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IMPLEMENTATION FRAMEWORK TO FACILITATE DIGITALIZATION OF CONSTRUCTION-PHASE INFORMATION MANAGEMENT BY PROJECT OWNERS

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SUMMARY: *The use of software applications which have been developed for owner management of large public capital-intensive projects lags that of similar applications made for contractors, resulting in negative implications for the productivity of the construction industry. In response, this paper provides a framework to facilitate the implementation of such digital construction-phase information management (DCIM) systems by project owners. This framework is developed by relating industry assessment of the potential positive impacts with factors that influence DCIM implementation in owner organizations (agencies). Specifically, the identified potential positive impacts were grouped into five improvement aspects and each group was related with a set of potential influencing factors. These were then related to the stakeholder entities that could control the relevant potential influencing factors. Two sets of primary data that were collected through a survey to industry experts were used in this research. The findings showed that 16 potential influencing factors significantly correlated to one or more improvement aspects. The findings further showed that five potential influencing factors are critical for maximizing one or more of the improvement aspects and thus overall system performance. This study shows that plans of technology implementation, selection of software, continuous support (technical capabilities and human efforts), and implementation monitoring and evaluation represent the four main steps for DCIM systems implementation. The presented framework can serve as a practical guide for project owners, especially public agencies, for the successful implementation of DCIM systems and evaluation of the systems' performance.*

KEYWORDS*: Implementation Framework, Digitalization, Construction Phase, Information Management, Project Owners*

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1. INTRODUCTION

The construction industry in the USA has been experiencing steady declines in its productivity and lags behind other similar engineering industries in their use of digitalization technologies (Agarwal et al., 2016, Barbosa et al., 2017, Li et al., 2021). An industry study by McKinsey (2019) has suggested a strong causal effect between the industry's lack of technology use and its low productivities. This paper thus aims to improve productivity in the construction industry by increasing the use of digitalization technologies – specifically focusing on software systems and applications that digitize project documents and digitally manage the projects' activities during the construction phase. These technologies are referred to herein as digital construction-phase information management (DCIM) systems and consist primarily of two software systems types: construction management software (CMS) and electronic document management systems (EDMS) (Shah et al., 2017). Such systems benefit project management by replacing time-intensive and expensive analog processes with real-time digital workflows that can greatly streamline project management and collaboration among project stakeholders.

To understand technology implementation in the construction industry, it is worthwhile to examine the roles of the various major stakeholders in a project – primary of which are contractors and project owners. Most technologies are created for contractors, who are more directly involved in managing construction projects. Consequently, most research into technology implementation in construction has focused on contractors (Lu et al., 2015). However, owners also have a significant role in construction project management being responsible for activities such as material approval, inspection, and change order processing, especially for large public projects. While digitalization technologies have been created for owners as well, there is considerably little information relating to best practices for implementation in owner organizations, especially large public agencies (Stewart et al., 2002, Lu et al., 2015). This lack of knowledge can negatively affect the broader adoption and use of information and communication technology (ICT) systems in the construction industry, which translates to lost productivity and increased project management costs.

In response to this lack of knowledge, the goal of this paper is to provide guidance for the digitalization of construction-phase information management by project owners.

Section 2 provides an overview of related literature to set the context for this paper, followed by a description of the research methodology and analysis of data collected from owner organizations. This is then followed by analysis of statistical results and development of a framework for DCIM implementation, which comprise the contributions of this paper towards its stated goal.

2. LITERATURE REVIEW

The literature review in this paper focuses on the research performed to develop frameworks to implement digitalization in the construction industry for contractors and owners to set the context for the research and to clearly delineate the gaps in knowledge and point of departure.

2.1 Implementation Frameworks for Digitalization by Contractors

In order to advance the knowledge in the area of implementation frameworks for project management digitalization, Stewart et al. (2002), built on five available frameworks (Leslie, 1996, Myllymaki, 1997, Miozzo et al., 1998, Jung and Gibson, 1999, Peña-Mora et al., 1999) and introduced a strategic implementation framework for information technology and information systems (IT/IS) in construction. The proposed framework served to accelerate the rate at which changes in people, tasks, and organizational structure can take place. However, the framework was developed to facilitate the implementation of IT/IS by only contractors, especially on large-scale projects.

One of the largest efforts to promote and facilitate the adoption of ICT systems by a large number of stakeholders in the European construction sector was the development of a roadmap called ICT vision in 2003 (Rezgui and Zarli, 2006). This roadmap was developed to identify the research and development actions required to attain comprehensive automation in the construction industry and to assist IT manager decision-making for technology, research, and development related issues, as well as deployment and adoption of ICT (Rezgui and Zarli, 2006).

In the USA, Nitithamyong (2003) introduced an implementation model to implement web-based project management systems on construction projects for contractors consisting of five main steps: (1) project selection, (2) implementation planning, (3) system selection, (4) ongoing support, and (5) performance monitoring. However, the model was developed for project-based implementation of rented web-based systems by contractors and is thus not widely applicable to a broader range of systems covered by DCIM.

2.2 Implementation Frameworks for Digitalization by Owners

Goger and Bisenberger (2020) reported that while there are many promising approaches for digitalization of project management for infrastructure construction, there is a lack of standardized and scientifically proven methods for their implementation for owners. Among the strategies of importance, the note implementation in pilot projects, analysis of the workflow methods, transparency of results, suggestions of new approaches, and investment in education. They also explained that many further steps are necessary for holistic implementation of digitalization in the lifecycle of infrastructure projects.

Shah et al. (2017) conducted research to address challenges and calculate return on investment for paperless project delivery known as e-Construction, which is an initiative promoted by the FHWA (Weisner et al., 2017). In this study, general implementation guidance, including activities and timelines, was developed and presented to facilitate the implementation of e-construction applications by departments of transportation (DOTs) (Shah et al., 2017). However, the guidance was developed for just one type of public agency (DOTs) and provides general recommendations for eight different e-Construction applications for different phases of projects. Lu et al. (2015) reported that research regarding project owners represented the lowest (4.1%) among 145 reviewed papers. It was also noted that none of this research relates specifically to implementation frameworks for owners. Therefore, more research is needed to develop or enhance IT implementation frameworks (or guidelines), especially those specified for one type of application and/or one phase of projects.

Jahanger et al. (2021a) published work that discusses project owner perceptions on the potential positive impacts that DCIM systems can bring to their projects. Eighteen potential positive impacts, shown later in Table 2 in section 4.1, were identified and assessed based on agreement levels from industry respondents that represent public owner agencies (Jahanger et al., 2021a). The impacts that were expected from the use of DCIM systems related to financial benefits, time savings, and improvement in task performance and productivity. Jahanger et al. (2021b) also identified and ranked 28 potential influencing factors, shown in Table 3 in section 4.2, that can affect the implementation of a DCIM system by project owners. More information about these works is presented in the methodology section as it closely relates to the work presented in this paper.

2.3 Gaps in Knowledge and Point of Departure

Based on the review of existing literature and previous work, the authors have identified the following specific gaps in knowledge for this research:

1. Less consideration of project owners in digitalization research: While there generally is significant research regarding the digitalization of project management by contractors, there is a clear lack of research in this regard for project owners. This is despite the fact that project owners, especially those of public projects, have a significant role in project management ranging from materials approval to final payment, and the fact that such software systems that cater exclusively to owners do exist. This non-consideration of project owners may negatively affect successful implementation by owners and thus broader adoption of digitalization in the construction industry.

2. Lack of practical implementation frameworks: While there exists significant literature regarding the digitalization of project management, especially for contractors, most of this research focused on topics other than implementation frameworks (or guidelines). While studying these topics is important to support and facilitate construction digitalization, these efforts could be augmented and made practical through the development of implementation frameworks, especially those that relate influencing factors and positive impacts to maximize the usefulness and effectiveness of technologies. Although some implementation models or guidelines have been developed for contractors as explained earlier, no frameworks have been generally developed for project owners' implementation of DCIM systems.

Thus, the goal of this paper is to provide guidance for the digitalization of construction-phase information management by project owners. The following specific objectives are pursued to fulfill this goal.

Objective 1: Determine relationships between potential influencing factors (PIFs) and potential positive impacts (PPIs) of DCIM systems for project owners.

Objective 2: Identify the entity that exercises greatest control over a potential influencing factor and thereby has influence over a desired potential positive impact in owner organizations.

Objective 3: Create knowledge and guidelines for the successful implementation of DCIM systems by project owners.

The point of departure of the current study is that it focuses on the perspectives of project owners unlike previous research; and in its development of a practical implementation framework that facilitates and provides guidance for DCIM systems implementation.

3. RESEARCH METHODOLOGY

Fig. 1 shows a conceptual map of the framework to facilitate the transition of owner organizations from analog to DCIM systems. This is conducted by associating the positive impacts that DCIM systems can bring to organizations (referred to as potential positive impacts in Fig. 1) and the factors that influence software implementation by owners (referred to as potential influencing factors in Fig. 1).

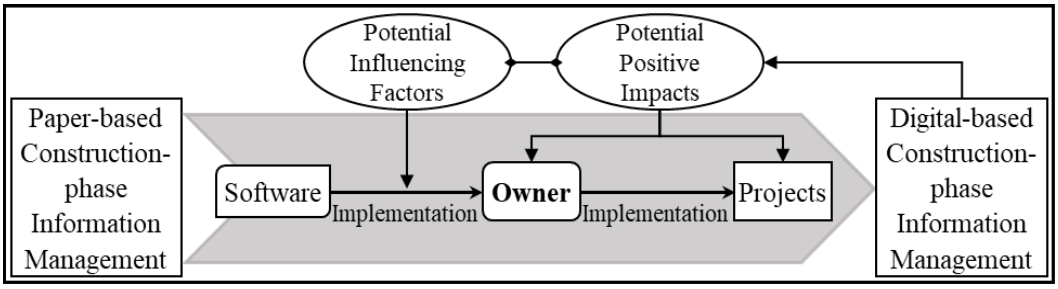

FIG. 1: Conceptual Map of DCIM Systems Implementation

Fig. 2 presents an overview of the methodology that was followed to fulfill the research objectives for this research.

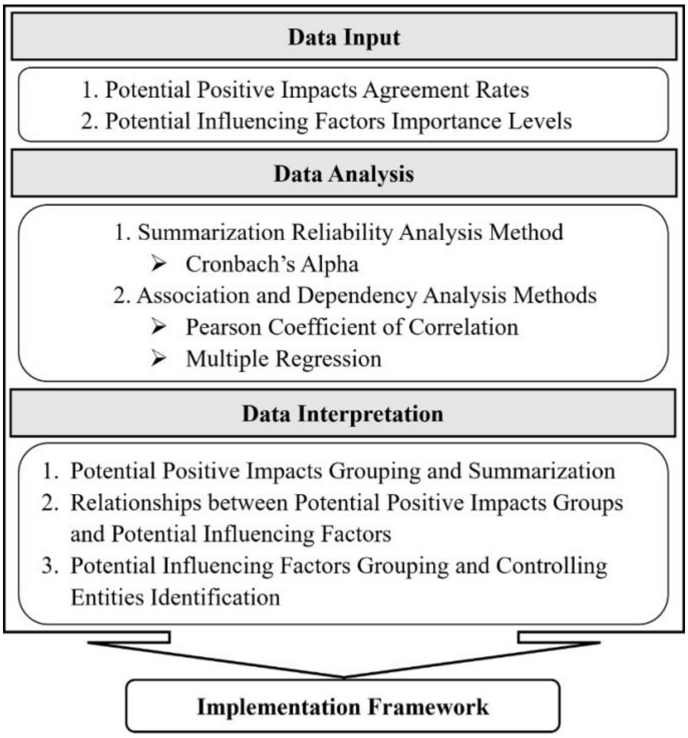

FIG. 2: Research Methodology

As shown in Fig. 2, the research methodology consists of three main stages: (1) data input, (2) data analysis, and (3) data interpretation. The data input consists of agreement rates regarding potential positive impacts (PPIs) and importance levels of potential influencing factors (PIFs) obtained from industry experts through survey questionnaires. The data analysis stage includes data preparation, grouping and summarization, and association and dependency analyses. The final stage of data interpretation includes analysis of the correlation and regression findings to draw research findings that can aid with the development of an implementation framework. Data input and data analysis phases are described in detail in the following subsections. Data interpretation is presented and discussed next in the Results and Discussion section.

3.1 Data Input (Potential Positive Impacts and Potential Influencing Factors)

Two sets of primary data that were previously collected through a survey (A self-administered web-based questionnaire) to industry experts were used in this research. The survey consisted of questions related to demographic information of respondents, questions related to respondents' perception of potential positive impacts (PPIs) of DCIM systems for project owners, and the respondents' evaluation of importance of potential influencing factors (PIFs) related to DCIM systems implementation. For the PPIs, the respondents were asked to rate their agreement with each PPI using a slider that ranged from one (lowest level of agreement with statement) to 100 (highest level) with increments of 1 degree. For the PIFs, the respondents were asked to rate each PIF importance also using a slider that ranged from 1 (not at all important) to 100 (extremely important) in increments of one unit. To enhance the clarity, quality, and minimization of time fatigue of the survey, it was pilot tested through multiple steps and with different subject matter experts (Ph.D. candidates, professors, a survey specialist, and an industry practitioner) before being distributed to industry experts.

A homogeneous purposive sampling technique was used to select the targeted sample due to the limitation in the number of experts available who can serve as primary data sources. Purposive sampling is a nonprobability sampling technique in which a sample is selected by researchers based on the characteristics of a population and the goal of the study (Crossman, 2018, Dudovskiy, 2019). Surveys were optional and directly distributed to employees (particularly owners' project administration and delivery staff) from two types of US owner agencies – state departments of transportation (DOTs) and public universities (PUs). These two large groups of project owners were targeted to obtain generality in findings with respect to owner type because they are different in size and capabilities as well as in type and complexity of projects they manage. The DOTs were selected because they are public agencies that perform construction projects to construct, maintain, and develop horizontal transportation infrastructure, especially highways. The PUs were selected because they also are public agencies and usually perform construction projects to construct, maintain, and develop vertical facilities ranging from educational and residential buildings to advanced research and sport facilities. Table 1 shows sample size and response rates as well as number of states represented in the survey.

TABLE 1: Sample Size, Response Rate, and Represented States

Owner Group	Sample Size	Responses	Response Rate	Represented States
DOTs	233	53	22.75%	30
PUs	643	40	6.22%	28
All	876	93	10.62%	43

The first set of data relates to agreement rates for identified PPIs that result from DCIM implementation (Jahanger, 2020, Jahanger et al., 2021a). The second set of data relates to the reported importance levels of the 28 PIFs that affect the implementation of DCIM systems (Jahanger, 2020, Jahanger et al., 2021b). The data are numerical, continuous, and consistent with the normal distribution. This enables the application of statistical analysis techniques such as correlation and regression. These inputs are important because project owners desire positive impacts and because PIFs directly influence implementation. The reason to connect is therefore to make a project owner, who aims for specific desirable impacts, realizes what factors need to control to get them.

3.2 Data Analysis

To achieve the research goal, Cronbach's alpha, Pearson coefficient of correlation, and multiple regression were used to group and summarize data, measure correlations between PPIs of DCIMs and PIFs related to DCIM systems implementation, and model dependency relation between them.

3.2.1 Cronbach's Alpha

Cronbach's Alpha coefficient enables researchers to measure the internal reliability of composite scores observed for a group of related items such as questions on a math test with one underlying construct (Goforth, 2015, Bland and Altman, 1997) to validate the test for further use. However, the coefficient should be measured each time the test or scale was used to check if it remains stable over multiple studies (Tavakol and Dennick, 2011, Connelly, 2011). In this paper, Cronbach's Alpha was used to measure the internal reliability for each of the PPIs group of improvement aspects. This is to ensure that the members of each group have one underlying construct and thus can be represented by the group instead of individually for the analysis to fulfill Objective 1 outlined earlier.

3.2.2 Pearson Coefficient of Correlation

Pearson Coefficient of Correlation (r) is a test to measure the degree of association between two variables (Keller and Warrack, 2003). This test was used in this paper to measure associations in terms of bivariate correlations between a PPI and a PIF. The coefficient, r, varies between 1 (perfect positive linear relationship) and -1 (perfect negative linear relationship).

3.2.3 Multiple Regression

Multiple regression (Hair et al., 1998, Ramsey and Schafer, 2013) is used in this research to investigate how the PIFs act together to affect each PPI group in order to determine the critical factors for each impact. The following equations mathematically represent the multiple linear regression model:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon \qquad (1)$$

Or

$$\mu(Y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \qquad (2)$$

Where Y is the response variable and $\mu(Y)$ is its expected value; $x_1, x_2, \ldots, x_n$ are explanatory variables; $\beta_0, \beta_1, \ldots, \beta_n$ are the coefficients, and ε is the error variable. To fit a model, three sequential variable-selection techniques can be followed: forward selection, backward elimination, and stepwise estimation (Ramsey and Schafer, 2013). Among the three techniques, the stepwise estimation approach is probably the most frequently used technique and considered one of the best variable selection procedures (Draper and Smith, 1998, George and Mallery, 2011).

3.3 Data Interpretation for Framework Development

The following procedure was followed to fulfil the third objective and develop a framework (guidelines) for DCIM implementation in owner organizations. First, the previously identified 18 PPIs are examined and synthesized into five groups (called as "improvement aspects"). This grouping paved the way to efficiently identify the nature of relationships between the PPIs represented by the five groups and the PIFs using multiple data analysis methods (bivariate and multivariate techniques). Then, the stakeholder entities that can exercise the most control over the PIFs, were identified and presented. Using the findings from the above analyses an implementation framework in terms of steps and procedures was developed and proposed. Section 4 presents data interpretation and discussion of the analysis results.

4. DATA ANALYSIS AND IMPLEMENTATION FRAMEWORK CREATION

This section presents the results and discussion of analysis conducted to enable the development of an implementation framework for DCIM systems. It first presents and discusses grouping and summarization of the potential positive impacts (PPIs). Next, the relationships between these PPIs groups and PIFs are analyzed and described. Finally, the grouping of the potential influencing factors (PIFs) and identification of their controlling entities is performed.

4.1 Potential Positive Impacts Grouping and Summarization

The PPIs were grouped into five groups (improvement aspects) based on three steps: (1) analytical thinking, (2) group judgment, and (3) reliability analysis. The analytical thinking and group judgment are subjective steps that including collective decision-making by consensus between 3 research professors and 1 research student with a collective experience of 50 years of construction research experience between them. Apart from this subjective preliminary categorization, an objective step was also undertaken which included a reliability analysis performed using Cronbach's Alpha that measured the internal consistency (reliability) of each group as one underlying construct. The 18 PPIs were first analytically grouped based on the literature review. The initial analytical grouping was then performed by a group of researchers to confirm or modify the groups, resulting in a minor modification for the group content. After that, Cronbach's Alpha was measured for each group and found to be greater than 0.8 for all groups – serving to validate the initial subjective grouping process (George and Mallery, 2011). Table 2 details the groups of the 18 PPIs. Please note that the abbreviated form of the PPIs group name (column 2 of Table 2) will be used henceforth for brevity. Further explanation regarding the PPIs is available in Appendix A which shows the PPIs as listed and described in the survey.

TABLE 2: Potential Positive Impacts Groups and Their Cronbach's Alpha Coefficients

PPI	**PPIs Group (Improvement Aspect)**	**Cronbach's Alpha**
Efficiency of documentation	Documentation and Archiving – Related Improvement (D&A–RI)	0.867
Documentation in the office as well as on the job site		
Transparency of information on projects		
Document management during construction		
Contract administration	Process and Time – Related Improvement (P&T–RI)	0.852
Work processes		
Tracking project activities		
Workflow management and progress		
Long-term strategic benefits	Strategic and Financial – Related Improvement (S&F–RI)	0.844
Financial capabilities		
Cost savings		
Risk mitigation		
Staffs Performance	Management and Productivity – Related Improvement (M&P–RI)	0.896
Construction management in terms of minimizing waste of time and effort		
Construction management in terms of carrying out the right tasks		
Worktime distribution of construction management		
Communication capabilities	Communication and Cooperation – Related Improvement (C&C–RI)	0.813
Teamwork cooperation		

4.2 Relationships between Potential Positive Impacts Groups and Potential Influencing Factors

Bivariate correlation and multiple linear regression were used to determine the relationship between the PIFs individually and collectively and each PPIs group (Objective 1).

4.2.1 Correlations between Potential Positive Impacts Groups and Potential Influencing Factors

Bivariate correlation was first used to determine the individual relationship between each PPIs group and each PIF. This is to depict how the PIFs independently affect each PPIs group and the overall DCIM system performance. It is hypothesized in this research that each PIF is significantly related to each PPI. Thus, the null hypothesis to be statistically tested is that there is no correlation between any PIF and any PPIs group, and the alternative hypothesis is that there is a correlation between each PIF and each PPIs group.

$$\begin{aligned}&\text{Null Hypothesis: } H_0\text{: Correlation } (r) = 0\\&\text{Alternative Hypothesis: } H_1\text{: Correlation } (r) \neq 0\end{aligned} \tag{3}$$

Table 3 presents the bivariate correlation between each one of the PPIs groups and each one of the 28 PIFs. Please note that the abbreviated form of the variable (PIF) will be used henceforth for brevity. Further explanation regarding the PIFs is available in Appendix B which shows the PIFs as listed and described in the survey.

TABLE 3: Bivariate Correlations between DCIM Systems PPIs Groups and the PIFs

#	Variable (PIF)	D&A–RI	P&T–RI	S&F–RI	M&P–RI	C&C–RI
1	Reasonable minimum capabilities of software (*RMCS*)	0.492**	0.440**	0.487**	0.473**	0.422**
2	Upper management support (*UMS*)	0.376**	0.335**	0.439**	0.397**	0.322**
3	Responsiveness (technical support) of service provider (*RSP*)	0.114	0.096	0.178	0.056	0.154
4	Quality of output (data and documents) (*QO*)	0.311**	0.248*	0.330**	0.318**	0.243*
5	Software alignment with needs, processes, and objectives (*SANPO*)	0.306**	0.321**	0.284**	0.313**	0.281**
6	Availability of financial resources (*AFR*)	0.129	0.197	0.306**	0.203	0.145
7	End-users' satisfaction with software (*ESS*)	0.143	0.038	0.159	0.058	0.127
8	Software compatibility with existing systems and tools (*SCEST*)	0.269**	0.197	0.261*	0.433**	0.431**
9	Necessary rethinking of organization's business processes (*NROBP*)	0.259*	0.368**	0.286**	0.318**	0.294**
10	Organizational culture (*OC*)	0.221*	0.213*	0.263*	0.266**	0.224*
11	Level of training available to end-users (*LTAE*)	0.081	0.001	0.108	0.098	-0.054
12	Effective IT department (*EITD*)	-0.02	0.019	0.17	0.116	0.220*
13	Service provider with expertise in construction (*SPEC*)	0.026	-0.051	0.07	-0.016	-0.077
14	Wireless access and networking capabilities (*WANC*)	0.265*	0.185	0.284**	0.272**	0.437**
15	Long-term plan of technology implementation (*LPTI*)	0.267**	0.229*	0.348**	0.367**	0.403**
16	Modernity of mobile computing devices (*MMCD*)	0.289**	0.345**	0.288**	0.262*	0.297**
17	Knowledge of return on investment (*KRI*)	0.209*	0.210*	0.320**	0.244*	0.210*
18	All capabilities provided in a single software (*ACPSS*)	0.177	0.018	0.13	0.074	0.05
19	End-users' computer proficiency (*ECP*)	-0.03	-0.092	0.046	0.003	-0.045
20	External funding decision makers (*EFDM*)	0.163	0.15	0.233*	0.220*	0.250*
21	External stakeholders (*ES*)	0.102	0.123	0.209*	0.145	0.281**
22	Complexity of projects (*COMP*)	-0.063	-0.016	0.124	0.008	0.038
23	Concerns from legal issues (*CLI*)	0.014	0.086	0.195	0.157	0.102
24	Cost of projects (*COSP*)	0.009	-0.058	0.138	0.097	-0.003
25	Type of contracting arrangements (*TCA*)	-0.069	-0.074	0.121	0.033	0.126
26	Duration of projects (*DP*)	-0.03	-0.093	0.165	0.058	0.074
27	Organization's project location (*OPL*)	0.078	0.056	0.251*	0.194	0.234*
28	Organization's project type (*OPT*)	0.01	0.01	0.156	0.119	0.111

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

As can be seen in the Table 3, nine of the 28 PIFs (Rows 1, 2, 4, 5, 9, 10, 15, 16, and 17) are significantly related, at least at 0.05 level, to all the PPIs groups. Thus, the hypothesis that each PIF is significantly related to each PPIs group is fully supported for these PIFs. This indicates that the conviction of getting each of the PPIs groups (improvement aspects) tends to increase when the importance individually given during the implementation for each one of these PIFs increases. On the other hand, 12 of the PIFs are not significantly related to any PPIs group.

Therefore, the hypothesis is not supported for any one of these 12 PIFs. For the remaining seven PIFs, each one of them is significantly related to, at least, one PPIs group. Thus, the hypothesis is partially supported for each one of these PIFs. The *SCEST*, and *WANC* are the most partially supported PIFs. Both have a significant positive correlation with each one of the PPIs groups except the P&T–RI. The *AFR* and the *EITD* are the least partially supported PIFs because it has a significant positive correlation with only one PPIs group. While the *AFR* is correlated to the S&F–RI, the *EITD* is correlated to the C&C–RI. If the Table 3 is analyzed from the other side (the improvement aspects), it can be seen that the D&A–RI is significantly correlated to 11 PIFs, the P&T–RI is significantly correlated to nine PIFs, the S&F–RI is significantly correlated to 15 PIFs, the M&P–RI is significantly correlated to 12 PIFs, and the C&C–RI is significantly correlated to 15 PIFs.

4.2.2 Regression Models of Potential Positive Impacts Groups

After the bivariate analysis and determination of PIFs that are significantly related to PPIs groups, multiple linear regression was used to investigate how these PIFs act together to affect each PPI group and thus complete the fulfillment of Objective 1. Therefore, in this research, the response (dependent) variables for the regression models are the five PPIs groups, and the explanatory (independent) variables are the significantly correlated PIFs to each PPIs group. The significantly correlated PIFs to each PPIs group are marked with (**, *) in Table 3 and explained in subsection 4.2.1. The stepwise estimation approach was used to fit a final “optimal” model (regression equation) for each one of the PPIs group. The SPSS software was used to develop the final models that were reached by testing many models, which consisted of different combinations of variables (PIFs), to the final model. The models' predictive powers were judged through statistical measurements, especially the adjusted coefficient of determination (adjusted R^2). One model with the most contributed and not inter-correlated (collinear) independent variables, and the highest adjusted R^2 was fitted for each PPIs group. The five models represent the best fit for the collected data and yield the most precise insight into the critical PIFs for the PPIs groups. Table 4 provides summaries of the models. Table 5 details the variables included in each model. A guide to reading Table 5 follows.

TABLE 4: Summary of the Optimal Regression Models

Model Description	Number of Variables in Model	Adjusted R^2	Standard Error
D&A–RI	2	0.272	11.72
P&T–RI	2	0.25	11.383
S&F–RI	2	0.306	13.166
M&P–RI	3	0.351	13.464
C&C–RI	3	0.396	13.323

TABLE 5: Results of the Five Improvement Models

Model	PIF	β	SE	β^*	t	*p*-value
D&A–RI	Constant	22.9	10		2.287	0.025
	RMCS	0.534	0.102	0.469	5.238	0
	WANC	0.157	0.066	0.214	2.395	0.019
P&T–RI	Constant	32.7	9.202		3.558	0.001
	RMCS	0.426	0.1	0.391	4.257	0
	MMCD	0.172	0.058	0.275	2.991	0.004
S&F–RI	Constant	-0.7	11.5		-0.057	0.955
	RMCS	0.591	0.115	0.451	5.146	0
	LPTI	0.278	0.083	0.292	3.335	0.001
M&P–RI	Constant	-6.2	11.828		-0.522	0.603
	RMCS	0.492	0.124	0.354	3.957	0
	LPTI	0.267	0.087	0.265	3.064	0.003
	SCEST	0.21	0.077	0.249	2.722	0.008
C&C–RI	Constant	-9.4	11.585		-0.814	0.418
	WANC	0.351	0.075	0.384	4.706	0
	SCEST	0.266	0.075	0.307	3.553	0.001
	RMCS	0.392	0.123	0.275	3.177	0.002

PIF is the explanatory variable identified through the stepwise estimation approach; β is the regression coefficient for each variable, which was calculated using the ordinary least squares (OLS) technique; SE is the standard error of the variable regression coefficient. It is the expected distribution of an estimated regression coefficient; β^* is a standardized regression coefficient. Beta coefficients are calculated based on standardized data, and thus, unlike the regression coefficients, they enable direct comparison among them; t is a statistic, which is calculated by dividing any β by its SE. It is used to test the significance of the coefficient against zero by comparing it to a critical t-distribution statistic; *p*-value (significance of the t-statistic) is the estimated probability of observing this statistic when the hypothesis (the coefficient does not differ from zero) is true. It is compared to a threshold (usually 0.05) to determine the significance of the coefficient.

The D&A–RI model identified the PIFs that are critical, especially together, for maximizing D&A–RI of DCIM systems. In other words, this model identified the critical PIFs that can influence a DCIM system performance in term of D&A–RI. The optimal model contains two variables and a constant. The model shows that this improvement aspect is positively affected by two PIFs: The *RMCS* and the *WANC*. The adjusted R^2 is 0.272, which means that the model could explain approximately 27.2% of the variance in the output.

The resultant regression equation for D&A–RI, therefore, is:

$$\mu(D\&A\text{–}RI) = 22.9 + 0.534RMCS + 0.157WANC \tag{4}$$

The P&T–RI model identified the PIFs that are critical, especially together, for maximizing P&T–RI of DCIM systems. In other words, this model identified the critical PIFs that can influence a DCIM system performance in term of P&T–RI. The optimal model contains two variables and a constant. The model shows that this improvement aspect is positively affected by two PIFs: The *RMCS* and the *MMCD*. The adjusted R^2 is 0.25, which means that the model could explain approximately 25% of the variance in the output.

The resultant regression equation of the P&T–RI, therefore, is:

$$\mu(P\&T\text{–}RI) = 32.7 + 0.426RMCS + 0.172MMCD \tag{5}$$

The S&F–RI model identified the PIFs that are critical for maximizing S&F–RI of DCIM systems. In other words, this model identified the critical PIFs that can influence the performance of a DCIM system in term of S&F–RI. The optimal model contains two variables and a constant. The model shows that this improvement aspect is positively affected by two PIFs: The *RMCS* and the *LPTI*. The adjusted R^2 is 0.306, which means that the model could explain approximately 30.6% of the variance in the output.

The resultant regression equation of S&F–RI, therefore, is:

$$\mu(S\&F\text{–}RI) = -0.7 + 0.591RMCS + 0.278LPTI \tag{6}$$

The M&P–RI model identified the PIFs that are critical for maximizing M&P–RI of DCIM systems. In other words, this model identified the critical PIFs that can influence the performance of a DCIM system in term of M&P–RI. The optimal model includes three variables and a constant. The model shows that this improvement aspect is positively affected by three PIFs: The *RMCS*, the *LPTI*, and the *SCEST*. The adjusted R^2 is 0.351, which means that the model could explain approximately 35.1% of the variance in the output.

The resultant regression equation of M&P–RI, therefore, is:

$$\mu(M\&P\text{–}RI) = -6.2 + 0.492RMCS + 0.267LPTI + 0.21SCEST \tag{7}$$

The C&C–RI model identified the PIFs that are critical for maximizing the C&C–RI of DCIM systems. The optimal model includes three variables and a constant. The model shows that this improvement aspect is positively affected by three PIFs: The *WANC*, the *SCEST*, and the *RMCS*. Thus, increasing the level of these PIFs maximizes C&C–RI of DCIM systems. The adjusted R^2 is 0.351, which means that the model could explain approximately 35.1% of the variance in the output.

The resultant regression equation of C&C–RI, therefore, is:

$$\mu(C\&C\text{–}RI) = -9.4 + 0.351WANC + 0.266SCEST + 0.392RMCS \tag{8}$$

Equations 4, 5, 6, 7, and 8 predict the D&A–RI, P&T–RI, S&F–RI, M&P–RI, and C&C–RI respectively for a project owner (an organization) from a DCIM system implementation and are the best statistical fit for the collected data through a survey.

Findings from the five models can be used to guide owner organizations aiming for D&A–RI, P&T–RI, S&F–RI, M&P–RI, and/or C&C–RI when implementing DCIM systems to the most important PIFs that must be further focused on to ensure achieving any desired aim.

Reasonable minimum capabilities of software: This variable, which is presented in the five models, indicates that adopting software that has capabilities higher than the RMCS would increase the DCIM system potential in D&A–RI, P&T–RI, S&F–RI, M&P–RI, and C&C–RI depending on the variable coefficient (weight) in each model.

Wireless access and networking capabilities: This variable, which is presented in two models, indicates that an owner organization with higher WANC would increase the DCIM system potential in the D&A–RI and C&C–RI depending on the variable coefficient (weight) in each model.

Long-term plan of technology implementation: This variable, which is presented in two models, indicates that increasing an owner organization's LPTI would increase DCIM system potential in the S&F–RI and M&P–RI depending on the variable coefficient (weight) in each model.

Software compatibility with existing systems and tools: This variable, which is presented in two models, shows that when SCEST is high at an owner organization, using the system to coordinate, exchange, and document information would be more convenient and reliable, resulting in a maximization of M&P–RI and C&C–RI depending on the variable coefficient (weight) in each model.

Modernity of mobile computing devices: This variable, which is presented in one model, shows that increasing the *MMCD* by an owner organization would increase the DCIM system potential in term of the P&T–RI.

4.3 Potential Influencing Factors Grouping and Controlling Entities Identification

To fulfill Objective 2 of the paper, two techniques (analytical thinking and group judgment by a group of researchers) were used to subjectively group the PIFs and identify for each PIF the stakeholder entity that can exercise the most control over it. The grouping and controlling entity identification were conducted to facilitate the development of the DCIM systems implementation framework. Table 6 shows the groups of the 28 PIFs and their controlling entities.

Owner organization (leadership) refers to the top management of an organization that can provide administrative and financial support to implementation of a DCIM system.

Owner Organization (Project Administration) refers to employees (e.g., project managers, engineers, etc.) who are responsible for developing, designing, and managing construction projects of the organization.

Software firm refers to the software vendor or service provider that provides the DCIM system to the organization and after sale services.

Owner Organization (Staff) refers to employees of the owner organization who use the system to achieve their work.

Decision Makers (Legislators) refer to legislators (state representatives) who can provide legislative and funding support to implementation of a DCIM system.

Stakeholders (Contractors, Others) refer to the other stakeholders of a project such as contractors whose jobs may affect (and might also be affected by) the use the system.

TABLE 6: Potential Influencing Factors Groups and Controlling Entities

PIFs Group	PIF	Controlling Entity
Owner Organization-Related PIFs	*UMS*	Owner Organization (Leadership)
	AFR	Owner Organization (Leadership)
	NROBP	Owner Organization (Leadership)
	EITD	Owner Organization (Leadership)
	WANC	Owner Organization (Leadership)
	LPTI	Owner Organization (Leadership)
	MMCD	Owner Organization (Leadership)
	KRI	Owner Organization (Leadership)
Project-Related PIFs	*COMP*	Owner Organization (Project Administration)
	COSP	Owner Organization (Project Administration)
	TCA	Owner Organization (Project Administration)
	DP	Owner Organization (Project Administration)
	OPL	Owner Organization (Project Administration)
	OPT	Owner Organization (Project Administration)
	CLI	Owner Organization (Project Administration)
Software-Related PIFs	*RMCS*	Software Firm
	QO	Software Firm
	SANPO	Software Firm
	SCEST	Software Firm
	ACPSS	Software Firm
User-Related PIFs	*ESS*	Owner Organization (Staff)
	OC	Owner Organization (Staff)
	LTAE	Owner Organization (Leadership)
	ECP	Owner Organization (Staff)
Software Firm-Related PIFs	*RSP*	Software Firm
	SPEC	Software Firm
Externality-Related PIFs	*EFDM*	Decision Makers (Legislators)
	ES	Stakeholders (Contractors, Others)

5. FRAMEWORK FOR DCIM SYSTEMS IMPLEMENTATION

To fulfill Objective 3 of this paper, the results in this paper and knowledge from the research were used to develop a framework for DCIM systems implementation. The results of the bivariate correlations, as seen in Table 3, showed that 15 potential influencing factors (PIFs) are significantly related to all or part of the five improvement aspects. The findings of the regression analysis showed that five PIFs out of the 15 significantly related PIFs are critical for the maximization of one or more improvement aspects. Table 7 presents a summary of the regression results. Fig. 3 shows overall implementation success relationships including controlling entities, critical PIFs, improvement aspects, and their related potential positive impacts (PPIs).

TABLE 7: Critical PIFs for Maximization of DCIM Systems Improvement Aspects

Controlling Entity	Critical PIFs	All PPIs				
		D&A–RI	P&T–RI	S&F–RI	M&P–RI	C&C–RI
Software Firm	*RMCS*	✓	✓	✓	✓	✓
	SCEST				✓	✓
Owner Organization (Leadership)	*WANC*	✓				✓
	LPTI			✓	✓	
	MMCD		✓			

The PIFs that were found to be related to and/or to influence the DCIM systems' five improvement aspects and thus its performance, through the analyses presented in subsections 4.2.1 and 4.2.2, were used to develop an implementation framework for DCIM systems. The guidelines are presented as a framework that can help project owners, especially public agencies, to successfully implement DCIM systems and achieve better performance in term of the improvement aspects when implementing DCIM systems on construction projects.

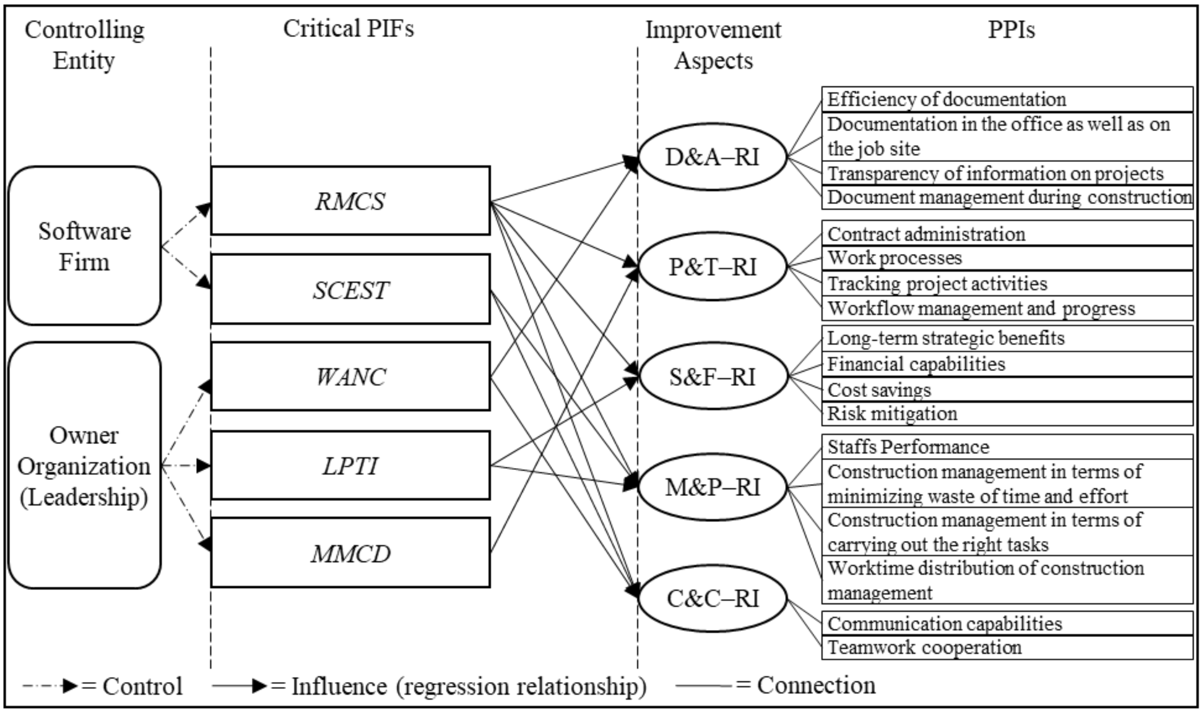

FIG. 3: DCIM Systems Implementation Success/Relationships Model

The framework is organized based on the five PIFs that are critical for implementation of DCIM systems as presented in Fig. 3 and from the steps that should come first to the steps that should come later.

5.1 Plans of Technology Implementation

Findings regarding the *LPTI* shows that an owner organization needs to have a *LPTI* (DCIM systems and others) when working to implement a DCIM system. The availability of a *LPTI* helps the owner organization adopting digitalization to move toward this step at the right time and in the proper sequence and thus the ability to progress in the implementation adequately and in a timely manner. The owner organization implementing a DCIM system also needs to establish based on the *LPTI*, an appropriate plan (procedures and a timetable) specified for DCIM systems implementation, and the following recommendations offer guidelines for such a plan.

- **Enable Wide Participation in the Development of the Implementation Plan**: Representatives from all the divisions (departments) of an owner organization that are responsible for project development, design, and administration should be involved in the process of planning the implementation. This would allow the participants from different divisions to provide helpful notes and suggestions to ensure that the DCIM system implementation plan aligned better. This enables divisions' members to understand the constraints and opportunities that the others may face and thus to find methods to tailor their processes to one another. Thereby, an owner organization could avoid many problems related to the commitment of the divisions, the appropriate variety of services, and the facilitation of a DCIM system implementation. To ensure that everyone fully understands the concept of DCIM systems and their role in the project, a formal presentation to explain the PPIs of DCIM systems implementation on projects can be highly beneficial. Thus, the presentation can be used to solve possible conflicts before the piloting and actual wide use of the system.

- **Pilot the DCIM System before Fully Using It on Other Projects**: An organization should pilot the system before the actual wide use on projects, especially in the construction season. Organizations need to pilot the system on two or more projects that are different in scope before fully introducing it to be used on other projects. This step will help organizations, overcome issues, especially technical, and increase readiness before full-scale implementation.

- **Rethink of an Organization’s Business Processes**: Implementation of a DCIM system by an owner organization usually necessitates a rethinking of the business processes and practices currently followed. The changes or modifications could be either incremental or radical, depending on the level and spread of use and the owner organization’s current business processes and practices. Thus, the owner organization, especially the implementation team, must be ready for such changes or modifications.

5.2 Selection of Software

Findings regarding the *RMCS* and *SCEST* shows that software selection, including taking into consideration its provider, is an essential step. An owner organization team can progress to the choice of software and other supporting technologies, such as the e-signature, after establishing an implementation plan for a DCIM system. For this step, the following recommendations are suggested.

- **Capabilities of the Software:** There is a number of software options available commercially for owner organizations. Examples of such software are provided in Jahanger et al. (2021a). Nevertheless, the selection of software should be made with caution. Because the features and functions supported by each software most likely vary although the common goal of all software may be the same. Thus, an owner organization team should work to know the capabilities of all candidate software and think creatively about the offered features or functions and their potential applications. This is to select a software that best aligns with the needs, processes, and objectives of implementing a DCIM system by an owner organization.
- **Compatibility of the Software with Existing Systems and Tools**: Software compatibility (interoperability) is essential in today’s construction digitalization. The ability of software to be compatible both internally and externally is very important to the flow of project information. In addition to the integration among the software features, it is important that the system to be compatible (integrated) with existing systems and tools, such as Computer-Aided Design (CAD), Radio-Frequency Identification (RFID), and Personal Digital Assistant (PDA), at an owner organization as well as with external systems, especially those belonging to contractors.
- **Characteristics of the Software Firm (Vendor or Service Provider):** After identification of what an owner organization needs in software in term of capabilities (features and functions) and compatibility (interoperability and integration) that fulfill their needs, processes, and more importantly their objectives, the owner organization team then proceed to select the software to be implemented. This is important due to the firm role in controlling or improving software, especially capabilities, integration, and compatibility. Software provided by a prominent company might be intuitively preferred by the team since such software may seem to be more reliable and secure. However, the owner organization team should seriously take into consideration several other important factors associated with the features and functions of the software and the characteristics of the software provider.

Regarding the software features and functions, it has been noticed that public agencies generally prefer to host a DCIM system in-house (client/server-based system). However, this does not prevent the implementation of web-based systems, if desired. Other features and functions of the software that have important impacts on the system performance and should be considered as the significant criteria for system selection including, but are not limited to, ease of use (e.g., data input/output, search, etc.), functionality and reliability, antivirus capabilities, stability of state, version update, application on mobile devices, etc.

In addition to the software features and functions, findings from both the literature review and the survey show that several characteristics of a software provider, i.e., responsiveness (technical support) of the software provider and expertise in construction, especially business and problems, are critical to the success of a DCIM system implementation. An owner organization team should notice the significance of these characteristics and take them into consideration as selection criteria. The owner organization team should also aim to obtain background information on the candidate software firms, especially the quality of their services.

5.3 Continuous Support (Technical Capabilities and Human Efforts)

Findings regarding the *WANC* and *MMCD* shows that ongoing technical support is also a very important part of DCIM systems implementation and thus its framework. After a DCIM system is selected and before implementation on projects, an owner organization team needs to prepare and provide an adequate level of support in term of technical capabilities and human effort for the DCIM system use throughout projects. The recommendations below are proposed for this step.

- **Provide an Adequate Level of Wireless Access and Networking Capabilities:** *WANC* including wireless network/mobile network data rate, frequency, geographic coverage, and technological standard is important to implement an IT project successfully. Thus, an owner organization needs to have an adequate level of these capabilities. If an owner organization does not have these capabilities, it is important to work on increasing its preparation in this aspect. These capabilities become more important and necessary if an owner organization has projects scattered in different regions, especially remote areas.
- **Provide Sufficiently Modern Mobile Computing Devices:** The results show that the *MMCD* including brands, operating systems, and storage capacity, is clearly important to implement a DCIM system. Therefore, an owner organization team should also take into consideration the modernity of the mobile computing devices available at the owner organization. This means if the implementation of the DCIM systems necessitates modern or even different devices, these devices should be provided.

5.4 Implementation Monitoring and Evaluation

Although the steps above can help facilitate the implementation of DCIM systems, owner organizations still need to monitor the DCIM systems, especially their use on projects. This is to get feedback on the systems' performance. The feedback is useful for enhancing systems' performance during the use in future projects. Recommendations for the implementation monitoring and evaluation are provided below.

- **Monitor the System Performance Continuously:** Performance of a DCIM system should be continuously monitored by an owner organization team during the use in projects. There is no particular rule for how often the system performance monitoring should be done. However, owner organization team members can work to establish a general agreement (a rule) on how frequently this monitoring should be conducted. As a main part of the research, 18 PPIs that the implementation of a DCIM system can bring to the project administration and delivery process of owners were identified and presented in Jahanger et al. (2021a) . The PPIs were grouped in this paper into five groups represent five different improvement aspects for the project administration and delivery process. They are Documentation and Archiving, Process and Time, Strategic and Financial, Management and Productivity, and Communication and Cooperation. Thus, these five improvement aspects can be used by an owner organization team as a guide to conduct an implementation (performance) assessment, where opinions from all participated units and departments at an organization and external parties such as contractors if needed should be considered. A simple survey using a scale (100-degree ruler) as utilized in the survey used in Jahanger et al. (2021a), may be used for this implementation assessment. An owner organization team can also individually weigh the five improvement aspects to suit the owner organization's specified objectives and goals. For example, an owner organization seeking improvement to task performance and productivity through the implementation of a DCIM system can assign a high weighting to the "M&P–RI" aspect. However, this might be at the expense of the other improvement aspects. This can help an owner organization team to understand how the system performs in each aspect and how the owner organization 's objectives and goals have been achieved. A spider diagram shown in Fig. 4 and explained below was developed to provide owner organizations a tool in this regard. The spider diagram can also be used to assess the performance of DCIM systems and thus identify areas where efforts are needed to improve or adjust the system.

  Benefiting from the method that Mohamed and Stewart (2003) used to develop a spider diagram for performance assessment of a web-based communication system implementation by construction firm on a large construction project, the spider diagram was developed as follows. A total mean (expected value) was calculated for each improvement aspect using the means calculated based on all respondents' data presented in Jahanger et al. (2021a). The total means for the five improvement aspects rated as follow: Documentation and Archiving (82.6%), Strategic and Financial (73.7%), Process and Time (83.5%), Management and Productivity (75.8%), and Communication and Cooperation (75.3%). The overall mean of the five improvement aspects is 78.5%. Then the average standard deviation was calculated for each improvement aspect by summing the standard deviations related to the PPIs in that aspect divided by their number. This was conducted to identify the possible range of the expected value for each aspect.

The expected value of improvement aspect and the system performance are assumed connected and reflect each other. Therefore, in Fig. 4, the total mean for each improvement aspect is assumed as the expected value of improvement in this aspect for future implementation and thus the system performance in this regard. The overall mean of improvement is assumed to be the expected value of the overall improvement for future implementation and thus the system's overall performance.

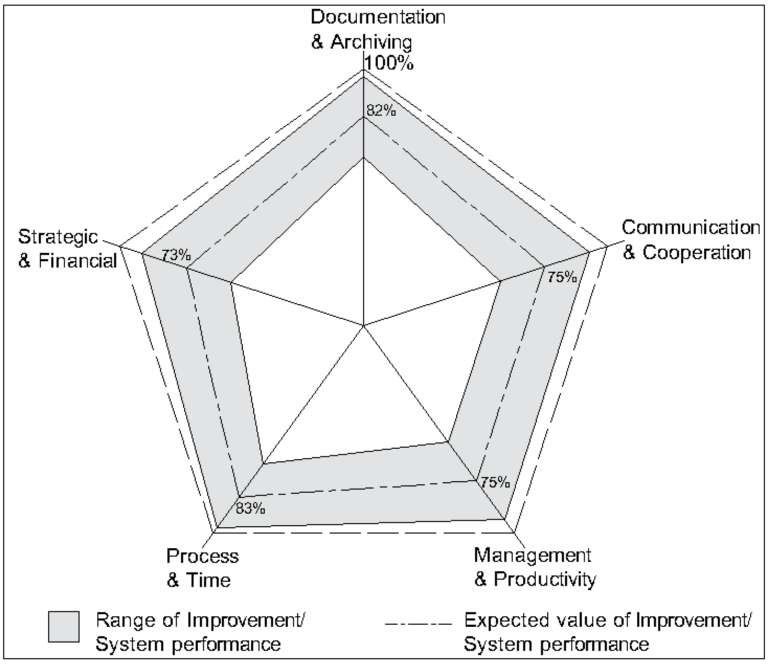

FIG. 4: Expected value of each improvement aspect on system performance

This tool (spider diagram) provides owner organizations with a simple, yet effective way to evaluate the expected improvement of DCIM systems and thus the system performance.

- **Evaluate Post-Project Performance:** In addition to the continuing assessments during the course of a construction project, the owner organization team should also perform a post-project DCIM system performance assessment once the construction is completed. This is to compare the results previously obtained from the continuing assessments with the results of the post-project assessment. This post-project assessment can shed light on how the owner organization team administered the implementation of the DCIM system. It can also be used to establish a baseline for evaluating any implementation enhancements on future projects. This assessment will also enable an owner organization team to obtain more knowledge on what was good to be further supported and on what was not good to be enhanced, and thus the performance of the system can be modified and improved for future projects.

6. LIMITATIONS OF THE RESEARCH AND RECOMMENDATIONS FOR FUTURE WORK

The limitations of this research include the following: First, limitation of the collected data to use more rigorous statistical techniques such as factor analysis to support or confirm the grouping of PPIs. Nevertheless, the use of the three steps: analytical thinking, group judgment, and reliability analysis iteratively was sufficient to group the PPIs and validate the results (groups). Second, limitation in the validation of the implementation framework using specialized validation methods such as structured interviews. Future work is needed to validate the implementation framework with a group of owner organizations. This work could include the development of an instrument consisting of questions that assess the validity of the framework and recruitment of industry professionals with technology implementation experience to conduct the validation. This recommendation for future research can help in refining and improving the framework provided in this paper for DCIM systems implementation by project owners.

7. CONCLUSIONS

A framework for the successful implementation of new technologies in construction, especially software systems, can greatly enhance digital technologies adoption and use and thus project administration and delivery process. In this regard, this paper presents a framework for project owners that can facilitate the implementation of DCIM systems within their organizations and thus digitalization of construction-phase information management. This paper using bivariate and multivariate analysis determined the nature of relationships between previously identified potential positive impacts (PPIs) that were grouped into five main improvement aspects and the identified potential influencing factors (PIFs) for DCIM implementation. This was conducted to enable development of an implementation framework that reflects these relationships to maximize usefulness and improve DCIM systems performance. This paper also identified entities that can control the PIFs and thus could influence the performance of a system. Results of the bivariate analysis showed that 16 of the 28 PIFs significantly correlated to at least one improvement aspect. Thus, this indicates that the probability of achieving any improvement aspects increases when the importance given during the implementation for any significantly correlated PIFs increases. Twelve of the PIFs do not significantly correlate to any improvement aspect. To extend the findings from the bivariate analysis, multivariate analysis using regression was conducted to identify the nature of relationships between each improvement aspect and the various (multiple) PIFs that significantly correlated to it. Results of the multivariate analysis showed that five PIFs are critical, especially together, for the maximization of one or more of the improvement aspects and thus the system performance. *RMCS* is found to be the most critical PIF (critical for all improvement aspects) and *MMCD* is found to be the least critical PIF (critical for only one improvement aspect).

This research made a significant contribution to the body of knowledge and industry, especially on construction digitalization, by developing an implementation framework to facilitate and provide guidance for DCIM systems implementation by project owners. The implementation framework consists of four main steps: (1) Plans of Technology Implementation, (2) Selection of Software, (3) Continuous Support (Technical Capabilities and Human Efforts), and (4) Implementation Monitoring and Evaluation. Each step includes several sub-steps in the form of recommendations or procedures for implementation. The framework was developed to be a useful guide for project owners, especially public agencies, for a successful implementation of DCIM systems and evaluation of the system performance.

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APPENDICES

APPENDIX A: POTENTIAL POSITIVE IMPACTS AS LISTED AND DESCRIBED IN THE SURVEY (JAHANGER ET AL., 2021A)

PPI
1) DCIM systems could improve the **financial abilities** of the organization. For instance, application of DCIM systems could competitively benefit owners by attracting more sophisticated parties (e.g., contractors) leading to lower bids and thus the ability to do more business.
2) DCIM system could lead to **long-term strategic benefits** to the organization. For example, digitalization could improve construction program growth and success, could increase capability for national cooperation, could enhance disaster recovery, could improve the organization's image in the industry, etc.
3) DCIM systems improve **staff's performance** in projects for the organization. For instance, using DCIM systems optimizes utilization of staff, enables efficient organization on projects, and improves a project team's computer literacy.
4) DCIM systems improve **contract administration** of organizations. For example, payments to contractors can be more accurate and quicker by using DCIM systems. It improves cash flow.
5) DCIM systems enable significant **cost savings** for the organization. For instance, DCIM systems reduce the need for travel, phone usage, physical documentation and storage, etc.
6) DCIM systems improve **work processes** in the organization. For instance, DCIM software facilitates streamlining of processes, and/or enhances processing of progress claims, and/or enhances integration with other business functions (core systems) such as accounting and asset management systems, etc.
7) DCIM systems improve **communication capabilities** on projects. For instance, DCIM systems reduce barriers in communications, and reduce the need for physical and/or direct communication such as face-to-face meeting, faxes, mails, etc.
8) DCIM systems facilitate **tracking project activities** for project management and control. For instance, DCIM systems improve maintaining updated and organized records, especially for tracking purposes, and owners can verify that issues are being addressed and closed out in a timely manner.
9) DCIM systems improve the **efficiency of documentation** within the organization. For instance, application of DCIM systems facilitates further standardization of reports or forms within agencies, generates reports for distribution with photo and comments attached, enables instant status updates on issues, improves the accuracy and quality of data and documents, etc.
10) DCIM systems facilitate **documentation in the office as well as on the job site**. For instance, DCIM systems make completion and approval of the digital daily field reports easier than the traditional paper reports, eliminate the need to transfer hand-written notes to electronic format, prevent documents (e.g. material tickets) from being lost, etc.
11) DCIM systems improve **transparency of information on projects**. For instance, a DCIM system is a centralized hub for project information, plans, and issues, and these documents are available for viewing by all authorized persons. This information is compiled and available to be disseminated to other projects.
12) DCIM systems significantly improve **document management during construction.** For instance, DCIM systems allow for the easy access and distribution of documents to other parties, allow for the retrieval of project information from many locations, decrease in document multiple handling, etc.
13) DCIM systems improve **risk mitigation** on projects. For instance, the application of DCIM systems reduces numbers of claims on projects, helps in conforming to contracts, enables audit trails for risk mitigation, and helps to operate in a secure environment.
14) DCIM systems improve **teamwork cooperation** on projects. For instance, DCIM systems facilitate and support project alliance and industry partnerships, improve business relations and satisfaction on projects, enable necessary parties to observe and communicate on issues, facilitate decision making, etc.
15) DCIM systems facilitate **workflow management and progress** on projects. For instance, plans, specifications, RFIs are available to project members in a mobile electronic format, action items regarding QA/QC deficiencies can be automatically created and distributed for responsible trades, and with a digital signature, documents can be signed remotely.

16) DCIM systems improve **construction management in terms of carrying out the right tasks** to attain desired project goals (duration, budget, etc.). For instance, DCIM systems enable a robust management program and thus increase the effectiveness of management by helping them to carry out the right tasks when needed. DCIM systems can effectively help management to identify errors in documents and thus reduce the risk of rework or delaying a project goal.
17) DCIM systems improve **construction management in terms of minimizing waste of time and effort** when working to accomplish managerial tasks. For instance, by using DCIM systems, management can save time due to less clerical tasks, more efficiency in data processing and document approval, ability to quickly sort and filter issues, ability of faster reporting and feedback on projects, etc. DCIM systems further enable management to speed up document processing by reducing repetitive activities and to enhance processing accuracy by reducing errors.
18) DCIM systems improve **worktime distribution of construction management** on projects. For instance, using DCIM systems allow project managers to spend more time on managerial tasks rather than clerical tasks, digitalization also enables field staff to have more time on the job site instead of the office.

APPENDIX B: POTENTIAL INFLUENCING FACTORS AS LISTED AND DESCRIBED IN THE SURVEY (JAHANGER ET AL., 2021B)

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1) What is the importance of the **availability of financial resources** for purchasing, maintaining, and updating a DCIM software system when necessary.
2) How important is it for an organization management to **know what the return on investment** will be for the organization if it started using DCIM system? Note that this is not about the actual return on investment itself, but on you knowing what it will be.
3) How important is an **effective IT department** within your organization to the successful implementation of a DCIM software?
4) How important is it to convince **external funding decision-makers** of your organization need for a DCIM software system? For instance, state highway agencies may need to convince the legislature to buy new software.
5) Application of new technology most likely necessitates a **rethinking of an organization's business processes**. How important is this step for software deployment and use? Rethinking of business processes means review, documentation, and adjustment of the business processes.
6) Please rate the importance of **organizational culture** in terms of employees' attitudes and commitments towards new processes and technologies. For instance, are they receptive to change? How well will participants commit to the implementation plan?
7) How important is it to obtain the support of **external stakeholders** whose jobs will be affected if you adopted the DCIM software? These stakeholders (e.g., contractors, consultants, vendors) are not necessarily the users of the software itself.
8) How important is it for an organization to have **a long-term plan** for technological development when deciding to purchase and use DCIM software system?
9) How important is **upper management support** for DCIM software adoption and use? For instance, the upper management specifies a leader (a champion) to lead the software implementation.
10) How important is it to obtain software that is **compatible with existing systems and tools** in your organization? Systems and tools could include radio-frequency identification (RFID), personal digital assistant (PDA), etc.
11) How important is to have a DCIM software that meets the **reasonable minimum capabilities** expected from software when you consider purchasing it? The reasonable minimum expectations from a software refer to ease of use, security of data, functionality, stable state, etc.
12) How important is it for **one software** to meet all (or most) of your construction management-related IT needs? Provide a lower rank if you prefer having different specialized software for different processes.
13) To what extent is the **quality of output (data and documents)** important for DCIM software adoption and use? Quality refers to the accuracy of data, relevancy to users' tasks, and suitability to construction projects.
14) To what extent is the **responsiveness (technical support) of a service provider** important when deciding on using a specific DCIM system?
15) How important is it to have **a service provider with expertise in construction** when purchasing and implementing a DCIM software?
16) How important is the **level of training** provided for a DCIM software, when you consider purchasing it?
17) How important is the **users' computer proficiency** when considering a DCIM software implementation?
18) How important is it to have **users' satisfaction** for DCIM software adoption and use?
19) To what extent is the **complexity of projects** important for your decision to purchase and use a DCIM software? Would increasing the complexity of a project, especially construction, push you towards purchasing a DCIM system?

20) To what extent is the **type of contracting arrangements** (D-B-B, D-B, CM, etc.) important in your decision to purchase and use a DCIM system?
21) To what extent do you think **durations of projects** are important for successful software adoption and use by an organization?
22) To what extent do you think **costs of projects** are important for successful software adoption and use by an organization?
23) How important is **an organization's project type**, such as highways or water network, for successful software adoption and use?
24) How important is an **organization's project location** (e.g., remote areas, cities, etc.) for successful software adoption and use?
25) To what extent **concerns from legal issues** related to digitalization will be important to an organization when deciding to purchase and use a DCIM system. Legal issues such as ownership of drawings and information, acceptance of electronic and digital signatures, document retention, etc.
26) To what extent is **modernity of mobile computing devices** (e.g., tablets) available at an organization is important for DCIM software adoption and use?
27) How important is **software alignment with needs, processes, and objectives** of an organization and its processes for purchase and adoption?
28) To what extent are an organization's **wireless access and networking capabilities** important for a DCIM system deployment and use? The focus is on the technical capabilities of wireless (mobile) networking (e.g., data rate, frequency, geographic coverage, etc.) for an organization, especially for work in areas with low connectivity.