Systemic View to Understanding Design Change Causation and Exploitation of Communications and Knowledge

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Abstract

Frequent changes pervasively undermine project schedule performance. Despite voluminous research into project delays, however, the persistence of the problem demands that a systemic approach be adopted to investigate design change causation and to explore the efficacy of communications and knowledge as strategic project controls. Drawing on a hybrid research design, the critical variables are identified and mapped onto causal loop diagrams to enable practical holism. The findings indicate that effective project communications engenders collaborative team dynamics and collective learning, whereas project learning contributes to knowledge reuse and the improved expert judgment needed for transforming design change management and schedule control.

Keywords: Change management; systems thinking; performance management; schedule overrun, project control; project-based learning; construction

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Introduction

Despite a wealth of research in the quest to investigate the causes of delays in construction, design changes remains a perennial plague inhibiting schedule management worldwide, both in developed (e.g., United States: Han, Lee, & Peña-Mora, 2012; United Kingdom: Olawale & Sun, 2010; Taiwan: Yang, Chu, & Huang, 2013) and developing countries (e.g., Thailand: Ikediashi, Ogunlana, & Alotaibi, 2014; Vietnam: Le-Hoai, Lee, & Lee, 2008; United Arab Emirates: Mpofu, Godfrey, Moobela, & Pretorious, 2017). Yap and Skitmore's (2017) recent survey of Malaysian building projects reports that design changes can induce 5 to 20% time-cost overruns. More than 70% of rework in construction and engineering projects is design change-induced (Burati, Farrington, & Ledbetter, 1992).

Part of the problem appears to be due to the adversarial 'them and us' attitude engendered by the high degree of fragmentation between the various contracting parties hampering the level of project communications (Yap & Skitmore, 2018) required for coordination and trust building (Cheung, Yiu, & Lam, 2013), contributing to project management problems in general (Wearne, 2014). Teamwork and experience sharing are subdued given the limited trust within project teams (Eriksson, Leiringer, & Szentes, 2017). A further issue is that construction involves incredibly complex and highly dynamic projects that involve multiple feedback processes, non-linear relationships, and critical managerial decision-making (Sterman, 1992). According to Wearne (2014), time, change and inexperience constitute the greatest problems for project management across project-based industries in Europe. One aspect is that the contracting parties have little appreciation of the disruptive knock-on effects of a design change request on another parties' portion of work, leading to snowballing modifications and spiraling rework. The lack of competency of project personnel also inevitably proliferates variations (Yap et al., 2017).

It is evident, however, that there are gaps in knowledge germane to the causality of overruns and strategic project management in construction. For example, Alsehaimi, Koskela, and Tzortzopoulos' (2013) critical evaluation and synthesis of 16 delay studies in developing countries reveals that, although poor project management practice is consistently identified as the prime cause of delays, the major shortfall of these published studies is the absence of practical recommendations to address delays. Similarly, Ahiaga-Dagbui, Love, Smith, and Ackermann's (2017) recent examination of a large amount of academic literature on construction cost overruns studies conducted worldwide concludes that most research is superficial, replicative and ineffectual in alleviating the problem. This may be considered surprising by many in view of the project management research community's relentless pursuit of alternative approaches to offer additional insights from different perspectives for both project management practice and theory (Ackermann & Alexander, 2016).

Systems thinking offers a potential way forward to this problem. Ackermann and Alexander (2016), for example, prescribe causal mapping to take a systems viewpoint. For better project control decisions, Lyneis and Ford (2007) advocate the need for more studies within the change management, risk management, and project control domains. System dynamic models in these areas are required to train and teach these heuristics among project management practitioners (Sheffield, Sankaran, & Haslett, 2012). This is in agreement with Coyle (2000) on the use of a qualitative causal model to place complex problems that may require many pages of narrative explanation onto a single piece of paper to enable practical holism. To improve project performance, Lyneis and Ford (2007) also propagate controlling dynamic systems through management actions. Applications in delay studies are limited however, with little work being conducted integrating project communications management and knowledge using the systemic approach in the management of design changes and schedule control for example. In a similar vein, conceptualizing construction as a nonlinear system may engender a more practical context for the understanding of the causal relationships involved (Olaniran, Love, Edwards, Olatunji, & Matthews, 2015).

Given the current shortcomings, Ahiaga-Dagbui et al. (2017) recommend future delay studies to shift from single-cause identification and conventional correlation analysis between variables to pursue the causal nature of overruns through systemic thinking and retrospective sensemaking. Likewise, given that time and cost management are inseparable (Kerzner, 2017), a similar observation can be inferred for delay studies. To gain further insights into construction delays and the complex interactions between the causative factors, Aibinu and Odeyinka (2006) also suggest the need for adopting a systemic approach to evaluate the interrelatedness of the critical factors involved. Their proposal concurs with Lyneis, Cooper, and Els (2001) on utilizing system dynamics models to improve the performance of the management of complex projects.

In response to Ahiaga-Dagbui et al.'s (2017) assertion of the methodological deficiencies of the majority of cost overrun research and the call by Ackermann and Alexander (2016) on the use of causal mapping for researching complex issues, this study adopts a systemic paradigm to understand the causes of design changes. It seeks to understand design change causation vis-à-vis scope creep that results in schedule delays induced by frequent design changes during construction. The effects of these factors are systemically explored to provide more profound insights into how active communications and continuous learning in projects can be leveraged to control design changes and ultimately improve schedule performance in a project environment. Heeding Olawale and Sun's (2010) proposition for exploiting preventive measures in project schedule management, the study seeks to examine the value-addedness of project communications management and project knowledge management as project control actions. Both are outlined by Project Management Institute's (2017) Project Management Body of Knowledge (PMBOK) Guide as key areas to achieving on-time and within-cost delivery of projects. The paper also contributes to bridging the gap in the literature concerning design change causation employing a systemic thinking approach with the aid of causal mapping to understand the multiple causal relationships beyond the traditional identification of single-causes.

Literature Review

Design Change-induced Overruns

More than two decades ago, Ogunlana, Promkuntong, and Jearkjirm (1996) examined the causes of delays of high-rise building construction projects in Thailand to observe that project clients request for changes in plans are predominantly responding to changing economic climate, meeting customer demands or some marketing reasons. This is akin to Kaming, Olomolaiye, Holt, & Harris's (1997) findings for high-rise building projects in Indonesia, where the leading causes of delays are design changes, poor labor productivity, and inadequate planning. In 2010, Olawale and Sun's (2010) survey conducted on 250 construction organizations in the UK revealed design changes, risks/uncertainties and inaccurate evaluation of project duration as the three leading factors inhibiting the effective schedule management and cost control of construction projects. A year later in Australia, Orangi, Palaneeswaran, and Wilson's (2011) case study of three pipeline projects in Victoria identified the major root causes of delays as including design changes, design errors and design submission delays – all of which are related to design matters. Another comparable observation is also reported by Hanna, Camlic, Peterson, and Lee (2004) in the U.S.

In Denmark, Larsen, Shen, Lindhard, and Brunoe (2015) observed that errors in design documents, inconsistencies in project documents, and late user changes to function, demand extensive modifications, resulting in significant cost increases. Their findings concur with Josephson, Larsson and Li's (2002) claim in Sweden that 26% of rework is relating to design-related causes. Likewise, a more recent study in Malaysia by Nurul, Aminah, Syuhaida, and Chai (2016) examined National Audit Reports, noting that change in design by the client in the implementation phase is listed as one of the 69 low-performance factors in public development projects. It is evident that design changes persistently hinder construction projects from attaining schedule and cost objectives in many parts of the world – further justifying the need for further research to access this problem. This provided the motivation to examine this phenomenon from the alternative systemic perspective used in this study.

A design change is a form of change that deviates the way work is planned, budgeted or scheduled (Abdul-Rahman, Wang, & Yap, 2016). Almost all projects undergo various degrees of design changes throughout the project lifecycle. Even though design changes are widely accepted by practitioners in the construction industry, however, they have undesirable adverse consequences on project outcomes (Mohamad, Nekooie, & Al-Harthy, 2012). Notwithstanding the voluminous reports of projects having run over time and over budget due to frequent design changes during construction, there has been limited academic research, particularly regarding the nature and causes of design changes. This motivated Yap and Skitmore (2018) to investigate the various reasons for design changes in Malaysian building projects. They conducted a review of the extensive literature to categorize the 39 causes into those related to the project (1) client, (2) consultant, (3) contractor, (4) site, and (5) external. The three most significant causes observed are poor coordination among various professional consultants, variations in the specification, and frequent changes to scope requirements. A study by Suleiman and Luvara (2016) in Tanzania evaluated the implications of design changes to include schedule delays, increase in costs, abandonment, wastage of materials and disputes among the contracting parties. Their major causes are owner changes, an unclear initial design brief, and inadequate design details. In Indonesia, Yana, Rusdhi, and Wibowo (2015) grouped the influential factors of design changes under internal and external factors. Using a questionnaire survey, they further analyzed the data using partial least squares (PLS) to reveal that the client was the main responsible party inducing design changes, followed by professional consultants. However, the ranking of the causes is not available. Consistent with Ahiaga-Dagbui et al.'s (2017) reflection, these captioned studies are merely replicative where similar causal variables are identified. Another shortcoming worth highlighting is that these studies lack clear recommendations for mitigation measures, in line with Alsehaimi et al.'s (2013) claim noted earlier – limiting the construction industry's efforts to devise effective strategies to contain the problem. Olaniran et al. (2015) further echoed that research is often fixated on apportioning leading reasons for overruns without proffering remedial actions. An exception is Mohamad et al.'s (2012) corrective actions of allowing longer time for the design process, involving experienced personnel, providing a clear design brief from the client and delivering prompt information concerning the impact of each proposed change. It is the interest of this study, therefore, to explore the avenues for reducing avertable design changes during construction.

Related to design changes, many past studies blame rework for undermining project performance. Design change-induced rework can account for nearly 50% of cost overruns (Love, 2002). Senaratne and Sexton (2009) note that rework due to unplanned changes can cost up to 15% of contract value. Likewise, Chang, Shih, and Choo's (2011) study found an average of 8.5% cost increase due to design changes in Taiwan, which concur with Cox, Morris, Rogerson, and Jared's (1999) claim that the cost associated with design changes was 5-8% in the UK. The reasons are obvious: design-change induced-rework results in a higher cost due to the further efforts of disassembling and restarting some completed works (Emuze, Smallwood, & Han, 2014; Yap, Low, & Wang, 2017), resulting in the loss of project productivity (Cooper & Reichelt, 2010) and higher wastage (Kakitahi, Alinaitwe, Landin, & Mone, 2016). These non-value adding activities generate multiple knock-on effects that result in delays and disruptions to the construction workflow (Howick, Ackermann, Eden, & Williams, 2009). When rework increases, the project cost, and schedule is likely to increase, which eventually leads to unnecessary disputes and claims (Ibbs & Liu, 2005).

Project Control Measures

To better control time and cost, Olawale and Sun (2010) conducted in-depth interviews with 15 industry practitioners to devise 18 mitigating measures for design changes, which were then classified as: preventive, predictive, corrective, and organizational measures. Following their classification, Chai, Yusof, and Habil (2015) conducted a broad survey in Malaysia to explore the relationship between the mitigation measures and delay factors in housing delivery, employing a structural equation modeling approach (SEM). Their SEM analysis revealed preventive measures to be the most influential in mitigating delays. For this reason, the preventive approach is adopted to strategically control design changes in this study.

To explore the factors influencing project success, Andersen et al. (2006) gathered critical factors from four culturally different regions (France, Norway, UK, and China), in which a principal components analysis (PCA) found strong project commitment and effective communications significantly contribute to project success. Their study in Norway also revealed that such 'soft skills' as rich communications and learning from experience are prerequisites for the project team to deliver results on time and within budget. Another study of critical success factors by Yong and Mustaffa (2013) in Malaysia also acknowledges the significance of human-related factors such as commitment, competence, communication and cooperation on the successful delivery of construction projects. This is akin to Eriksson et al.'s (2017) attributes of successful co-creation practices and requisites to project knowledge management (Gasik, 2011).

Anantatmula’s (2015) project performance enhancement model, developed using interpretive structural modeling (ISM), suggests that effective communication is the critical contributing factor, resulting in a cohesive project team that encourages participative decision-making. Love and Smith (2016) propose a collective learning framework in the pursuit of productivity and performance improvements, particularly focusing on experiential learning in error management. A separate study by Love et al. (2016) using a case study of a mega Australian water infrastructure alliance project advocates the critical need for project learning and continuous improvement to be engendered through mutual trust, shared values and rich project communications to reduce rework in order to improve overall project performance. In the following year, Yap et al. (2017) interviewed 12 experts from the construction industry to conceptualize a collaborative model that stresses the importance of project communications and continuous learning towards enhancing team capacity and synergy in managing construction projects. Their model explicitly elucidates the enablers of effective communication, enablers of project learning and types of reusable project knowledge. Manley and Chen (2017, p. 3) describe construction project collaborative learning as “an absorptive capacity … to explore, transform, and exploit knowledge” which positively influences project performance. It is worth mentioning that the exchange of information, knowledge and new ideas between team members is motivated by synergic team dynamics (Koutsikouri, Austin, & Dainty, 2008) and facilitated by an effective communication management plan (Senaratne & Ruwanpura, 2016). As such, collaborative teams can successfully learn from change events in construction projects (Senaratne & Sexton, 2009) and reuse the knowledge gained for future projects (Kivrak, Arslan, Dikmen, & Birgonul, 2008). Tan, Carrillo, and Anumba (2012) stress the need to learn from construction projects, and that the real benefit in time-cost control can only be realized when project knowledge is effectually reused. Nevertheless, project knowledge management is significantly influenced by organizational leadership and culture (Zhang & Cheng, 2015). In recognizing learning in project-based organizations (Chroneer & Backlund, 2015; Gasik, 2011; Koskinen, 2012; Mueller, 2015; Reich, 2007), 'manage project knowledge' is incorporated as a vital process within project integration management in the latest (6^{th}) edition of Project Management Institute's (2017) PMBOK Guide.

Having synthesized the above studies, project communications management and project learning are envisioned as the strategic preventive measures to control design changes to reduce rework and improve project performance in this study. Although previous studies indicate the efficacy of project communications management and project learning as effective measures for time-cost control, there is little systemic evidence of the implications of these measures in managing design changes in project environments. According to Anantatmula (2015), managerial strategies for enhancing project performance are more akin to mental models. In addition, Lyneis and Ford (2007), Senge (2006), and Sterman (2000) advocate that building shared mental models engenders learning by creating a shared vision using systemic thinking. Different actors in the system can make sense of discerning feedback mechanisms to schedule control under a common perspective and shift mental models (Galanakis, 2006). Hence, the relationship between these variables is explored using a systemic approach to bridge the knowledge gap in this domain and encourage project manager practitioners to implement changes in project management.

Systemic Approach

Systems thinking is the underpinning paradigm and research approach for this study. Systems thinking is a holistic (integrative) approach to problem-solving based on general systems theory (Bertalanffy, 1968), a philosophy of science and engineering based on the idea of combining the knowledge gained through analysis and the understanding attained through synthesis to address the root causes of problems (Caulfield & Maj, 2001). Systems theory is an approach to intellectually engaging change and complexity (Chen & Stroup, 1993). Weinberg (1975) describes systemic thinking as a way of thinking about problems. Checkland (2000) notes that systems thinking is an inquiring process in making sense of complex situations. This lead to Senge (2006) introducing systems thinking as the key component of organizational learning, where the process of inquiry into real-world complexity is itself a system for learning. More recently, Gates (2016) points out the emerging trend of integrating systems thinking into complexity science to provide an alternative science paradigm and methodological approach to studying complex systems.

There are generally two distinctions in systems practice – soft and hard systems thinking. While 'hard' systems thinking is often used to understand a relatively well-defined technical problem, 'soft' systems thinking is more suitable for solving complex management problems involving human beings (Checkland, 2000). In dealing with real-world managerial issues, soft systems methodology can be instigated to develop conceptual models to evaluate the underlying dynamics of the system-problem structuring (Reisman & Oral, 2005). Hard systems thinking on the other hand, involves problem-solving using formal models following the results of the process of inquiry (Reisman & Oral, 2005). It is the purpose of this paper to employ the soft systems approach using cognitive mapping to offer guidance in structuring design change management and project schedule performance with an integrative systems perspective and methodological pluralism. This is in agreement with Reynolds and Holwell's (2010) first purposeful orientation of systems thinking in making sense of, or simplifying (in understanding), the interrelationships in a complicated situation. They assert that the prime intention of the systems approach in research is to acquire more profound insights in order to improve the situation.

Monat and Gannon (2015) conducted a systematic literature review to recommend systems thinking in solving complex problems that are not solvable using traditional reductionist (dissective) approach because this ‘new way of thinking’ stresses interactions between elements in the systems. Arnold and Wade (2015, p. 675) describe systems thinking as “the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects.” All things considered, complexity in project management may be tamed by systemic thinking (Sheffield et al., 2012) in the pursuit to improve efficiency and project performance. As such, the systemic approach is a fast emerging technique for applying non-linear causal thinking to improve understanding of project management problems over the past decade. This includes rework causation (Emuze & Smallwood, 2014), risk management (Wang & Yuan, 2017), delay factors (Das & Emuze, 2017), change management (Lee, Peña-Mora, & Park, 2006), procurement management (Park, Ji, Lee, & Kim, 2009) and sustainability performance (Onat, Egilmez, & Tatari, 2014). The notion of examining the underlying dynamics of the causes of design change creates a complex net. As such, a systemic approach is adopted to deal with the complexity and attempts to create the paradigm shifts needed to transform current work practices in managing change in a project environment.

Integrated Model of Systemic Thinking

The iceberg analogy representing the four levels of systemic thinking outlined by Maani and Cavana (2007) is illustrated in Figure 1. The tip of the iceberg, which is the most visible part, represents the event level - in this case the observable late delivery of building projects. In reality, most interventions to address the problem take place at this reactive level (Maani & Cavana, 2007), oftentimes ineffectually (Kim, 1999).

Hidden from view, the second level of thinking involves noticing a pattern/trend by linking together a set of consistent and recurring discrete events, where schedule control is inhibited by frequent design changes (Olawale & Sun, 2010), lack of project communications (Doloi, Sawhney, Iyer, & Rentala, 2012) and poor project knowledge of members from wide-ranging disciplines (Al-Kharashi & Skitmore, 2009). These patterns are more meaningful than events, because the underlying causes of schedule delays are recognized so that a response can be taken.

A further hidden third level of thinking is systemic structures, which reveals the interconnected relationships of the patterns that cause schedule delays. Thus, the salient fundamental aspect at this level of thinking is to make sense of how these causes interact. With this in mind, causal mapping is an effective tool to provide a visual depiction in revealing the cause-and-effect interdependent relationships among a set of variables that jointly operate as a dynamic system (Sheffield et al., 2012).

The most hidden level of thinking is mental models reflecting the paradigms, values, and assumptions of people to understand and respond to the situation at hand. The explicit mental models promote mutual understanding of problems among team members (Sterman, 2000), and therefore motivate meaningful communications and the development of collective vision and action (Maani & Cavana, 2007). In this study, the discerning dynamics of preventive control measures are evaluated using active communications and project knowledge to transform the perennial problem of schedule delays due to frequent design changes – with the vision of pursuing enhanced project schedule performance.

According to Maani and Cavana (2007), the systemic thinking paradigm shifts project stakeholders from the event level at the surface to deeper levels of thinking to handle complex problems, akin to the claim by Ackermann and Alexander (2016) and the purpose of this study. It is envisaged that the process and methodology adopted in this study will help to understand the causality of design changes and improve project schedule performance by explicitly inferring the dynamics of effective communications and continuous learning from project experiences in the effective control of design changes in building projects. A shift in mental models will significantly improve overall team and project performance (Sterman, 2000).

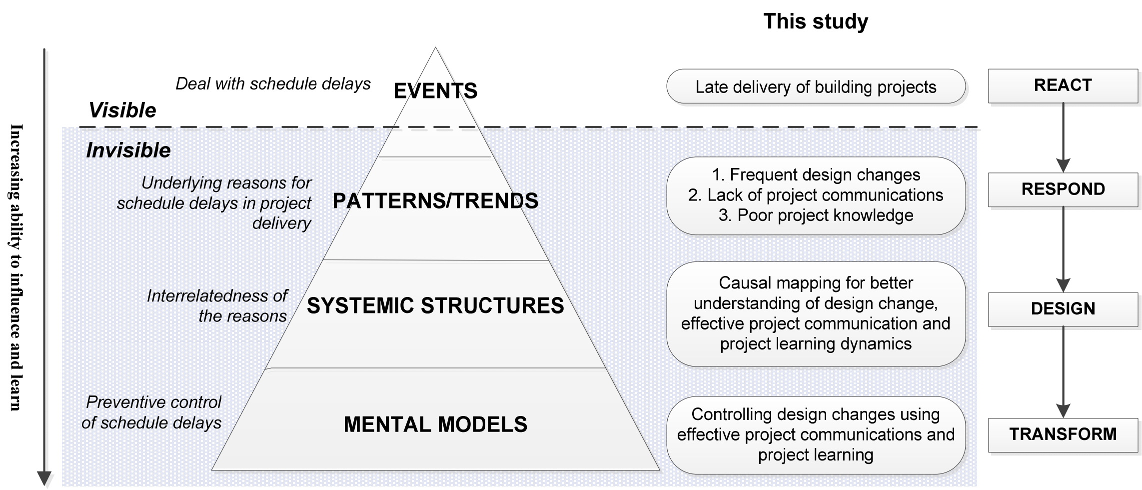

Figure 1: The iceberg model for systemic thinking (Adapted and modified from Maani and Cavana, 2007)

Research Methodology

This study adopts a hybrid research strategy (see Figure 2), heeding Ackermann and Alexander's (2016) suggestion to mix qualitative data with that obtained from a structured survey in the development of causal mapping. In addition, the triangulated approach provides rigor and robustness to the empirical findings (Joslin & Müller, 2016). First, a comprehensive review was conducted of the literature to formulate the potential causes of design changes. This comprised that relating to design changes, construction delays, cost overruns, rework, and change orders. The review resulted in initial list of 43 causes relating to project (1) clients, (2) consultants, (3) contractors, (4) site, and (5) external.

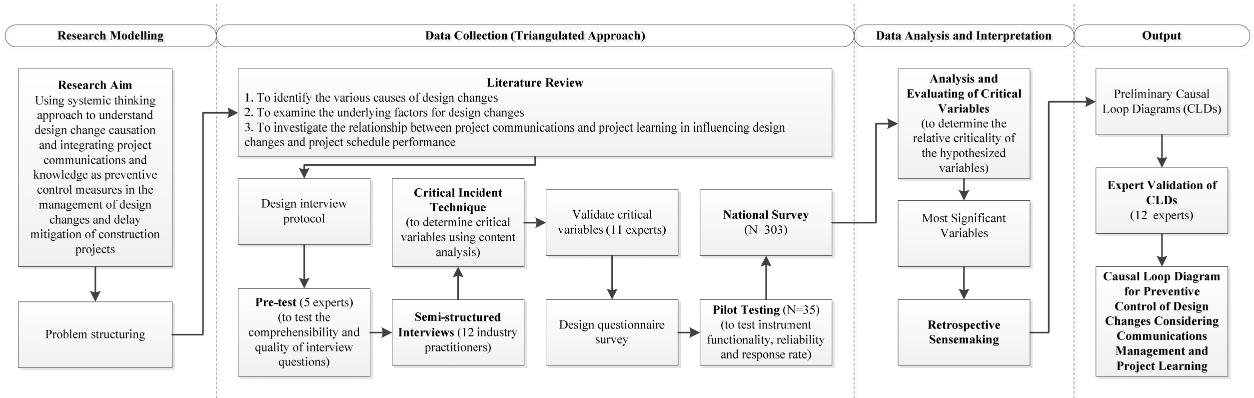

Figure 2: Research process

Data Collection using the Triangulated Approach

Both qualitative and quantitative data collection were conducted sequentially employing semi-structured interviews and a questionnaire survey, which was then amalgamated to achieve data triangulation to increase reliability (Joslin & Müller, 2016) as well as reduce complications associated with bias and validity (Love et al., 2016). The building construction sector in Malaysia was chosen for the primary data collection. Interviews are considered a suitable data collection mechanism to gain insights into a phenomenon in an exploratory study (Creswell, 2014). According to Arksey and Knight (1999, p. 2), "interviews are concerned with exploring data on understandings, opinions, what people remember doing, attitudes, feelings and the like, that people have in common." The overall quality of the interview questions was first pretested with five experts and their feedback was used to improve the questions further. To explore the aptness of the causes to the Malaysian context, a total of 12 face-to-face semi-structured interviews were conducted with industry practitioners, involving 4 representatives from clients, consultants and contractors respectively to provide an equitable understanding of the research topic (see Table 1). All these practitioners had sufficient working experience in the building construction sector. They were requested to identify the causes of design changes from the projects in which they were involved, to pinpoint the effects of design changes-induced rework, and to elucidate how active communications, knowledge and past project experience influences project performance. To elicit the participants' rich experiences in dealing with design changes, critical incident (Flanagan, 1954) and retrospective sensemaking (Weick, 1995) techniques were adopted, using probing questions such as 'can you share with me how this event happened?', 'please give an example' and 'how are these causes related?' to motivate them to share more details. Ahiaga-Dagbui et al. (2017) recommend this approach for developing the meaning of cost overrun causation in construction projects. Love, Ackermann, Smith, Irani, and Edwards (2016) also used face-to-face interviews with experienced professionals in their sensemaking conversations to explain how and why rework arose in offshore hydrocarbon projects from their perspective. Note-taking and consented digital audio recordings were made throughout the interviews to maintain the accuracy of data collection and to facilitate transcription. Each interview took approximately 60 minutes. Upon reaching data saturation, an Nvivo content analysis was then utilized to identify the critical variables from the interview transcripts. This resulted in the identification of 39 causes of design changes, 9 effects of design change-induced rework to project performance, 4 influences of effective project communications, and 2 benefits of project knowledge in construction. These critical variables were further validated by 11 experts with an average experience of 29.1 years in the Malaysian construction industry.

Table 1: Information of interview participants

No.	Position in company	Years of working experience	Company type
1	Project Associate	6-10 years	Consultant
2	Project Director	21 years and above	Contractor
3	Director	21 years and above	Consultant
4	Deputy General Manager	11-15 years	Client
5	Assistant General Manager	16-20 years	Client
6	Senior Project Manager	21 years and above	Client
7	Principal	16-20 years	Consultant
8	Chief Executive Officer	21 years and above	Contractor
9	Director	21 years and above	Contractor

10	Director	16-20 years	Consultant
11	General Manager	21 years and above	Contractor
12	Project Manager	11-15 years	Client

Depending on the validated critical variables fit for the Malaysian context, a questionnaire was developed for the four categories of variables. The questionnaire consists of five parts. The first part aims to collect the respondents' background information, and the second, third, fourth and fifth parts contain the 39 causes of design changes (category 1), 9 effects of design change-induced rework to project performance (category 2), 4 influences of effective project communications (category 3), and 2 benefits of project knowledge (category 4) to be evaluated. A 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) was adopted to measure the agreement of each variable. A pilot survey involving 35 industry practitioners was conducted to ensure clarity and unambiguity – an essential step to ensure the success of the main survey. For the main survey, a total of 1100 questionnaires were distributed over a period of 3 months, of which 303 valid responses were returned, attaining a consolidated response rate of 29.4% with a total of 338 responses after combining with the responses from the pilot survey, which is considered an acceptable practice (Fellows & Liu, 2008). The responses collected were analyzed using the Statistical Package for the Social Sciences (SPSS) for Windows (Version 23). Table 2 presents the descriptive statistics concerning the respondents. With 69% of the respondents having more than 5 years' experience and 49% having more than 10 years of experience, the sample is representative and can reflect current positions in the industry.

Table 2: Descriptive statistics of questionnaire respondents

Characteristic	**Category**	**Number of respondents**
Position in company	Executive	174
	Manager	76
	Senior Manager	54
	Directors	34
Work experience (years)	1 to 5	106

	6 to 10	68
	11 to 15	59
	16 to 20	48
	> 20	57
Education background	Diploma	21
	Bachelor degree	229
	Master degree	82
	Doctorate	6
Company type	Client	85
	Consultant	174
	Contractor	79

Analysis and Evaluation of Critical Variables

The scale reliability of the four categories is established considering the computed Cronbach's alpha values ranges from 0.745 to 0.901, which is greater than the 0.7 value for exploratory research (Hair, Black, Babin, & Anderson, 2010). Table 3 presents the mean score of the ten most significant critical variables identified in category 1 and the mean score of the critical variables in categories 2, 3 and 4. The one sample t-test (test value = 3) indicates that all these critical variables are perceived to be significant by the respondents at the 95% confidence level, attaining both content and construct validity requirements - where the critical variables amply represent and measure the phenomenological reality of the study (Lucko & Rojas, 2010).

Table 3: Mean score of critical variables identified

Overall ranking	Critical variables for Category 1	Mean	Standard deviation
Category 1: Causes of design changes (10 most significant)			
1	Value engineering (cost savings, alternative materials)	4.000	0.847
2	Lack of coordination among various professional disciplines/consultants	3.979	0.866
3	Change of requirement/specification	3.947	0.853
4	Addition/Omission of scopes	3.908	0.851
5	Additional requirements (add-on features)	3.867	0.810
6	Changes in government regulations, laws and policies	3.867	0.903
7	Erroneous/discrepancies in design documents	3.864	0.864
8	Design omissions/incomplete drawings	3.834	0.886
9	Slow decision-making	3.778	1.037
10	Modification to design (improvement)	3.743	0.794

Category 2: Effects of design changes-induced rework to project performance			
1	Time delay	4.278	0.731
2	Cost increase	4 180	0.774
3	Generates more tasks to do	4 044	0.834
4	Excessive claims	3 953	0.761
5	Disputes	3.870	0.786
6	Loss of productivity	3.799	0.876
7	Coordination issues	3.754	0.893
8	Loss of rhythm	3.719	0.879
9	Degrades morale of workforce	3.447	0.980
Category 3: Influences of effective project communications			
1	Common understanding of problem	4.361	0.640
2	Sharing of experiences	4.278	0.662
3	Team cohesion	4.275	0.675
4	Collaborative culture	4.228	0.692
Category 4: Project learning in building construction			
1	Project experiences are important to be captured for reuse in future projects	4.660	0.567
2	Past project experiences will improve your decision-making in future projects	4.610	0.556

A close examination of Table 4 reveals that 83% of the respondents acknowledged that design changes induce rework. The majority of the respondents agreed that active project communications (mean = 4.305) and project learning (mean = 4.340) can effectively shorten the project duration of construction projects, with apparently increased productivity from less design changes and resultant rework. More than 80% of the respondents are of the opinion that graphical representation of the causal relationships could assist in their better understanding of overrun causation.

Table 4: Hypothesized relationships of variables

S. no.	Hypothesized relationships	Percentage of respondents scoring					Mean	Standard deviation
		1	2	3	4	5		
1	Design changes causes rework	0.3	3.0	13.9	58.0	24.9	4.041	0.730
2	Effectiveness of project communication management in project time control	0.0	1.2	8.3	49.4	41.1	4.305	0.671
3	Effectiveness of project learning in project time control	0.0	0.9	8.0	47.3	43.8	4.340	0.662
4	Graphical representation in assisting understanding of overrun causation	0.3	1.2	17.8	53.3	27.5	4.065	0.724

According to Ackermann and Alexander (2016), traditional approaches can be integrated with causal mapping to provide new insights. This study adopted a similar approach utilized by Wang and Yuan (2017) and Emuze et al. (2014) of using the significant variables evaluated based on the responses of their questionnaire surveys as essential elements in the CLDs. Based on the critical variables identified in Table 3 and the hypothesized relationships in Table 4, retrospective sensemaking was used to determine why and how design changes occurred and how project communications management and project learning can facilitate the schedule control of building projects. As such, a more nuanced understanding of the critical variables can be accomplished to maintain internal validity and ensure the causalities involved are logical (Lucko & Rojas, 2010).

The next section discusses the steps employed to systemically formulate the CLDs for design change causation, design change-induced rework, effective project communications, project learning, and causal relationships for preventive control of design change-induced overruns considering active communications and the continuous learning approach. The resulting visual representation of the diagrams provides a more explicit understanding that is useful to articulate, share and modify mental models of the managerial problem at hand with the objective of improving decision-making and strategizing mitigation measures (Grösser, 2017).

Conceptualizing Causal Loop Diagram

As noted earlier, independent single-cause identification and simply ranking variables do not provide a complete understanding of causation and may even be counterproductive. According to Ahiaga-Dagbui et al. (2017), a systemic approach is therefore required to make sense of causality by examining the interdependencies of the critical variables using causal mapping. Qualitative project causal mapping provides a rich grounding for understanding why the key events behave in the way they do and make sense in establishing causality and learning lessons from project experience (Howick et al., 2009). With this in mind, the causes of design changes should not be considered in isolation but are dynamically linked accommodating combinations of cause-and-effect feedback loops with the aid of the Vensim PLE software.

The causal loop diagram (CLD) is a valuable tool for systemic thinking, particularly for representing the feedback for a problem, eliciting, capturing and comparing mental models of people, and enabling explicit graphical representation (Sterman, 2000). As such, CLD reveals the causal relationships among a set of variables influencing a system where the variables are connected by arrows (causal links) (Maani & Cavana, 2007). Each causal link is allotted a polarity, either positive (+) or negative (-), to show the way the dependent variable is affected each time the independent variable changes. The dynamics of all systems derive from the interaction of two types of feedback loops. Thus, the causal relationships can be recognized by tracing the direction of the arrows, starting from any one variable, traversing the loop, and coming back to the same variable. Positive loops (R) tend to reinforce or amplify whatever is already occurring, whereas negative loops (B) counteract and oppose change (Sterman, 2000). Hence, positive or reinforcing loops create a vicious or virtuous cycle while a negative or balancing loop is goal seeking.

According to Sterman (2000), CLD conceptualization involves two primary steps, namely (1) problem articulation and (2) formulation of dynamic hypotheses. The initial step is concerned with articulating the problem, which involves defining the problem or issue at hand to be solved and outlining the objective of the model. Here, the boundary of the model is established and key variables identified. In this case, the model represents how design changes could potentially influence project schedule performance and how active communications and continuous learning potentially control design changes to mitigate schedule delays. The second step is related to deriving dynamic propositions. Here, the key variables are identified from data triangulation involving the published literature, in-depth interviews, and questionnaire survey.

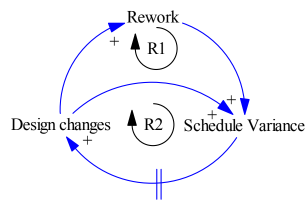

Figure 3: Dynamic hypothesis 1

Design changes lead to more rework and greater schedule variance as depicted in Figure 3, representing the first dynamic hypothesis. Figure 3 also shows that schedule variance leads to more design changes, which closes the two R-loops (R1 and R2). In this sense, this study assesses the influence of design changes along with design change-induced rework on project schedule performance. Both loops have reinforcing effects, suggesting that an increase in design changes will create more rework and require additional time for completion. To understand the causal relationships of the 10 most critical causes of design changes from Table 3, these causes are mapped in a causal loop diagram as depicted in Figure 4. It is evident that the causes have multiple interrelated relationships, with seven reinforcing loops, suggesting that the relationships are non-linear and the traditional net-effect correlational analysis are insufficient to cope with the systemicity of the design changes. The reinforcing loops R1 to R4 appear to be 'vicious loops' denoting that the critical variables need to be dealt with care as they act together to generate further design changes, resulting in lack of control of scope creep. Contrary to popular belief, the insight gained is that, although 'value engineering' is always considered to have a positive effect on controlling cost, the effects on project schedule are unfavorable, particularly due to rework. To explain this, 'value engineering' exercises initiate further 'modification to design' that impede problem-solving decision-making. As a result, further 'changes to specification' may prompt 'haphazard decision-making', which then leads to superfluous 'scope creep' as the system becomes out of control. The other vicious reinforcing loops, R5 to R7, indicate that 'changes to specification' triggered from 'additional requirements' and 'changes to government regulations' induces excessive design changes from 'design errors' and 'incomplete drawings', which results in an exponential upsurge in rework and further increases schedule delays. This can propel the rapid growth of design changes at an ever-increasing rate that supports dynamic hypothesis 1 as depicted in Figure 3. Given the undermining effects on project performance, preventive actions are essential to alleviate these dynamics.

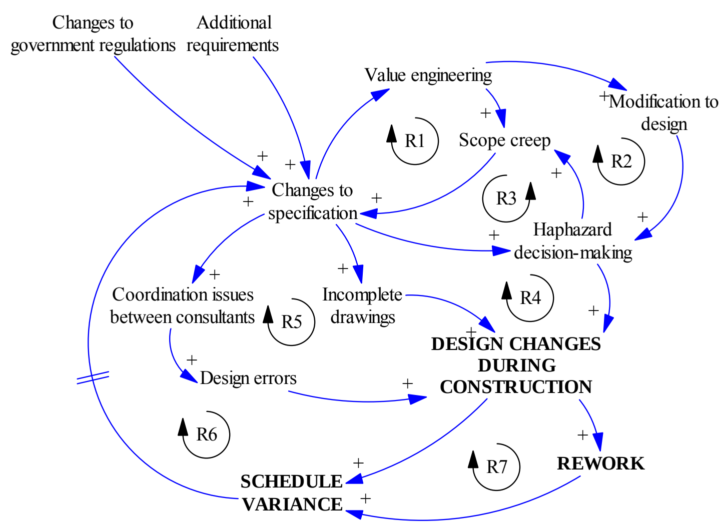

Figure 4: CLD depicting the causal relationships for critical causes of design changes

The critical variables of the effects of design change-induced rework from Table 4 are mapped in Figure 5 to illustrate the causal relationships that influence schedule performance. A close examination of Figure 5 reveals three reinforcing loops – expanded from dynamic hypothesis 1. As such, by reversing the polarity of the causal relationships (from vicious to virtuous loops), schedule performance can be improved by reducing design change-induced rework, consistent with previous studies (Dehghan & Ruwnapura, 2014; Hegazy, Said, & Kassab, 2011). Referring to loop R2, abortive rework increases project cost, resulting in disputes between the contracting parties and excessive contractual claims. In essence, a schedule delay from reworking is due to lower productivity because of loss of work rhythm and lower workforce morale when a completed section of work entails further dismantling and reinstallation (loop R3).

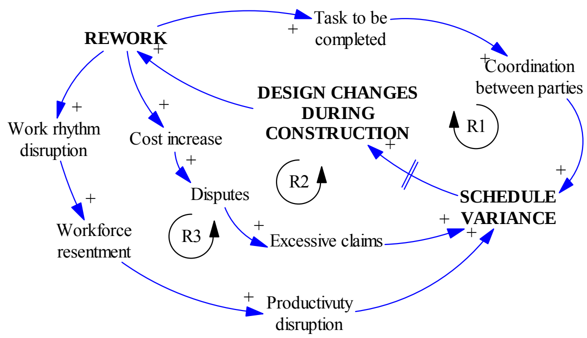

Figure 5: CLD depicting the causal relationships for critical variables of design change-induced rework

The second dynamic hypothesis is depicted in Figure 6, where project learning is facilitated by active communications for solving problems relating to design changes. Learning increases the competency of project managers which leads to enhanced expert judgment (Yap, Abdul-Rahman, & Wang, 2018). On the other hand, miscommunication hampers project coordination (Yap & Skitmore, 2018), resulting in a 'blame-shifting game' that delimits trust and collaboration between project team members (Mainga, 2017). As such, less communication also leads directly to more design changes. For this reason, two balancing loops are formulated alongside design changes, project learning and communication required for problem-solving. However, there seems to be a side effect loop R1 based on the parallelism of design changes and communication required for problem-solving after a delay period. To explain this, the reinforcing loop leads to early exponential growth, but then, after a delay, the negative feedback loops come to dominate the system with goal-seeking behavior. As such, an S-shaped pattern is attained. To control design changes at some point, some exploitation of past project experiences - such as best practices and lessons learned coupled with synergic team dynamics - can stop the growth.

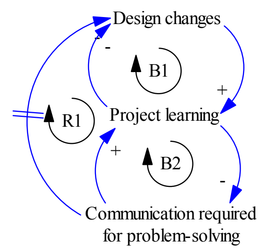

Figure 6: Dynamic hypothesis 2

The causal loop diagrams developed from the critical variables for effective project communications and project learning from Table 3 are presented in Figures 7 and 8 respectively. As is evident in Figure 7, effective project communication is capable of reducing schedule delays through team cohesion, collaborative culture, sharing of project experiences and a common understanding of problems (loops B1 and B2). It is worth mentioning that, although frequent design changes are detrimental to schedule performance, they demand intensified project communications between team members - a counterintuitive effect of team collaboration. Frequent face-to-face interactions and project meetings engender an effective communication of storytelling (Abdul-Rahman, Yahya, Berawi, & Low, 2008). Considering this, there is an aspect around the problematic design change events that offers excellent opportunities to elicit more communication and the collective sharing of lessons learned to enhance the likelihood of future project time savings. This collaborates with Akkermans and van Oorschot's (2016) observation in complex radical aircraft development projects that time lost due to rework cycles in past projects expedites team learning, which leads to higher productivity in future projects.

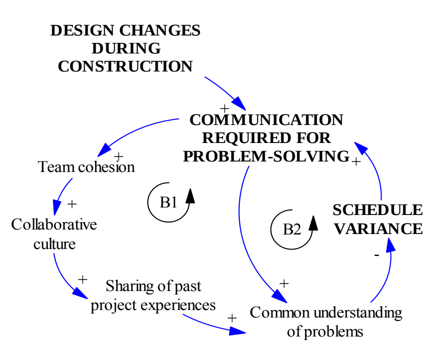

Figure 7: CLD depicting the causal relationships of the critical variables for effective project communications

A closer examination of Figure 8 manifests that project learning from experiences engenders knowledge reuse, resulting in better decision making that makes up a virtuous reinforcing loop R1. On the other hand, more learning from past projects will improve future project performance, as shown by balancing loop B1. Many studies, as discussed earlier, accentuate the significance of project learning (Abdul-Rahman et al., 2008; Gasik, 2011; Love et al., 2016) and it is apparent that collective learning depends on team cohesion and rich communications (Anantatmula, 2015; Yap et al., 2017; Yong & Mustaffa, 2013).

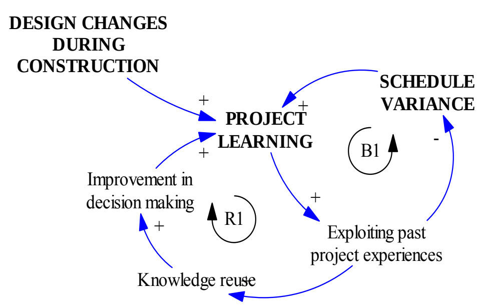

Figure 8: CLD depicting the causal relationships of the critical variables for project learning

To gain a complete understanding of how project communications management and project learning effectively control the amount of design changes during construction holistically, all the CLDs depicted in Figures 4, 5, 7, and 8 are now integrated, as presented in Figure 9 which was validated by 12 industry experts with an overall project experience of 339 years (mean of 28.3 years). The relationships between variables are clearly illustrated in the CLD, where reducing design changes will lead to a lower amount of rework and further improve schedule performance (loops R6 and B4). However, it is also interesting to note that increased design change events generate added essential learning for the team. In line with the discussion above, Figure 9 explicitly explains the virtuous influence of active communications and continuous learning (loop B2) to mitigate schedule delays (loop B3). However, a substantial delay in loop B3 and B4 may lead to unintended consequences. Here, the delay in communicating schedule variance and neglected learning often leads to a backlog of rework owing to unenlightened design changes. As such, the project team is forced to work in a reactive mode, continuously 'fighting fires' to overcome problems that could have been prevented (Wearne, 2014).

The interconnected relationships of effective communication and collaborative learning from experience facilitate knowledge generation and reuse, provide informed decision-making capabilities and enhancing expert judgment and competency to reduce preventable design changes to improve project schedule performance. A synergetic working environment alleviates fragmentation within the project team (Behera, Mohanty, & Prakash, 2015) to reinforce a shared understanding of design changes and shortens project duration through the co-creation of solutions and adaptation of best practices from collective past experiences. Notwithstanding these desirable effects, the pressure to complete and the risk of liquidated and ascertained damages (LADs) for late delivery of the project will limit the growth of co-creation practices to some extent.

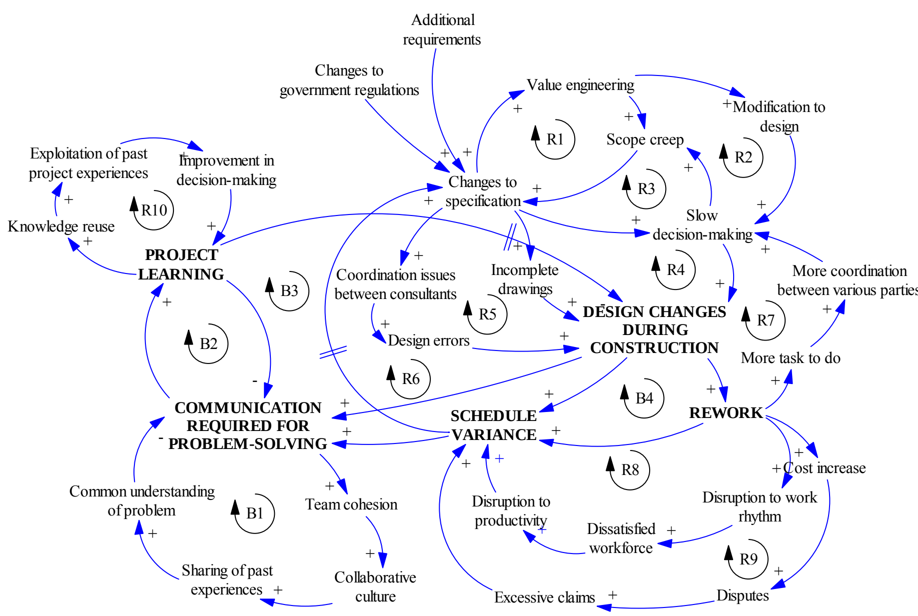

Figure 9: CLD depicting the causal relationships for preventive control of design change-induced schedule delays considering project communications management and knowledge

Implications for Research into the Causes of Design Changes and Overruns

The present study aims to extend the understanding of the causes of design changes, and exploring control measures using communications and knowledge, by employing a systemic approach. However, while a significant amount of research has been carried out in the past to identify the major causes of overruns, the single or independent root cause evaluation is inadequate to contain frequent design changes. As asserted by Ahiaga-Dagbui et al. (2017), these studies merely assess the 'events level' that is visible (see Figure 1). As noted earlier, in reality, most decisions and interventions take place at this reaction level. According to Maani and Cavana (2007), events simply represent the symptoms of complicated problems. Therefore, quick fixes and fire-fighting policies reacting to events often only address superficial problems. It is therefore crucial for more studies to move to a deeper level in order to respond, design and transform the industry. With this in mind, instead of simply identifying and listing the critical variables involved, the dynamic interactions between the critical variables determined from the empirical study are further explored to provide insights into multiple cause-and-effect relationships. The CLDs for critical variables of design changes (Figure 4), design change-induced rework (Figure 5), effective project communications (Figure 7) and project learning (Figure 8) provide alternative perspectives to understand the underlying dynamics of design changes and the preventive control measures from a systemic viewpoint, particularly examining the systemic structures involved. The conceptualized CLD (Figure 9) is useful for making sense of design changes and delay causation and mitigation through effective communication and project learning. In addition, this study makes a contribution to addressing the methodological weakness in mainstream time-cost overrun research in project management domain that lacks systems thinking and demonstrable causality as underscored by Ahiaga-Dagbui et al. (2017).

Practical Implications and Exploitation

This paper documents the critical causes of design changes in building projects and the effects of design change-induced rework on project performance. The use of the systemic thinking approach helps to address the critical variables more systematically. The conceptualized CLDs will support industry practitioners in appreciating the causal relationships of these significant variables with project outcomes. The preventive control measures using communications and knowledge suggested in this study generate virtuous effects in augmenting active communications, team synergy, continuous learning from experience and competency to eradicate frequent design changes. To address both Alsehaimi et al. (2013) and Olaniran et al.'s (2015) concern that most overrun research falls short of practical solutions, the strategic preventives measures explored in this study provide a timely alleviation of problems attributable to miscommunication and incompetency in project management (Wearne, 2014) to complement PMBOK (6th edition) that emphasizes the need for project knowledge management to accomplish project goals and engender organizational learning (Project Management Institute, 2017).

As the use of systems thinking tools by project managers is still limited (Sheffield et al., 2012) and mostly researcher-led (Ackermann & Alexander, 2016), making an overwhelming complex CLDs have negative consequences on the comprehensibility and appreciation by managers in project-based settings. For the sake of both clarity and ease of better understanding, the simplicity of the conceptual CLDs presented in this paper help in framing the multiple relationships of the critical variables for better design change management. They also support the need for close collaboration and continuous learning in managing projects as propagated by Eriksson et al. (2017), Love and Smith (2016) and Yap et al. (2018). In essence, the conceptual CLDs demonstrate the cause and effect cycles of a complex problem into graphical representations that are easy to understand, as acknowledged by over 80% of the survey respondents in this empirical study. The increased understanding of the causes of design changes and the commendable benefits of effective communication and project learning have the potential to transform design change management in the global project-based community. Thus, industry practitioners are advised to shift to a new form of practice and 'discover' for themselves the efficacy of project communications management towards collaborative team dynamics to exploit project knowledge management to enhance competencies in the quest to transform existing project management practices to attain the desired project performance.

Conclusions and Future Studies

Design changes are inevitable in any construction project. However, frequent design changes during construction are extensively blamed for schedule delays and cost overruns worldwide. Despite the plethora of studies involved over the years, efforts to contain the problem have yielded little success to date, partly attributable to the superficial and replicative traditional single-cause identification research without proffering solutions that has stagnated the development of a robust theory to mitigate the problem (Ahiaga-Dagbui et al., 2017; Alsehaimi et al., 2013; Olaniran et al., 2015). In response, this study adopts a systemic approach to understand the systemic and dynamic nature of design changes and explore the efficacy of communications and knowledge as strategic preventive measures for their control.

From the hybrid research strategy, the ten most significant causes of design changes, effects of design change-induced rework, critical variables of project communications and project learning are identified. A systemic thinking tool using causal loop diagram (CLD) is employed to represent the causal relationships of the critical variables explicitly. The conceptualized CLDs help make sense of the complex nature of the critical variables that in reality are influenced by multiple interdependencies. A thorough understanding of the multiple causal relationships involved is essential for devising intervention strategies.

The major contribution of this study is that it heeds the calls from various researchers (Ahiaga-Dagbui et al., 2017; Maani & Cavana, 2007; Sheffield et al., 2012) for a crucial shift from the event level of thinking to deeper level of thinking to explore the patterns/trends and systemic structures to provide an understanding of how these factors interact. Reacting to the problem at the event level merely addresses the problem superficially. The ability to respond, design, and transform the perennial problem of frequent design changes is strengthened by deeper levels of thinking. In addition, the systemic approach using causal mapping in this study supports Ackermann and Alexander's (2016) stated need for a pluralism of approaches in researching the management problems of construction projects to provide an understanding from a different perspective. The conceptualized CLD (Figure 9) supports the notion that project communication management engenders collaborative team dynamics and collective learning while project knowledge management contributes to the knowledge reuse and improved expert judgment needed for project controls in design change management.

This study is not without some limitations. The industry practitioners involved were sampled from the building sector. Thus, a generalization of the study's findings to other sectors such as infrastructure or hydrocarbon may be limited, although it is likely that the results will equally apply to such other similar flexible-design-change project-based industries as information technology, aerospace, marine shipyard, and defense. Nevertheless, this empirical study has provided insights into the underlying dynamics of design changes and their influence on project performance in construction and beyond.

As building projects are distinctively categorized into private and public sectors, future research may perhaps compare the causes of design changes, and the implications for project performance and practice in project communications management and project learning in both sectors. Hence, specific strategies could then be customized to meet the sectors' discrete requirements. To further understand the virtuous benefits of effective communication and project learning in design change management, it would be interesting to extend this research by exploring the influence of leadership styles, cultural contexts, and organizational issues in project communications and knowledge management.

The conceptualized CLDs can be further validated using real case studies and be extended as a pre-cursor to form stock and flow diagrams so that computer modelling with system dynamics tools can be employed, as the hard systems approach to investigating the quantum of the multiple relationships of the critical variables (identified in the current study) over time as well as to postulate and test strategies exploiting communications and knowledge in design change management and project time-cost control.

Disclosure statement

No potential conflict of interest is reported by the authors.

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