for the uptake of CPS for the delivery of FM functions. The peculiarity of CPS as an advanced computational system and also an emerging technology in engaging FM tasks are gradually receiving scholarly attention. However, studies have yet to attempt to unravel the drivers for the use of innovative technology for FM use. Consequently, the findings from this study fill a knowledge gap. It also provides practical insights to organisations on the enabling measures that would aid in propelling the espousal CPS for the engagement of FM tasks. With these findings, organisations can make informed decisions on the need to overhaul their systems or modes of engaging FM functions by using digital technologies such as CPS. Moreover, the study's findings serve as a good theoretical base for further studies on the conversation for digital transformation in the construction, engineering and FM industry.

One important area of the study that needs to be clarified is the limitation of the study. As a peculiar attribute in most Delphi studies, not all experts invited for the Delphi study indicated an interest in participating in the process. If all invited experts had participated in the process, the outcome might have taken a different outlook. Furthermore, the findings from this study can be validated using other methodologies, such as quantitative and mixed methods. Moreover, the current study was conducted in one province of South Africa. Future studies can be carried out in other provinces of the country, as this might project a different outlook or help in giving broader insights into the findings of the current study.

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