Exploring the underlying factors inducing design changes during building production

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Exploring the Underlying Factors Inducing Design Changes during Building Production

Although design changes is a significant inhibiting factor to schedule management and cost control in building projects globally, however, the reasons remain largely unknown, and the construction industry is unable to manage the problem effectively. A triangulated approach was employed to converge qualitative and quantitative data. 39 reasons were explored through semi-structured interviews with 12 experienced industry practitioners in Malaysia. Subsequently, a national survey was used to rank the reasons. Value engineering, lack of coordination among various professional consultants and change of requirement ranked the highest. Next, exploratory factor analysis revealed eight underlying factors. Finally, the influence of these manifested factors on design changes was validated statistically using partial least squares based structural equation modelling (PLS-SEM). The three most critical factors found to induce a design change during production are 'competency of project team', 'quality and workmanship', and 'site constraints and safety consideration'. This paper contributes to the development of new underlying factors inducing design changes, which largely explain design changes as well as enable practitioners and researchers to devise effective preventive measures in controlling design changes in building projects.

Keywords: Design management, Construction, Factor analysis, Partial least squares (PLS), Preventive, Performance management

Introduction

Changes in design are common occurrences in building production (Mohamad, Nekooie, and Al-Harthy 2012). It significantly inhibits schedule management and cost control (Olawale and Sun 2010) resulting in cost overruns and schedule delays (Le-Hoai, Lee, and Lee 2008; Khurshid and Nauman 2016). The cost increment due to design changes varies between 10 to 15% of the contract value whereas schedule growth stretches from 10 to 15% of the contract period (Yap, Abdul-Rahman, and Wang 2017a) which is beyond the 5% acceptable threshold (Caffieri et al. 2017). Design changes are also a major reason generating non-value adding rework during production which degrades project performance (Adam, Josephson, and

Lindahl 2017). Effectively diminishing design changes is, therefore, crucial to the project management of building projects (Abdul-Rahman, Wang, and Yap 2016).

Past studies have repeatedly identified design changes as a significant root cause for project failures worldwide (see Kaming et al. 1997; Olawale and Sun 2010; Le-Hoai, Lee, and Lee 2008; Abdullah, Rahman, and Azis 2010; Bagaya and Song 2016). Notwithstanding the adverse effects of frequent design changes to project success, the literature on the reasons for design changes during production is still limited (Yap, Abdul-Rahman, and Wang 2017b). Although the primary contributors to changes in building production are predominantly clients, consultants, contractors, project or external related (e.g. Yana, Rusdhi, and Wibowo 2015; Mohamad, Nekooie, and Al-Harthy 2012; Suleiman and Luvara 2016), they adversely affect time, cost, productivity, and risk (Sun and Meng 2009). It is therefore important to gain a better understanding of the root causes. For this reason, this paper aims to examine the reasons for a design change in building projects in order to explore the underlying factors inducing design changes during production so that effective preventive measures can be devised to contain the perennial plague and ultimately improve project performance. To achieve this, both qualitative and quantitative data collected from the Malaysian building sector were combined to achieve data triangulation. Eight underlying factors emerged from the exploratory factor analysis (EFA). The hypothesised relationships of the eight factors inducing changes in design were statistically validated to be significant using partial least squares (PLS) method. This paper contributes in expanding the existing body of knowledge of the underlying factors inducing design changes for the international construction fraternity.

Design Changes in Literature

Abdul-Rahman, Wang, and Yap (2016, p.33) conducted a synthesis of literature and defined design changes as "regular additions, omissions and adjustments to both design and construction of work in a construction project that occurs after the award of contract which affects the contract provisions and work conditions that make construction dynamic and unstable". Mohamad, Nekooie, and Al-Harthy (2012) combined interviews, case studies and questionnaire findings to reveal that engineering design changes are frequent events in the construction of residential reinforced concrete buildings and often result in excessive claims and disputes. As design changes are common occurrences in the construction industry, it is no surprise that design changes, repeatedly, have adverse time and cost implications if the fundamental root causes of a change in design is not well managed. It is worth mentioning that the systemic effects of design change dynamics are still not well understood by construction practitioners (Yap, Abdul-Rahman, and Wang 2017b). Thus, frequent and haphazard design change requests can result in non-value adding and abortive rework to all contracting parties (Emuze, Smallwood, and Han 2014), which consequently lead to degradation of quality (Hwang, Zhao, and Goh 2014) and productivity (Arashpour et al. 2014).

A variety of studies has been conducted worldwide to examine the underlying basis and nature of changes in construction projects. It is worth mentioning that many studies (such as Kikwasi 2013; Oyewobi, Abiola-Falemu, and Ibironke 2016; Assaf and Al-Hejji 2006) have adopted the classification of factors from schedule delays and cost overruns within construction management literature. For example, Sun and Meng (2009) reviewed 61 project change causes and developed a taxonomy for change causes which include external causes (environmental, political, social, economical, technical factors), organizational causes (process, people, and technology related) and project internal causes (client, design consultant, contractor/subcontractor and others generated). On the other hand, Zarei, Sharifi, and Chaghouee (2017) evaluated projects' documents to categorise the delay causes into five standard processes of project management (adopted from Project Management Body of

Knowledge (PMBOK) Guide), namely initiating, planning, executing, controlling and closing.

A recent study by Yap, Abdul-Rahman, and Wang (2017b) in Malaysia grouped the causes of design changes in construction into client, design, site, contractor and external related causes. Similarly, Suleiman and Luvara's (2016) study in Tanzania considered the factors into internal and external factors. Internal factors comprise of owner, design consultant, contractor and managing consultant induced causes while external factors include environmental, third parties, and political and economic related causes. In a separate study, Yana, Rusdhi, and Wibowo (2015) in Indonesia used PLS to determine the loading factors for owner, consultant, consultant construction management, politics and economics, natural environment, contractors, third party and advances in technology variables. In Taiwan, Chang, Shih, and Choo (2011) classified the reasons into three types: under owner's control, under designer's control, and beyond control. All of the above studies conclude that owners and consultants have the most influence on changes of design in construction projects. It is imperative now to evaluate the root of the problem by exploring the underlying factors inducing frequent design changes during building production.

The Malaysian building construction sector is expanding rapidly (Construction Industry Development Board (CIDB) 2017) but the problem of frequent design changes consistently degrades project delivery performance which severely demeans the reputation of the industry (Nurul et al. 2016). Thus, there is a fundamental need to appraise the underlying factors involved. Given that the principal reasons for the schedule and cost overruns of construction projects are comparable across developing countries (Toor and Ogunlana 2008), the key findings in this study will open up areas for future research in the development of preventive measures to manage design changes in Malaysia and beyond more effectively.

Data Collection Using Triangulated Approach

To attain robust empirical findings in construction management research (Pinto and Patanakul 2015), this study adopted an exploratory mixed methods research design. A comprehensive literature review, in-depth interviews and a questionnaire survey were conducted sequentially to enable data triangulation (Love, Holt, and Li 2002) which increases reliability (Joslin and Müller 2016) as helps overcome complications associated with bias and validity (Love et al. 2016). Figure 1 depicts the routine of the empirical analysis. To collect the various reasons inducing a design change, a wide-ranging published literature was first synthesised to instigate the preliminary list. The systematic literature review sourced studies relating to change orders (Rounce 1998; Mohamad, Nekooie, and Al-Harthy 2012; Hsieh, Lu, and Wu 2004; Wu et al. 2004; Andersen et al. 2011; Cox et al. 1999; Ijaola and Iyagba 2012; Wu, Hsieh, and Cheng 2005), rework (Ye et al. 2014; Hwang and Yang 2014; Love et al. 2002), schedule delays and cost overruns (Chan and Kumaraswamy 1997; Sambasivan and Yau 2007; Rosenfeld 2013). The qualitative data collection employed semi-structured interviews using stratified proportionate purposeful sampling to select 12 experienced industry practitioners who are currently in senior managerial positions with over 10 years of construction experience. They are proficient managers, having a profound knowledge of project management (Lee and Rojas 2013). To attain an objective (unbiased) understanding of the research topic, four managers were selected from the principal parties in building projects: client, consultant, and contractor. The critical incidents technique (Flanagan 1954) was employed to evaluate the reasons for a design change in building projects. The critical incidents were a recollection of the interview participants' key facts, which provided the authors with a comprehensive appreciation on the occurrences of design changes. Participants were requested to answer based on their personal experiences. The interviews were kept open using phrases such as 'can you describe with an example' or 'please give more details' to stimulate the participants to elucidate on the events of design changes in the building projects they were involved. Handwritten notes along with audio recording were taken during the interviews for transcribing. A total of 39 reasons identified from the content analysis were further validated as appropriate by 11 experts – 5 with over 30 years and 6 with over 20 years of experience (with an average of 29.1 years of construction experience), which in turn was used to develop the questionnaire.

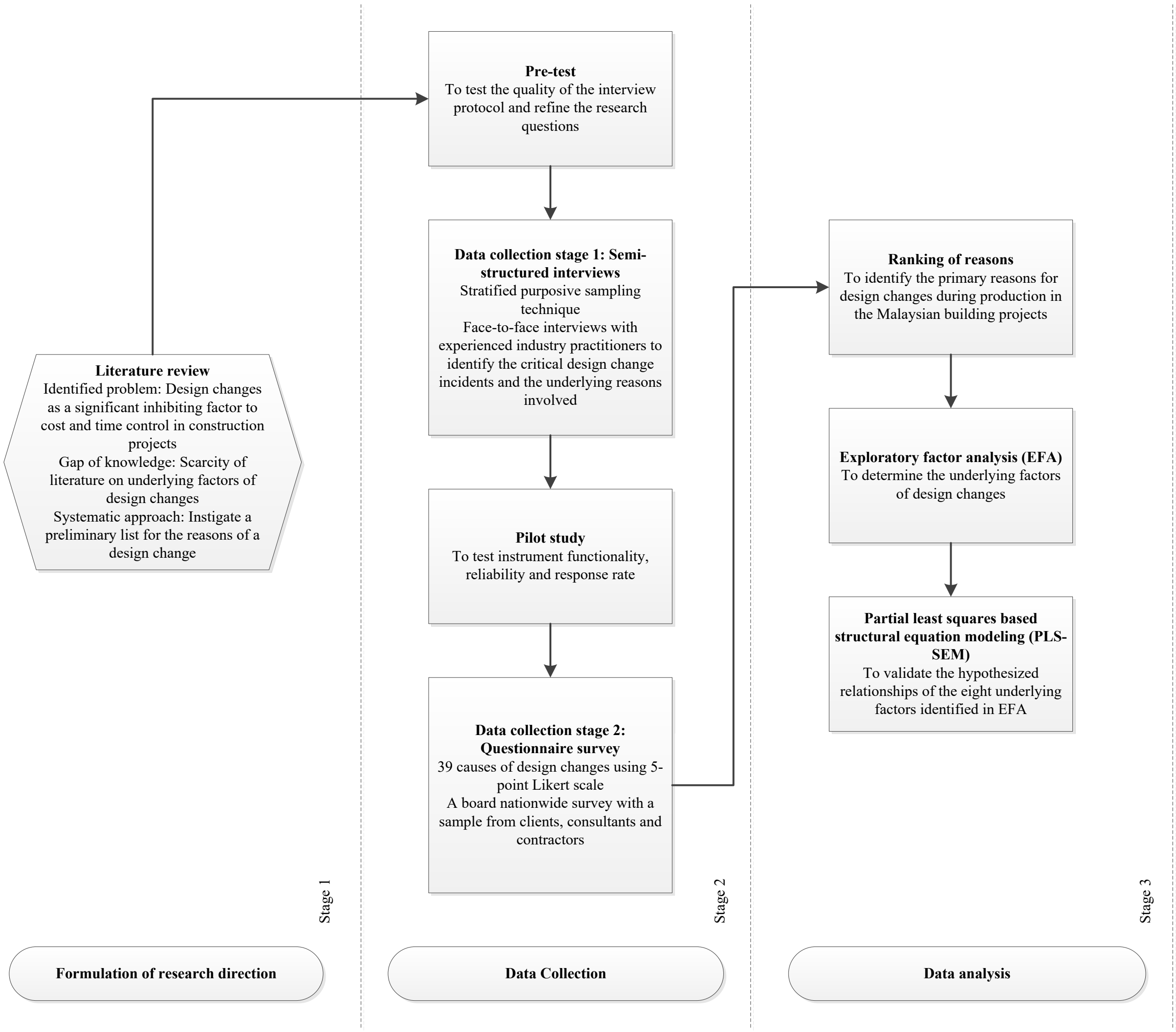

Figure 1. Research procedure

In the following quantitative phase, a pilot study was first undertaken with 50 selected industry professionals to test the likely response rate, clarity, and aptness of the survey questionnaire. Two sections of the questionnaire for a larger study are extracted for this paper. The first section is intended to gather demographic details of the respondents, such as their designation, educational background, and work experience. The second section requires the respondents to rate the 39 reasons based on a five-point Likert scale to measure the degree of agreement for each reason. Thirty-five (35) responses were received, indicating a response rate of 70.0%. The Cronbach's coefficient α for the 39 reasons was 0.89, which is higher than the 0.60 value needed to be acceptable in exploratory research (Hair et al. 2010). Thus, the questionnaire was deemed reliable.

In the main survey, 1100 questionnaires were emailed to practitioners within the clients, consultants, and contractors organisations throughout Malaysia. 303 valid survey questionnaires were received in the main survey. As there was no further change in the pilot questionnaires, they were combined with the main survey resulting in 338 valid responses, which represent a consolidated response rate of 29.4%. This response rate is considered adequate for a survey aimed at gathering responses from industry practitioners (Lucko and Rojas 2010). Table 1 summarises the detailed information regarding the respondents' background. Nearly half of the respondents have more than ten years' of experience in the building construction sector.

Table 1. Respondents' background

Parameter	Total	Frequency (%)
Current designation		
Executive	174	51.5
Manager	76	22.5
Senior Manager	54	16.0
Director	34	10.1
Educational background		
Diploma	21	6.2
Bachelor degree	229	67.8
Master degree	82	24.3
Doctorate degree	6	1.8
Working experience (years)		
1 - 5	106	31.4
6 - 10	68	20.1
11 - 15	59	17.5
16 - 20	48	14.2
> 20	57	16.9

Analysis and Ranking of Causes

As part of the analysis, the Cronbach's coefficient α is 0.94, indicating that the 5-point Likert scale used is reliable at 5% significant level (Akintoye 2000). As Table 2 indicates, all 38 reasons obtained mean scores above 3.000 except for one reason, namely 'to suit subcontractors' design/requirements' (Mean = 2.980) indicating that the respondents ranked this reason lowly. The one-sample t-test (Value = 3) results showed this reason has a p-value higher than 0.05 and therefore, was not perceived as significant by the respondents to induce a design change in building projects. 'Value engineering (cost savings, alternative materials)' topped the list with a mean value of 4.000. 'Lack of coordination among various professional disciplines/consultants,' 'change of requirements/specification' and 'addition/omission of scopes' are the common reasons, each has a mean value of exceeding 3.900. 'Additional requirements (add-on features)' and 'change in government regulations, laws, and policies' are tied with a mean value of 3.867. For the reasons with similar mean values, the reason having the lower standard deviation will be ranked higher (Ye et al. 2014) resulting in ‘additional requirements (add-on features) being ranked fifth while ‘change in government regulations, laws and policies’ is ranked sixth.

Changes in design often arise from time and cost savings measures requested by the clients. In order to reduce the overall construction cost, clients may seek alternative cheaper materials. This can be done through separate nominated sub-packages such as finishes or fittings. Thus, the designers are required to source for cheaper equivalent materials as part of the value engineering exercise. This creates much redesigning works and changes to specifications. Poorly coordinated design among the various consultants will result in discrepancies and technical complication during construction. When this occurs, designers are required to perform “fire-fighting” problem solving on site. Changes to specifications and scope creep often result in considerable changes in design. Improving change control mechanism (Sun and Meng 2009) may, therefore, help to reduce design changes during construction.

Table 2. Mean score and ranking of reasons for design changes during production

Overall ranking	Reasons	Mean	Standard deviation
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
11	Shop drawings coordination due to discrepancies	3.675	0.892
12	Undetected underground utilities	3.648	0.917
13	Rectify construction mistakes	3.642	0.891
14	Local authority planning permission requirements	3.633	0.963
15	Non-compliance with authority requirements	3.538	0.956
16	Current design too expensive	3.524	0.963
17	Improving buildability (ease of construction)	3.515	0.845
18	Alternative construction methods for schedule acceleration (i.e. use of metal formwork, IBS)	3.509	0.981
19	Change of financial status (funding of project)	3.491	1.040
20	Unclear client's brief	3.453	1.027
21	Constructability ignored in design process (difficult to build)	3.438	1.006
22	Improve quality of works (defective)	3.435	0.920
23	Request to use available materials	3.417	0.889
24	Driven by market demand (sales)	3.417	0.962
25	Insufficient soil investigation (SI) prior to design	3.382	1.033
26	Changes in government regulations, laws and policies	3.370	0.945
27	Poor understanding of client's needs	3.352	1.055
28	Site safety considerations (soil erosion, scaffolding, site access)	3.325	0.981
29	Problem with adjacent properties	3.314	0.985
30	Clashes with adjacent structures	3.293	1.022
31	Shortage of materials (resources not availability)	3.287	0.907
32	Change of use of building	3.246	1.037
33	Desire to use new technology/materials	3.225	0.957
34	Improve safety and health aspects (temporary structures, sequence of works)	3.213	0.932
35	Compliance to quality requirements (CONQUAS 21, QCLASSIC)	3.198	0.943
36	Outdated design (new technology/construction method)	3.178	1.001
37	Economic conditions (i.e. changes in tax structure, interest rates, exchange rates)	3.172	1.039
38	Skill shortage in certain trades (labour)	3.160	1.038
39	To suit subcontractors' design/requirements	2.980	1.046

Exploratory Factor Analysis (EFA)

Factor analysis is a data reduction and summarisation technique. It is often used to examine the relationships between a large number of significantly correlated variables and reduce to a manageable level for appropriate interpretation (Doloi 2008). Factor analysis is employed to explore the underlying factors of the 38 significant reasons for design changes.

To ensure suitability of the survey data, the Keiser-Meyer-Olkin (KMO) test and the Bartlett's Test of Sphericity are conducted (Field 2013). In this analysis, the KMO statistics is 0.912, which is greater than the 0.50 value for a satisfactory factor analysis (Field 2013). Hence, the variables are found to have a sizable correlation with one another. Bartlett's test is high at 5336.7 ($p = 0.000$), indicating that the correlation matrix is not an identity matrix and that the reasons are sufficiently inter-correlated (Table 3). Thus, both tests stipulate the aptness of the variables for factor analysis.

Table 3. Results of KMO and Bartlett's tests

Parameter	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.912
Bartlett's Test of Sphericity	
Approx. Chi-Square	5336.773
Df	703
Sig.	0.000

Note: Df = degrees of freedom; Sig = probability.

To determine the number of factors, both eigenvalues approach and the percentage of variance approach were used (Le-Hoai, Lee, and Lee 2008). The principal component analysis (PCA) extracted eight components with eigenvalues greater than 1.0. The scree plot (Figure 2) reveals that the graph is almost flat from the eighth component, indicating that each successive component accounts for decreasing amounts of the total variance. Varimax orthogonal rotation of PCA was used to interpret these factors. The first eight components cumulatively explain 58.0% of the total variances. According to Hair et al. (2010), no absolute threshold has been adopted and it is not uncommon to consider 60% or even less of the total variance as satisfactory. This is consistent with Peterson's (2000) meta-analysis of total variance explained by extractor factors in 803 different exploratory factor analyses in 568 empirical documents that reported a mean of 56.6%. It is also worthwhile to note that the proportion of total variance explained tended to decrease as the total number of items factored increased (Peterson 2000). Out of the 38 variables, 27 were extracted under the eight components with factor loadings of greater than 0.50, indicating the variables are practically significant (Hair et al. 2010). Table 4 summarises the final rotated component matrix. Commonalities of variables were generally good at over 0.50 for most variables. According to Hair et al. (2010), the label of the component can be assigned based on those variables with higher factor loadings or based on the whole set of variables representing the variables.

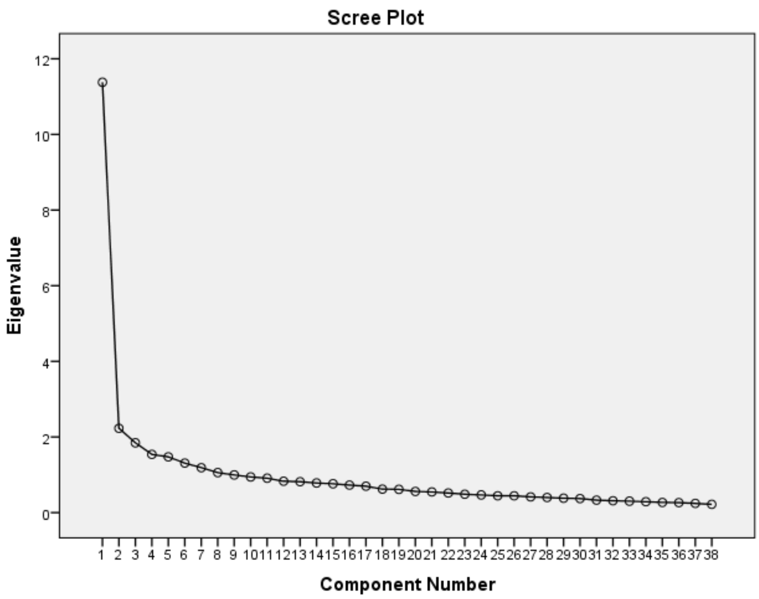

Figure 2. Scree plot for 38 items

Table 4. Factor profile

Details of the underlying factors and reasons for design changes	Factor loading	Variance explained (%)
Factor 1: Site constraints and safety consideration	-	10.5
C1F1: Site safety considerations (soil erosion, scaffolding, site access)	0.647	
C2F1: Problem with adjacent properties	0.724	
C3F1: Clashes with adjacent structures	0.724	
C4F1: Outdated design (new technology/construction method)	0.517	
Factor 2: Legislation and regulations	-	8.2
C1F2: Changes in government regulations, laws and policies	0.534	
C2F2: Local authority planning permission requirements	0.718	
C3F2: Skill shortage in certain trades (labour)	0.520	
C4F2: Non-compliance with authority requirements	0.606	
Factor 3: Quality and workmanship	-	8.2
C1F3: Improve quality of works (defective)	0.640	
C2F3: Improve safety and health aspects (temporary structures, sequence of works)	0.600	
C3F3: Shop drawings coordination due to discrepancies	0.600	
C4F3: Compliance to quality requirements (CONQUAS 21, QCLASSIC)	0.547	
Factor 4: Active rework	-	7.9
C1F4: Value engineering (cost savings, alternative materials)	0.696	
C2F4: Change of financial status (funding of project)	0.525	
C3F4: Modification to design (improvement)	0.509	
C4F4: Current design too expensive	0.612	
Factor 5: Project communication	-	7.7
C1F5: Lack of coordination among various professional disciplines/consultants	0.593	
C2F5: Poor understanding of client's needs	0.763	
C3F5: Unclear client's brief	0.721	
Factor 6: Competency of project team	-	6.0
C1F6: Addition/Omission of scopes	0.697	
C2F6: Erroneous/discrepancies in design documents	0.505	
C3F6: Additional requirements (add-on features)	0.692	
C4F6: Design omissions/incomplete drawings	0.612	
Factor 7: Risk management	-	4.8
C1F7: Change of requirement/specification	0.535	
C2F7: Unforeseen ground conditions (geotechnical issues)	0.694	
Factor 8: End-user requirements	-	4.6
C1F8: Change of use of building	0.694	
C2F8: Constructability ignored in design process (difficult to build)	0.598	
	Cumulative variance explained	58.0

Discussion of Factor Analysis Results

Factor 1: Site Constraints and Safety Consideration

Factor 1 accounts for 10.5% of the total variance explained. Unforeseen site conditions, constraints and restrictions require the consultants to modify the existing designs to suit actual site conditions (Hwang and Yang 2014). Cheng (2014) noted an increase in construction costs resulting from design changes due to site conditions in a common viaduct project in Taiwan. According to a study on design changes in residential building projects by Mohamad, Nekooie, and Al-Harthy (2012), insufficient details of existing site condition is one of the primary cause for design changes attributable to the consultants. More often than not, the design is performed without sufficient site information such as existing underground structures or constraints due to adjacent structures. Consultants are then required to perform regular site visits to resolve design problems (Rounce 1998). Differing site conditions require design adaptation on the temporary structures and protection of slopes to prevent extensive soil erosion during construction works. Given the increasing complexity of building projects and the growing demands for tighter margins, clients often fail to notice the actual site conditions in the pre-construction phase (Bonhomme-Delprato 2008).

Health and safety is another crucial issue in the construction supply chain (Behera, Mohanty, and Prakash 2015). During construction, contractors may request for changes to design to account for site safety and health management (Cheng 2014) such as alternative site access and new construction technology overlooked by the consultants during the design stage. This is aligned to the recent study by Love et al. (2018) that observed a positive relationship between rework and safety activities. According to Hsieh, Lu, and Wu (2004), safety consideration ranks second in significance among causes of change orders. These change orders are primarily intended to avoid potential hazards due to unsafe conditions.

Thus, a considerable number of design changes can be avoided with comprehensive planning in safety management at the earlier stages of construction.

Factor 2: Legislation and Regulations

Factor 2 accounts for 8.2% of the total variance explained. According to Abdullah, Harun, and Abdul Rahman (2011), the laws, procedures, and guidelines regarding building development projects in Malaysia are quite extensive. Planning permissions are subjected to the approval by the local authorities of the governing state. Thus, it is imperative that the proposed development fully complies with the rules and regulations stipulated by the local authorities.

According to Wu et al. (2004), design changes owing to government policy or regulations changes are very common. In addition, unfamiliarity with state rules and laws (Ruqaishi and Bashir 2013) possibly due to a lack of experience on similar building projects will result in design changes which may be preventable with the presence of a qualified submitting person. Complex and confusing government regulations (Toor and Ogunlana 2008) and changes in laws and policies (Doloi et al. 2012) are also significant factors to project overruns. Some building projects may face a change of decision-making authority during either the planning phase or the construction phase due to politics or election. The interpretation of regulations often varies with different authority (Hsieh, Lu, and Wu 2004). For example, in the Malaysian context, the State Planning Committee (SPC) at the state level is chaired by the Chief Minister of the respective state of Malaysia (Abdullah, Harun, and Abdul Rahman 2011). Head of states may have an extreme disparity in planning policies especially when they represent two political ideologies or replacement of incumbent due to retirement or other reasons. In addition, approving authorities may overlook the compliance of the submitted plans to the building by-laws, codes and government rules (Choudhry et al.

2017) and a late request for design amendment can be detrimental to the project performance. Both clients and consultants should maintain good rapport with government officers and seek regular updates to ensure smooth planning approval (Abdullah, Harun, and Abdul Rahman 2011).

Factor 3: Quality and Workmanship

Defective designs bring adverse impacts on project performances (Andi and Minato 2003). According to Choudhry et al. (2017), incomplete construction details from designers is the top-ranked causal factor of discrepancy between design and construction in Pakistan. Changes in niche architectural detailing often take place during construction. Clients and designers are often unable to visualise the aesthetic effects before actual physical mock-up being provided by the contractors. To address this costly and time-consuming design decision-making process, Majumdar, Fischer, and Schwegler (2006) propose a virtual reality mock-up model (VMM). The VMM is a computer simulation of a 3-D CAD model where the key stakeholders provide the design verification early before the commencement of construction works.

On the other hand, modifications to design are necessary to comply with statutory certification requirements such as Construction Quality Assessment System (CONQUAS) of Singapore and Quality Assessment System in Construction (QLASSIC) of Malaysia. In the Malaysian context, QLASSIC is a system to measure and evaluate the workmanship quality of a building construction work based on Construction Industry Standard (CIS 7:2006). QLASSIC enables the quality of workmanship between construction projects to be objectively compared through the scoring system (Construction Industry Development Board 2017). A possible explanation could be that the design details are unsatisfactory to achieve the desired quality score of the clients. Thus, corrections of design and completed works to conform to the quality requirements are therefore required and contribute to significant rework by contractors on site. Quality degradation may result, and this leads to loss of productivity (Arain and Pheng 2006).

Factor 4: Active Rework

Rework is frequently associated with higher cost, greater risk of failure, and lack of control in process industries (Flapper et al. 2010). In building production, consultants and contractors rework actively for cost and time savings, quality enhancements, and compliance to change requests from the clients (Ye et al. 2014). Once the construction phase started, any changes made can be detrimental to project time and cost performance (Mpofu et al. 2017). Given that a client's ability to influence the design of a building project decreases over time while the cost implication increases, early decision in providing clear and concise design specifications is crucial to minimise the costly ripple effects that generate delay and disruptions through the entire project supply chain. When the current design is too expensive or when there is a change in the financial status of a project, client often instructs designers to propose cheaper alternative materials. Thus, the notion of value engineering may result in beneficial changes in design intended to reduce cost, schedule or degree of difficulty (Ibbs, Wong, and Kwak 2001). In Malaysia, many developers regularly provide design improvements and value engineering while construction works are in progress. However, if changes are introduced too late, the loss in productivity can be significant. For example, the contractor may need to halt execution of an affected portion of works when the revisions of designs are not issued promptly by designers.

In fast-track projects, construction works often commence before the completion of the design (Mohamad, Nekooie, and Al-Harthy 2012). Therefore, any design changes made during construction can be very costly. To avoid expensive design changes, Mohamad, Nekooie, and Al-Harthy (2012) suggest allocating sufficient time for design and finalising client's and project requirements before the award of contract. They also advocate inclusive client's involvement at the design stage.

Factor 5: Project Communication

It is a mutual standpoint in construction project management practice that effective communication and collaborative teamwork is the key to the smooth execution of any project. Proper coordination between various consultants is critical to producing coordinated and accurate detailed drawings for construction. Discrepancies in the design lead to errors in field construction, requiring designers to issue instructions to resolve the design complications. Such design change orders may result in both design and construction rework (Hwang and Yang 2014). A lack of coordination between different group of design professionals can severely degrade the buildability of the project and integration of design solutions (Mohamad, Nekooie, and Al-Harthy 2012). Again, a similar observation is reported by Forcada et al. (2014) on miscommunication and poor coordination between clients and consultants contributing to rework. A recent study by Love et al. (2017) of the cost performance of public infrastructure projects advocates the need to engender collaboration for integrating design and construction to minimise change orders. To better manage changes in construction, Matthews et al. (2018) assert the use of building information modelling (BIM) which involves new ways of working, particularly collaborative workflows and processes.

The majority of building projects in Malaysia uses traditional methods of procurement (Shehu et al. 2014) which distinctly divide the design and construction phases. More often than not, this results in little or no communication between design consultants and contractors in the pre-construction stage. This fragmentation results in poor design quality and causes costly design changes in the construction stage (Yap, Abdul-Rahman, and Wang 2017b). In addition, ill-defined client's brief (such as extent of the scopes, requirements, and details) can affect the design intent. Providing clear and comprehensive design brief at an early stage is crucial in minimising the occurrences of modifying the design scope (Mohamad, Nekooie, and Al-Harthy 2012). Suleiman and Luvara (2016) also conclude that provision of a clear brief by the client is essential to diminish the occurrence of unnecessary changes of design during construction.

Inadequacy of information exchange results in a bad project performance (Chapman 1998). Past studies revealed that communication is a significant contributing factor to project success (Anantatmula 2015 and Yong and Mustaffa 2013). According to Taskinen (2003), increased interaction between project team members will lead to improved participation in decision making. Another study by Alashwal and Fong (2015) suggests cohesive relationship among professionals can be stimulated through partnering, team building, and effective communication. A separate study by Yap, Abdul-Rahman, and Wang (2017a) presented a collaborative model for design change management. The model is underpinned by the notion that effective design management requires the close collaboration of project team. The enablers of effective communication comprise of project meetings, mock-up units, informal gatherings, information and communication technology (ICT) and brainstorming sessions.

Factor 6: Competency of Project Team

Inadequate experience of clients and consultants is another key element to design changes in building construction. The related causes identified in a previous study by Forcada et al. (2014) comprise of lack of expertise, omission of checks, wrong distribution of information and misinterpretation due to lack of knowledge. According to Ling and Ma (2014), competency of consultants in terms of having superior market knowledge, problem-solving ability and technical capability are significantly correlated to client's satisfaction on the service provided by consultants. Yap, Abdul-Rahman, and Wang (2017a) opined that a lack of working knowledge among project team members significantly affects the project delivery outcomes. Thus, clients should appoint consultants with adequate experience in the field to be able to perform their expected tasks professionally (Mohamad, Nekooie, and Al-Harthy 2012). Unqualified and inexperienced consultants may give rise to design changes.

Incompetent designers unable to deal with demanding technical requirements may either omit vital information or be erroneous in their design documents (Long et al. 2004). This is further intensified when the projects are subjected to tight design schedules. According to Rounce (1998), design changes arise from the following: customer complaints on design details, reworking due to incorrect technical details, updating due to incorrect level of detail, changes resulting from unchecked drawing issue and redesign due to inappropriate original drawing scale. These problems result in extended design periods. A conclusion was made by Al-Kharashi and Skitmore (2009) when it was observed that public sector construction in Saudi Arabia where consultants engaged inexperienced engineers faced significant delays. According to Kaliba et al. (2009), effective project management requires competent technical personnel to undertake their project to minimise mistakes and to enhance coordination. In this regard, clients and consultants should ensure that they have personnel with the right qualifications and relevant experience to handle the projects. Clients' project managers, therefore, should be experienced to check and point out mistakes or discrepancies in the design documents.

Factor 7: Risk Management

Unforeseen ground conditions are significant problems requiring changes to the original design. In addition, this factor often contributes to schedule delay (Toor and Ogunlana 2008;

Le-Hoai, Lee, and Lee 2008). Kaming et al. (1997) assert that the magnitude of design changes depend on upon the extensiveness of site investigation. Site investigations provide engineers with critical design parameters such as the type and details of the underlying soil profiles (Mohamad, Nekooie, and Al-Harthy 2012). However, due to financial constraints, the engineers may reduce the scope of site investigations thus resulting in a lack of geotechnical data for foundation design. Hence, the engineers will need to make judgments and assumptions based on their experience in other projects within the vicinity. However, any problem arising from inaccurate judgment may not be discovered until the foundation contractor takes possession of the site and commences work. Unexpected soil conditions, for instance, will require engineers to redesign the foundation system and to issue revised drawings. In the worst scenario, the soil capacity is much lower than the anticipated value, and the engineers will need to advise some major changes to the design such as relocation of the heavy columns or even reduction in building load. These changes severely affect other professionals including architects as well as mechanical and electrical engineers.

A lack of detailed site investigation can also result in defective design. The consequences of defective design can be catastrophic (Love, Lopez, and Edwards 2013). A defective design will lead to disputes among the contracting parties (Acharya, Lee, and Im 2006). According to Andi and Minato (2003), defective design is due to human errors arising from workplace and organisational factors. They advocate the need of design review to discover errors and violations by designers.

Factor 8: End-user Requirements

New request from owner/end-users triggers variations due to changes in design and specifications (Arain and Pheng 2006). According to Ye et al. (2014), revisions and modifications of the project function may be initiated by the owner/end-user. This may be due to miscommunication or poor coordination between owner and end-users. In addition, demands by end-users to improve standards throughout construction require design changes or design improvements from the consultants. Hence, additional time is required for the redesigning works. Yang and Wei (2010) conducted a questionnaire survey to collect responses from engineers at the A/E companies in Taiwan and revealed that clients who frequently change their requirements during planning and design phases suffer significant delays in their construction projects. Poorly defined user requirements result in many reworks and demolitions due to change in specifications and design improvements (Arain and Pheng 2006). Thus, degrade quality and productivity to some extent.

The design team may also misinterpret the client's requirements (Koskela, Huovila, and Leinonen 2002), resulting in the development of a design brief that does not meet what the client or end-users require. It is worthwhile mentioning that this problem is common when the buildings are commissioned by clients who are not the users of the facility (Love, Edwards, and Irani 2012). Hence, the client's representatives may not interpret the end-users intentions correctly, leading to uncertainties in the design process and frequent design changes. According to Love and Li (2000), changes during construction initiated by end-users can account for up to 25% of rework costs that occur in a project. Hence, the redesigning works can be substantial.

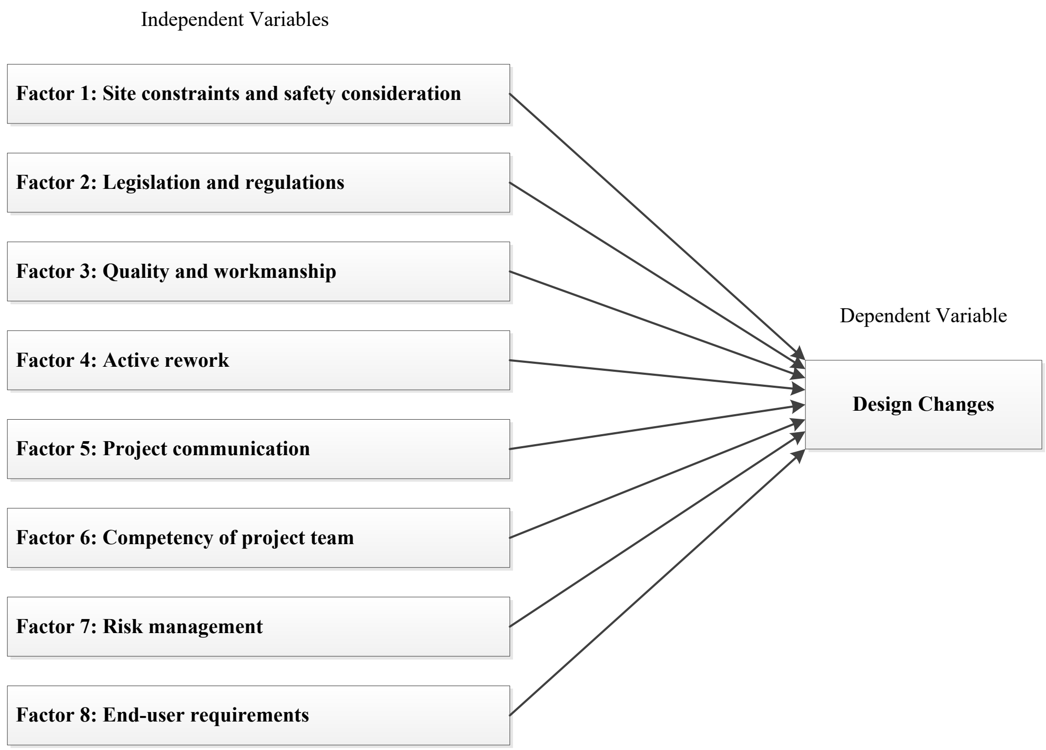

Figure 3. Framework of design changes

Validation of Factors Impacting Design Changes

Partial Least-Square Based Structural Equation Modelling (PLS-SEM)

PLS-SEM is a second-generation multivariate analysis technique (Hair et al. 2017) that has fast gained popularity among researchers in the construction management field in recent years (see Wen, Qiang, and An 2017; Alashwal and Abdul-Rahman 2014; Le et al. 2014; Alashwal and Fong 2015). This technique was selected because PLS-SEM is a tool well suited to validate the results of exploratory research (Rigdon, Sarstedt, and Ringle 2017), such as the current one, where the hypothesised relationships between variables have not been tested. According to Ali Memon et al. (2017), PLS-SEM is suitable when the theory is less developed and specifically used to predict and explain the causal relationships. In addition, PLS-SEM is known for its ability to handle both reflective and formative factors as well as placing minimal restrictions on distributional characteristics and sample sizes (Hair et al. 2017). Figure 3 illustrates the hypothesised relationships. As such, the influence of the eight underlying factors manifested in the above EFA method is further analysed by PLS-SEM using SmartPLS 3 software (Ringle, Wende, and Becker 2015). Figure 4 demonstrates the measurement model for factors influencing design changes.

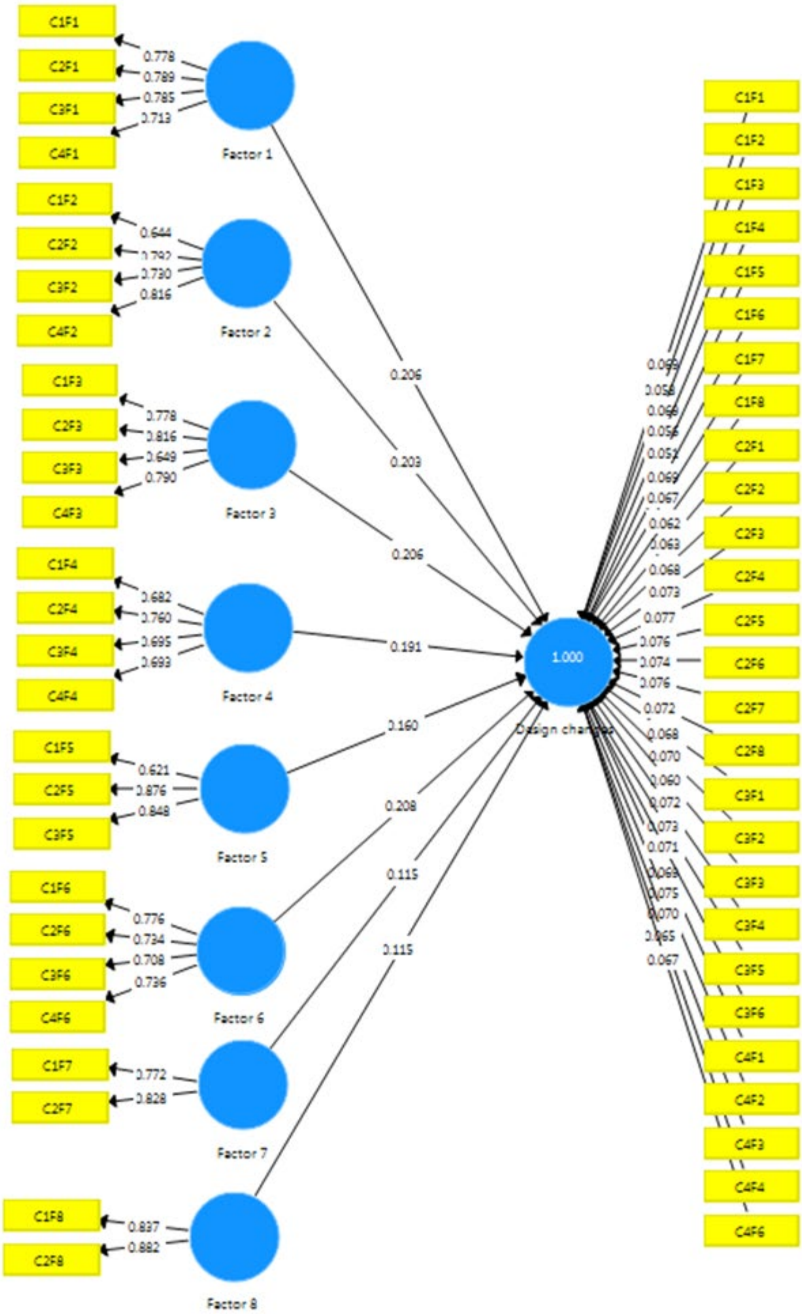

Figure 4. Measurement model of design changes

Model Quality Assessment

First, the convergent validity of the reflective constructs, which is the degree to which the multiple items that are used to measure the same concept are in agreement, was tested. As shown in Table 5, the loadings for all the items exceeded the recommended value of 0.60 for exploratory research (Hair et al. 2017). As suggested by Hair et al. (2017), the factor loadings, composite reliability (CR) and average variance extracted (AVE) were the indicators used to assess the convergent validity. Table 5 depicts the results of convergent validity. The loadings for all items exceeded the recommended value of 0.60 for exploratory research (Hair et al. 2017). CR values, which depict the degree to which the construct indicators indicate the latent construct, ranged from 0.781 to 0.851, which also exceeded 0.60. Thus, the internal consistency reliability of this model is adequate. AVE values for all eight latent variables are higher than 0.50 value required for convergent validity (Hair et al. 2017).

Table 5. Factor loadings and reliability

Items	Loadings	CR	AVE	Cronbach α
C1F1	0.778	0.851	0.588	0.766
C2F1	0.789			
C3F1	0.785			
C4F1	0.713			
C1F2	0.644	0.835	0.560	0.735
C2F2	0.792			
C3F3	0.730			
C4F4	0.816			
C1F3	0.778	0.845	0.579	0.754
C2F3	0.816			
C3F3	0.649			
C4F3	0.790			
C1F4	0.682	0.801	0.502	0.671
C2F4	0.760			
C3F4	0.695			
C4F4	0.693			
C1F5	0.621	0.830	0.624	0.690
C2F5	0.876			
C3F5	0.848			
C1F6	0.776	0.828	0.546	0.723
C2F6	0.734			
C3F6	0.708			
C4F6	0.736			
C1F7	0.772	0.781	0.641	0.442
C2F7	0.828			
C1F8	0.837	0.850	0.739	0.648
C2F8	0.882			

Note: CR = composite reliability; AVE = average variance extracted

Discriminant validity assessment has become a generally accepted prerequisite for analysing relationships between latent variables (Henseler, Ringle, and Sarstedt 2015). According to Hair et al. (2014), discriminant validity represents the extent to which the construct is empirically distinct from other constructs or, in other words, the construct measures what it is intended to measure. Henseler et al. (2015) recommend the use of heterotrait-monotrait ratio of correlations (HTMT) to assess discriminant validity. If the HTMT value is below 0.90, discriminant validity has been established between two reflective constructs. As Table 6 indicates, the measurement model demonstrated adequate discriminant validity.

Table 6. HTMT criterion results

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
Factor 1								
Factor 2	0.723							
Factor 3	0.738	0.840						
Factor 4	0.546	0.749	0.704					
Factor 5	0.489	0.434	0.457	0.527				
Factor 6	0.461	0.585	0.661	0.576	0.657			
Factor 7	0.586	0.628	0.603	0.773	0.594	0.587		
Factor 8	0.627	0.703	0.738	0.689	0.531	0.462	0.668	

Next, the quality of 'Design Changes' in Figure 4, which is a formative construct, can be evaluated by checking for collinearity using variance inflation factor (VIF) (Hair et al. 2017). The results of VIF are between 1.087 and 2.207 for all variables. These values are lower than the threshold value of 5.00 (Hair et al. 2017) indicating low collinearity levels among the factors inducing design changes.

Table 7 presents the results of the structural model from the PLS output. All the eight factors are validated to positively inducing design changes. A close examination of Table 7 revealed that competency of project team ($\beta = 0.208$, $p < 0.01$) was the most influential factor positively inducing a design change during construction, followed by site constraints and safety consideration ($\beta = 0.206$, $p < 0.01$), and quality and workmanship ($\beta = 0.206$, $p < 0.01$). The three primary factors can be observed as the cause-and-effect of one another that generates vicious cycle in design changes. These findings are akin to the claim by Yap et al. (2017a) that design changes in building construction projects are due to lack of experience of project team members. This problem is further aggravated when the practice of knowledge management is lacking in the construction industry which, according to Forcada et al. (2013), may result in the recurrence of similar design-related problems.

Table 7. Summary of the structural model

Path	Description	Path coefficient	t-value	Results
Factor 1 → Design changes	Site constraints and safety consideration → Design changes	0.206	25.332**	Supported
Factor 2 → Design changes	Legislation and regulations → Design changes	0.203	26.380**	Supported
Factor 3 → Design changes	Quality and workmanship → Design changes	0.206	28.591**	Supported
Factor 4 → Design changes	Active rework → Design changes	0.191	31.221**	Supported
Factor 5 → Design changes	Project communication → Design changes	0.160	23.659**	Supported
Factor 6 → Design changes	Competency of project team → Design changes	0.208	25.436**	Supported
Factor 7 → Design changes	Risk management → Design changes	0.115	19.105**	Supported
Factor 8 → Design changes	End-user requirements → Design changes	0.115	21.830**	Supported

Note: ** $p \leq 0.01$

Comparison with some Selected Countries

The literature review indicates there are limited studies concerning the underlying reasons for design changes in construction projects. As rework and time-cost overruns are significantly associated with design changes (Olawale and Sun 2010; Simpeh et al. 2015; Cox et al. 1999; Sun and Meng 2009; Abdul-Rahman, Wang, and Yap 2016), Table 8 shows a comparison of major factors contributing to design changes, rework, schedule delays, and cost overruns for some selected countries – both developed and developing. All the selected studies were carried out within the last 20 years.

A close examination of Table 8 reveals 'site constraints and safety consideration', 'project communication', 'competency of project team', 'end-user requirements', and 'quality and workmanship' to be the five most common factors of design changes and that are also contribute to rework and time-cost overruns. This is in agreement with the PLS-SEM results, in which the three factors with the highest path coefficients are 'competency of project team', 'quality and workmanship', and 'site constraints and safety consideration'. These critical factors are also observed in such developed countries as Australia and Hong Kong. This study contributes to understanding the trend of major design change factors adding to rework as well as affecting time-cost overruns in both developed and developing countries. Thus, it is now evident that effective design change management will lead to improved project delivery performance in building production.

Table 8. Comparison between countries

	Malaysia*	Taiwan	Australia	China*	Malaysia*	Vietnam*	Ethiopia*	Saudi Arabia*	India*	Hong Kong	
Factors	Current study	Wu, Hsieh, and Cheng (2005)[1]	Love et al. (2009)[2]	Ye, Jin, Xia, & Skitmore (2014)[2]	Yap, Low, and Wang (2017)[2]	Le-Hoai, Lee, and Lee (2008)[3]	Sinesilassie, Tabish, and Jha (2017)[3]	Al-Khalil and Al-Ghafly (1999)[3]	Doloi et al. (2012)[3]	Chiu and Lai (2017)[3]	Frequency
F1	Site constraints and safety consideration		X	X		X		X	X	X	6
F2	Legislation and regulations							X			1
F3	Quality and workmanship				X			X		X	3
F4	Active rework			X		X					2
F5	Project communication		X	X	X		X		X		5
F6	Competency of project team			X		X	X			X	4
F7	Risk management							X	X		2
F8	End-user requirements	X	X				X		X		4

Notes to Table 8:
[1] design changes/change orders
[2] rework in construction projects
[3] time-cost overrun studies
* developing countries

Preventive Measures for Design Change Management and Exploitation

The underlying factors inducing frequent design changes during production manifested contribute significantly in drawing up preventive control measures for unnecessary changes in design in building projects. Effective design management requires all related parties to be experienced and proficient in their respective areas of specialisation (Cheung, Yiu, and Lam 2013). To achieve this, collaborative project learning is essential (Yap, Abdul-Rahman, and Wang 2017a). Both experiential and shared project learning develop expert judgment in decision-making capability of project personnel (Williams 2003). For example, to prevent frequent changes in design, the client should provide clear design brief at the onset of the project (Lo, Fung, and Tung 2006). To do so, the client's project manager needs to align to end-user requirements and accustomed himself/herself with the processes involved in building projects (Love and Edwards 2004). Furthermore, the client should be mindful that late changes in design-related decisions are costly and will inflate project completion time and cause disputes (Ibbs, Wong, and Kwak 2001). Rework on-site degrades the quality of workmanship (Love et al. 2009). For example, simple hacking with succeeding patching up works due to the relocation of a power socket will result in uneven wall surface and different colour tone to the wall painting.

Clients should select design consultants based on their track records and experience in handling similar building projects (Ling and Ma 2014). As noted above, competency of design consultants considerably affects the quality of design documents which also influence the quality of workmanship and integrity of the buildings (Kärnä and Junnonen 2017). Poor detailing leads to substandard outcomes whereas defective designs could result in failures, accidents and even loss of life (Love, Edwards, and Smith 2013). Constructability requires the integration of knowledge and experience of key design and construction personnel (Forcada et al. 2014). In addition, lack of experienced site supervisors affects the quality of site management and supervision of works. According to Yong and Mustaffa (2013), the most significant critical success factors for Malaysian construction projects involves the competency and experience of the main parties, which includes team leaders, design consultants and site staff. Experienced personnel will have better analytical problem-solving aptitude dealing with site constraints. Work experiences and knowledge (Wang, Zou, and Li 2015) can guide site supervisors on safety measures required for the installation of temporary structures.

It is observed that performance of building projects such as design changes is significantly influenced by the experience of project team members. Basing on this reasoning, Yap, Abdul-Rahman, and Wang (2017a) advocate exploitation of reusable project knowledge to shorten the learning curve, omit the need to reinvent the same knowledge, produce better decisions, decrease mistakes and to use the best practices to repeat the project success. The recommended reusable project knowledge include construction process knowledge, design and construction detailing, client's expectations, authority requirements and submission procedures, dealing with contractors and subcontractors, construction techniques, planning of works, knowledge of good suppliers, quality control processes, team working and knowledge of who knows what. Ultimately, effective project learning improves job performance (Liu and Chan 2017), diminishes rework (Love et al. 2016) and enhances project delivery outcomes (Abdul-Rahman et al. 2008).

Conclusions and Future Studies

Building projects worldwide are plagued with underachieving schedule and cost performance due to frequent design changes during production. Despite relentless research efforts, little is known of the reasons behind a design change in the global construction industry. This paper rectifies the situation with a triangulated mixed methods data collection, a factor analysis and

PLS-SEM validation. The contribution of this study leverage in the examination of the underlying factors of design changes in building projects encompasses eight apparent factors (arranged according to their influence on design changes): competency of project team, quality and workmanship, site constraints and safety consideration, legislation and regulations, active rework, project communication, end-user requirements and risk management. The manifested underlying factors help expand existing knowledge of the reasons for design changes during production and provide global construction community with deeper insights in strategizing effective preventive measures in containing the perennial plague - with specific attention to improve the competency of project team, quality management, and site and safety management. In addition, practitioners and researchers can use these manifested underlying factors to gauge their influence to project schedule and cost performance.

The underlying factors are seen as having the ability to largely explain the cause of design changes during production. It is evident that construction practitioners should change their existing practices to control design changes effectively. This calls for comprehensive research into devising preventive design management system that considers effective project communications and knowledge management strategies within the clients, consultants, and contractors organisations. In addition, it would be interesting to extend this research by comparing the reasons in different project type such as infrastructure or megaproject. It is also suggested that future studies examine the different interdependencies between the various factors to gain more profound insights on the design change dynamics in construction.

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