Investigating design changes in Malaysian building projects

Yap, Jeffrey Boon Hui; Skitmore, Martin

Published in:
Architectural Engineering and Design Management

DOI:
10.1080/17452007.2017.1384714

Investigating Design Changes in Malaysian Building Projects

The complexity and uncertainties associated with construction projects mean that contracts invariably provide sufficient flexibility for changes in design as the work proceeds. However, the concomitant effects of this arrangement often cause time and cost control to be adversely affected – resulting in schedule delays and cost overruns. In seeking an improved understanding, this study aimed to identify the specific causes of design changes and their implications on the time-cost performance of Malaysia-based building projects. A total of 39 causes were first identified through a comprehensive literature review and, in conjunction with 12 semi-structured interviews with experienced construction industry practitioners, then categorised into those originating from clients, consultants, contractors, site and external sources. A questionnaire survey of 338 clients, consultants and contractors was then analysed to infer and rank the identified causes and their overall effect. The research reveals that building projects in Malaysia encounter time-cost overruns of 5 to 20% due to design changes. Lack of coordination among various professional consultants, change of requirements/specification, addition/omission of scope, erroneous/discrepancies in design documents and unforeseen ground conditions are the five most significant causes. The analysis also reveals considerable heterogeneity of perceptions between the respondent groups of the most significant causes of design changes, attributed to the adversarial culture within the industry.

Keywords: Design changes, Construction delay, Cost overruns, Time-cost performance, Malaysia.

Introduction

The construction industry is considered to be one of Malaysia's most substantial economic drivers, with the value of construction work reaching MYR 32.6 billion (USD 7.6 billion) by the 4th quarter of 2016 of which 30.6% and 29.5% were non-residential buildings and residential buildings respectively (Department of Statistics Malaysia, 2016). The large volume of construction work is mainly due to the 11th Malaysia Plan (11MP) commenced in 2016, with an estimated development allocation of MYR 260.0 billion (USD 60.6 billion). The five-year

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

11MP is the final phase gearing Malaysia towards being a developed nation by 2020. For the private sector, overall project schedule and cost is a major concern as it affects the profit/loss of the development. Public projects, on the other hand, focus more on the socio-economic development of the nation. The national statistics also show that building projects are dominated by the private sector by approximately 1.6 times the public sector (Department of Statistics Malaysia, 2016). Due to the large investment involved, there is a critical need to sustain the successful delivery of building projects.

The Malaysian construction industry suffers from a persistent inability to complete projects on time and within budget. Shehu et al. (2014), for example, reveal that approximately 55% of Malaysian construction projects experience cost overruns, with a 34.74% average time overrun (Memon et al., 2011) and 90% delay rate for government projects (Abdullah, Rahman, & Azis, 2010). Much of this is attributed to design changes, which can be a significant time-cost problem for construction projects (Abdul-Rahman, Wang, & Yap, 2016), as a functionality change during project execution necessitates modifications to specifications and deliverables. A similar observation can also be seen in the UK (Olawale & Sun, 2010) and the US (Hanna, Camlic, Peterson, & Lee, 2004) where design changes noticeably contributed to time-cost overruns. In Denmark, poorly coordinated design documents were found to significantly contribute to cost overruns (Larsen, Shen, Lindhard, & Brunoe, 2015) which apparently resulted from design changes during the construction phase of the project.

In seeking to improve the situation, an obvious first step is to identify the root causes of design changes and their negative influences on project time-cost performance but, with the exception of a few studies in other countries (e.g., Kikwasi 2013; Suleiman & Luvara 2016; Yana et al. 2015), little is known in the Malaysian context. Therefore, this study aims to understand the causes of design changes and their impact on time and cost performance in the Malaysian building sector. To achieve this, a sequential mixed methods approach is used in

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

which 39 causes are first identified through a comprehensive literature review of studies around the world and, in conjunction with 12 semi-structured interviews with experienced construction industry practitioners, then categorised into those originating from clients, consultants, contractors, site and external sources. A questionnaire survey of 338 clients, consultants and contractors is then analysed to identify and prioritise the significant causes involved and their overall effect. The analysis also reveals significant differences of perceptions of the causative factors between the three respondent groups, suggesting the existence of a "them and us" mentality within the Malaysian construction industry.

Literature Review

Table 1 summarises the studies that identified design changes as a major factor responsible for construction schedule delays and cost overruns. From the location of studies, it appears that construction design changes present a serious management problem in many countries (both developed and developing), including Malaysia. Abdul-Rahman et al. (2016, p.33) synthesise the definition of design changes as "regular additions, omissions and adjustments to both design and construction work in a construction project that occur after the award of contract which affects the contract provisions and work conditions that make construction dynamic and unstable". As this definition demonstrates, design changes are often perceived to be a negative and reactive influence on construction time-cost, although they can also be proactive in accelerating construction schedule or an alternative cost-saving solution.

[Insert Table 1 here]

A variety of studies globally has been concerned with identifying the detrimental effects of design changes on project performance. As Table 2 indicates, the direct effects are rework, schedule delay resulting in longer project duration and cost overruns from the additional resources and wastage involved. A recent study by Suleiman and Luvara (2016) also includes abandonment and disputes between parties. There have been several studies quantifying the magnitude of rework and overruns arising from design changes (see Table 3) - the quantum of schedule delay reported ranging from 3.3 weeks to 69% of project duration, and the influence on cost increase ranging from 4.5% to approximately 25%. This should be expected considering the magnitudes involved vary according to the severity of the associated changes and nature of the resulting indirect effects.

[Insert Tables 2 and 3 here]

Malaysian studies of the influence of design changes on construction project time and cost overruns have produced differing results. Abdul-Rahman et al.'s (2006) questionnaire survey and interviews with clients, consultants and contractors, for example, found the clients' top five causes of delays to be 'poor site organising', 'asking for many changes and/or additional work', 'labour shortage and lack of skills', 'not enough material' and 'poor planning and scheduling', the consultants' top five to be 'labour shortage and lack of skills', 'poor planning and scheduling', 'poor site organising', 'asking for many changes and/or additional work' and 'lack of equipment', while the contractors' top five were 'asking for many changes and/or additional work', 'labour shortage and lack of skills', 'poor planning and scheduling', 'delays in payment' and 'poor design'. One year later, Sambasivan and Yau's (2007) questionnaire survey of 67 Malaysian clients, 48 consultants and 35 contractors of the importance of 28 well-recognised delay causes and their effects on delays adopted from Odeh and Battaineh's (2002) study aimed to identify the major causes of delay in the Jordanian construction industry revealed the top five causes overall to be: (1) contractor's improper planning; (2) contractor's poor site management; (3) inadequate contractor experience; (4) inadequate client's finance and payments; and (5) problems with subcontractors, with 'change orders' ranked a lowly 21st. In the same year, Alaghbari et al.'s (2007) questionnaire survey of 78 'developers and government bodies' (23%), consultants (40%) and contractors (37%) on the importance of 31 factors influencing delays specifically to building projects revealed the top five cause overall to be: (1) financial difficulties and economic problems; (2) financial problems; (3) supervision too late and slowness in making decisions; (4) slow to give instructions; and (5) lack of materials on the market, with 'contract modifications (replace and add new works to the project; change in specifications)' ranked 15th. Nurul et al.'s (2016) recent content analysis of 2003-2012 Malaysia National Audit Reports, on the other hand, highlights 69 significant problems in public construction projects to include design changes by client, poor coordination among consultants, poor quality of design documents and unexpected soil conditions. In terms of cost overruns, Memon et al.'s (2012) questionnaire survey of 97 clients, consultants, and contractors study elicited 'frequent design changes' as the fourth most dominant cause of overruns for construction projects in southern Peninsular Malaysia, a factor also highly correlated with 'changes in project scope', 'incomplete design during tender' and 'errors in design documents', and moderately correlated with poor project management practices.

Previous research primarily focused on identifying the factors causing time and cost overruns of construction projects and very few similar studies have specifically examined the factors influencing design changes, particularly in Malaysia. Given that design changes are a recurring influence on time-cost overruns, there is a need to identify the underlying causes involved. This will enable the development of strategies or frameworks for effective management of design changes in future.

Method

A mixed method approach was used in the form of a sequential exploratory strategy (Creswell, 2014) comprising semi-structured interviews followed by a questionnaire survey to enhance the completeness and validity of the study (Creswell & Clark, 2011).

Semi-structured interviews

A comprehensive literature review was first carried, which identified a preliminary list of 43 potential causes of design changes. This not only relates to design changes but also rework, schedule delays and cost overruns (see Tables 1 to 3 for details), all of which helped to develop an in-depth understanding. This was supplemented by semi-structured interviews to convergence (Merriam & Tisdell, 2016), involving the three building project key stakeholders comprising four clients, four consultants (two architects, one structural engineer and one electrical engineer) and four contractors to elicit rich and balanced views of the research topic (Ye, Jin, Xia, & Skitmore, 2014). All had more than 10 years relevant work experience and frequently dealt with design change issues in Malaysian building projects. The interview questions were pretested in series of face-to-face meetings with five project management experts, consisting of two experienced academics and three industry experts with more than 20 years' work experience, and the questions were refined following their constructive feedback. Details of the design changes they have experienced were solicited by the Critical Incident Analysis technique (Flanagan, 1954), using such phrases as "tell me about it" or "can you give me an example" to allow participants to express themselves. During the interviews, the participants were also asked to estimate the quantum of schedule growth and cost increase arising from the design change incidents of the building projects in which they were involved. The face-to-face interviews were audio recorded using a digital voice recorder (with permission granted from the interview participants) for ease of transference and electronic storage. Hand written notes were also taken to supplement the interview data that was obtained. Each interview lasted between 45 to 60 minutes. An NVivo content analysis was carried out to determine the causes from the interview transcripts. From this, 'driven by market demand' was identified as a new cause - akin to Ogunlana et al.'s (1996) finding that the changing economic climate and marketing requirements can prompt developers to change their original plans. After consolidation, 39 well-recognised causes were identified and categorised as client-induced, consultant-induced, contractor-induced, site-induced and external-induced, as summarised in Table 4.

Eight participants asserted that design changes presented a significant problem for controlling time and cost, resulting in a 10% to 20% average increase in both project time and cost – a figure consistent with previous studies (see Table 3 for details).

[Insert Table 4 here]

Questionnaire survey

A draft questionnaire of 39 causes and effects was developed on the basis of a culmination of literature review and findings from the semi-structured interviews. A pilot e-survey was also conducted with 35 industry professionals to confirm the suitability, clarity and comprehensibility of the questionnaire (Chua, 2013). According to Ali Memon et al. (2017), a minimum pilot sample size of 30 was derived from the Central Limit Theorem which provides a distributional assumption to ensure the mean of any samples from the target population will be approximately equal to that of the population. The internal consistency reliability of the measures was tested – a crucial step to ensure the main study would be conducted successfully (Kothari, 2004).

The questionnaire contained three parts. The first part was designated to collect demographic background information regarding the respondents, such as their role in projects, designation, educational background, work experience, sector involved and category of building projects undertaken. The second part solicited ratings the 39 causes on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The last part involved quantifying the effect of design changes on schedule growth and cost increment. This section also elicited the extent to which a design change was due to the client, consultants, contractor, site or externally related causes.

For the main survey, 1100 questionnaires were distributed by email to industry professionals nationwide. 308 questionnaires were received over a period of 3 months, of which 303 were considered valid. As the pilot questionnaire did not involve any further alteration, these responses were also included in the sample. There were therefore 338 valid responses representing an overall combined response rate of 29.4%, which was sufficient for reliability analysis (Aibinu & Odeyinka, 2006) and considered adequate for a survey of this kind (Lucko & Rojas, 2010).

Table 5 summarises the demographic profile of the respondents, with the majority (approximately 94%) possessing a Bachelor or higher degree, almost half holding managerial positions and 48.6% having more than 10 years working experience in the industry. Hence the data source provides a sufficiently knowledgeable cross-section of practitioners (Oppenheim, 1992) to provide a sound judgment in a perception-based study of this nature (Ye et al., 2014).

[Insert Table 5 here]

Methods of data analysis

Several statistical procedures were used in the data analysis. For example, Cronbach's α tested the five categories of causes for reliability, with α values of 0.60 to 0.70 being deemed acceptable for internal consistency (Hair, Hult, Ringle, & Sarstedt, 2017; Mpofu, Godfrey, Moobela, & Pretorious, 2017), while the one sample t-test assesses the significance of the various causes.

[Insert Table 6 here]

The different methods used by previous studies for project delays, overruns and rework are summarised in Table 6, which shows the relative importance index (RII) and importance index (IMP.I) to be the most commonly used techniques for ranking attributes. $1 \leq RII \leq 0$ is used to rank the causes, with

$$RII = \frac{1}{AN}\sum_{i=1}^{5} W_i \tag{1}$$

where W_i denotes the rating given to each cause by the respondents (ranging from 1 to 5); A is the highest weight (i.e. 5 in this case); and N = total number of respondents. High RII values, therefore, indicate a higher level of agreement on the causes of design changes.

The average percentage of cost overruns (Avg%) for each cause was estimated by linear interpolation from the bands of 0-5%, 5.1-10% 10.1-15%, 15.1-20% and over 20.1% provided in the questionnaire. As will be seen, the results for time and cost are so similar that only cost needs to be considered. The importance index (IMP.I) is then given by

$$\text{IMP.I} = \text{RII x Avg\%} \tag{2}$$

Hence, IMP.I considered the frequency and severity of the causes. A similar approach was adopted by Bagaya & Song (2016) (see also Assaf & Al-Hejji, 2006; Le-Hoai, Lee, & Lee, 2008; Marzouk & El-Rasas, 2014) to prioritise the factors influencing schedule delays. These individual cause measures of RII, Avg% and IMP.I were then used to cross-compare the relative importance of the 39 causes as perceived by the three groups of respondents (clients, consultants, and contractors) surveyed.

Bearing in mind that this, as with all previous studies of Malaysian time and cost overruns with the exception of Nurul et al. (2016), were conducted by questionnaire survey as the single approach to facilitate data collection and therefore at risk of personal biases between project participants as found in earlier similar studies (e.g., Al-Khalil and Al-Ghafly, 1999; Abdul-Rahman et al., 2006; Al-Kharashi and Skitmore, 2009). The perceptions of different respondent groups were therefore also tested for this, referred to as the Al-Khalil and Al-Ghafly effect, using two-way analysis of variance (ANOVA) (Al-Kharashi & Skitmore, 2009). Pearson's correlation test was used in addition to testing the correlation of the cause categories between two groups of respondents, (El-Razek, Bassioni, & Mobarak, 2008).

Results

Effects of design changes on project performance

As Table 7 indicates, the range of percentage schedule growth and cost increment are virtually identical. Therefore, only the cost results are provided here on the understanding that the schedule results will be the same. Table 7 also indicates that approximately one-third respondents consider overruns to be between 10.1% and 15%, 10% or less and 15.1% or more.

[Insert Table 7 here]

In terms of the general sources of causes, these are ranked as: (1) client (mean percentage = 83.4%), (2) site (mean percentage = 73.0%), (3) consultant (mean percentage = 68.0%), (4) external (mean percentage = 63.0%) and (5) contractor (mean percentage = 61.8%).

Causes of design changes

The overall Cronbach's coefficient α for the causes is 0.94, which is higher than the 0.8 value needed for the scale reliability to be accepted (Doloi, 2009). In terms of the cause categories (Table 8), all can also accepted 'except site-related' and 'external-related'. The latter are only marginally below the cut-off and, with each containing only 4 items, are close enough to be acceptable.

Table 9 presents the cause RII values and their ranks for the three stakeholder groups. All the causes except 'to suit subcontractors' design/requirements' are significant at the 5% level, which means that 38 of the 39 potential causes are significant enough to be taken into serious consideration.

[Insert Table 8 here]

Ranked in ascending order, Table 9 and Table 10 summarise the RII and Avg% of cost overruns by cause categories. Figs 1, 2 and 3 respectively contain the average RII, Avg% and IMP.I according to the category of causes. For RII, this shows the five most agreed *causes* of design changes as perceived by *clients* to be:

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

(1) lack of coordination between various professional disciplines/consultants (0.821)

(2) change of requirement/specification (0.816)

(3) erroneous/discrepancies in design documents (0.805)

(4) value engineering (cost savings, alternative materials) (0.798)

(5) addition/omission of scope (0.793).

The equivalent for *consultants* are:

(1) value engineering (cost savings, alternative materials) (0.802)

(2) lack of coordination among various professional disciplines/consultants (0.790)

(3) unforeseen ground conditions (geotechnical issues) (0.779)

(4) change of requirement/specification (0.772)

(5) addition/omission of scope (0.769).

And for contractors:

(1) erroneous/discrepancies in design documents (0.815)

(2) design omissions/incomplete drawings (0.810)

(3) value engineering (cost savings, alternative materials) (0.797)

(4) change of requirement/specification (0.797)

(5) addition/omission of scope (0.797).

In order to identify how design changes can be minimised, it is important to identify those responsible. Of the five most agreed causes (overall), three of the causes are induced by the client and two are the consultants' responsibility. As Figure 1 illustrates, the top three categories are consultant-induced, followed by client-induced and site-induced with average RII's of 0.714, 0.705 and 0.704 respectively. There seems to be significant disagreement in opinion between the respondent groups over the client-induced and external-induced cause categories.

[Insert Table 9 here]

[Insert Figure 1 here]

[Insert Table 10 here]

[Insert Figure 2 here]

In terms of client Avg%, the five most *severe causes* are:

For clients

(1) clashes with adjacent structures (16.07)
(2) compliance to quality requirements (CONQUAS 21, QCLASSIC) (15.66)
(3) skill shortage in certain trades (labour) (15.59)
(4) insufficient soil investigation (SI) prior to design (14.97)
(5) alternative construction methods for schedule acceleration (i.e. use of metal formwork, IBS) (14.97).

For *consultants*, these are:

(1) economic conditions (i.e. changes in tax structure, interest rates, exchange rates) (14.29)
(2) lack of coordination among various professional disciplines/consultants (13.97)
(3) poor understanding of client's needs (13.95)
(4) shortage of materials (resources not available) (13.72)
(5) non-compliance with authority requirements (13.62).

While for *contractors*:

(1) shortage of materials (resources not available) (15.12)

(2) rectify construction mistakes (14.72)
(3) economic conditions (i.e. changes in tax structure, interest rates, exchange rates) (14.71)
(4) current design too expensive (14.67)
(5) outdated design (new technology/construction method) (14.46).

Of the five most severe causes (overall), two are related to contractors, two with consultants' responsibility and one due to external conditions. Except for the externally induced causes, the other four causes are related to inadequate pre-construction planning by the design team. As Figure 2 illustrates, the top three categories with the largest effects on cost overruns are client-induced, followed by external-induced and site-induced, with an average Avg% of 13.88, 13.86 and 13.85 respectively. The client group appears to rate client-induced causes lower than the other cause categories, further indicating the clients' likely biased view of their own contribution to increase in cost.

[Insert Table 11 here]

[Insert Figure 3 here]

For (IMP.I) (Table 11), the 5 most important causes *overall* are:

(1) lack of coordination among various professional disciplines/consultants (IMP.I = 11.10);
(2) change of requirement/specification (IMP.I = 10.68);
(3) addition/omission of scopes (IMP.I = 10.66);
(4) erroneous/discrepancies in design documents (IMP.I = 10.59)
(5) unforeseen ground conditions (geotechnical issues) (IMP.I = 10.50)

From the *clients'* point of view, these are

(1) lack of coordination among various professional disciplines/consultants;
(2) unforeseen ground conditions (geotechnical issues);
(3) change of requirement/specification;
(4) erroneous/discrepancies in design documents; and
(5) addition/omission of scope.

For consultants:

(1) lack of coordination among various professional disciplines/consultants;
(2) change of requirement/specification;
(3) value engineering (cost savings, alternative materials);
(4) addition/omission of scope; and
(5) erroneous/discrepancies in design documents.

And contractors:

(1) design omissions/incomplete drawings;
(2) addition/omission of scopes;
(3) erroneous/discrepancies in design documents;
(4) additional requirements (add-on features); and
(5) lack of coordination among various professional disciplines/consultants.

Of the five most important causes (overall), two are induced by the clients, two with consultants' responsible and one induced by site conditions. A close examination of Figure 3 reveals the three most impactful cause categories are (1) client-induced, (2) contractor-induced and (3) consultant-induced.

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Heterogeneity of responses by project parties

As most design changes are initiated by clients, it is interesting to compare the causes perceived by consultants and contractors. The two-way ANOVA is conducted with the three key stakeholders (1: clients, 2: consultants, 3: contractors) and the five- cause categories (1: client-induced, 2: consultant-induced, 3: contractor-induced, 4: site-induced, 5: external induced) for RII, Avg% and IMP.I (Table 12). For RII, the cause categories are significantly different ($p < 0.05$). Using Avg%, role groups are significantly different ($p < 0.05$). Using IMP.I, both cause categories and role groups are significantly different ($p < 0.05$). In term of correlations (Table 13), the result is clear that there is low correlation between the three parties on the severity of cost overruns.

[Insert Tables 12 and 13 here]

Discussion

Design changes have adverse effects on project time-cost performance. This is in agreement with Kerzner's (2013) claim that time and cost management are inseparable. Most building projects in Malaysia experience time-cost variance between 5 and 20% due to design changes. Given the large contract value involved, the non-value adding time-cost implications from design changes can be substantial. The findings of this study support those of Olawale & Sun (2010) who studied 250 construction project organisations in the UK (see also Kaming, Olomolaiye, Holt, & Harris, 1997; Mpofu et al., 2017) where design changes significantly inhibit the time-cost control of construction projects. This can also be compared with Yogeswaran et al.'s (1998) finding that 50% of their Hong Kong projects surveyed encountered time overruns due to frequent changes, and Burati et al. (1992) and Li and Taylor (2014) in the U.S. confirming that design changes can have a cumulative impact on project costs (Bonhomme-Delprato, 2008). Hence, a good understanding of the causes of a design change is

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

needed to devise effective measures for design change management that result in the improved time-cost performance of building projects.

Lack of timely coordination of between members of the design team is the most significant cause of design changes identified. Poor communication affects the accuracy of architectural drawings with structural and M&E services (Dainty, Moore, & Murray, 2006). This is akin to Josephson, Larsson & Li (2002) who conducted case studies of seven projects in Sweden to reveal that lack of design coordination and unsuitable design significantly contribute to rework. A recent survey of 114 construction practitioners in Malaysia by Yap, Low & Wang (2017) also reveals poor coordination among design team as the leading cause of rework in construction projects. They further suggest that proactive communication efforts are required to reduce errors and rework. In addition, poorly coordinated design documents result in major rework during construction (Hwang & Yang, 2014) and reduce the client values (Thyssen, Emmitt, Bonke & Kirk-Christoffersen, 2010). The client's frequent change of requirements is the second most significant cause of design changes perceived by the respondents. According to Yang & Wei (2010), changes in the client's requirements is the primary reason for inflated time and cost in the planning and design phases of construction projects in Taiwan. The third most significant cause of design change is related to the addition/omission of scope. Unplanned changes in the scope of works have contributed to protracted project durations in Zambia (Kaliba, Muya & Mumba, 2009) and 84% of cost overruns in Uganda (Alinaitwe, Apolot & Tindiwensi, 2013). The fourth most significant cause is due to incomplete or inaccurate design documents. Chang, Shih & Choo (2011) reveal that redesign time arising from errors and omissions in design documents can be as high as 33%. The fifth most significant cause is due to unforeseen geotechnical conditions that are not related to any of the contracting parties but is a common cause for changes that severely downgrade

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

time-cost performance of construction projects (see Chan & Kumaraswamy, 1997; Wu, Hsieh & Cheng, 2005; Wu, Hsieh, Cheng & Lu, 2004).

Many studies (e.g., Abdul-Rahman et al. 2016; Hamzah et al. 2012; Love et al. 2004; Mohamad et al. 2012; Suleiman & Luvara 2016) have found client-related causes to be the main reason for design changes. This applies especially to Malaysian building projects, in which the majority of clients are continuously developing the design and undertaking value-engineering exercises during the construction phase of the project. This contrasts with the clients' view in Singapore in which the root causes of variations orders are mostly attributed to the consultants (Arain & Pheng, 2005). However, the results of the present study indicate the conflicting opinions between the parties involved, which also contrasts with the conclusions reached by other studies (e.g., Faridi & El-Sayegh 2006; Ruqaishi & Bashir, 2013; Sweis et al. 2008) on the agreement of opinions between the different parties with regards to the most significant causes of time-cost overruns. In the present study, clients and contractors believe the consultants generate more design changes than the consultants believe to be the case. In addition, clients generally do not believe the design changes requested by them severely affect project time-cost performance. Given design is an iterative process, the ripple effects of a change usually affect various engineering disciplines, thus making their impact somewhat difficult to predict (Hindmarch, Gale & Harrison, 2010). However, as one consultant interviewee commented, some client-induced changes significantly affect the construction sequence, which further jeopardises the workflow and may also have a snowball effect on other subsequent activities. Similarly, another consultant interviewee explained that every change by the client through the architect would affect other designers such as civil and structural (C&S), mechanical and electrical (M&E) and security. According to Li and Taylor (2014), uncoordinated design changes by the designers can induce rework in the construction phase, thus increasing construction duration and variation claims. This reveals the parties are blaming each other to some extent, a trend quite similar to the findings of Bagaya and Song (2016) in Burkina Faso, Al-Kharashi and Skitmore (2009) in Saudi Arabia and El-Razek et al. (2008) in Egypt. As one contractor interviewee highlighted, there is a blaming culture generally in local construction practice that results in lower efficiency and effectiveness of the project team. As is well known (e.g., Yap et al., 2017), a communication breakdown between construction professionals from various disciplines degrades project performance. This also seems to be reflected in the results of this survey.

Approximately 80% of 359 construction projects sampled by Shehu et al. (2014) in Malaysia were procured using the traditional design-bid-build delivery system, indicating the dominance of the traditional procurement method in which the design work is separated from construction. This procurement method is popular due to its flexibility in allowing changes to be made (Davis, Love & Baccarini, 2008), although it is apparent that this flexibility can give rise to overly frequent design changes from the clients and consultants. Furthermore, the high degree of fragmentation between the design and construction parties restricts communications, leading to contractors not appreciating the reasons behind the design changes requested. According to Yong and Mustaffa (2012), the Malaysian construction industry is beleaguered with an adversarial culture which delimits trust and cooperation among the contracting parties. The lack of communication offers little motivation for synergic working relationships, which further restricts the clients' and consultants' understanding of the disruptive knock-on effects of design changes on many of the contractor's activities, resulting in productivity constraints and rework. The "them and us" mentality is not limited to Malaysia but a prevailing problem in many parts of the world (see Alinaitwe et al., 2013; Kartam et al., 2000; Love et al., 2004; Oyewobi et al., 2016). It is therefore timely for the construction sector to foster collaboration (Yap, Abdul-Rahman & Wang, 2017) and adopt relationship agreements (Doloi, 2013) to effectively control design changes, which ultimately leads to improved project time-cost outcomes.

Conclusion

Building projects in Malaysia encounter time-cost overruns of between 5 to 20% due to design changes. The five most important factors causing a design change in building projects in Malaysia are revealed as: (1) lack of coordination among various professional consultants; (2) change of requirement/specification; (3) addition/omission of scopes; (4) erroneous/discrepancies in design documents; and (5) unforeseen ground conditions. As there are significant differences of opinion among the three main parties involved, this study reflects the adversarial relationship resulting from fragmentation of the project team where one party tends to blame the other for the design changes and the resulting poor project performance. The lack of synergy between the contracting parties further jeopardises project coordination, suggesting the critical need for collaboration and effective communication in the Malaysian construction industry and beyond.

This study employed a mixed-methods research design, where the findings of the effects of design changes to project outcomes and the causes of design changes are validated through triangulation of the published literature, interview findings and questionnaire responses to improve validity and reliability. The large sample size permits the generalisation of the findings to building projects in Malaysia. Both researchers and practitioners can better understand the dynamics of design changes and make efforts to control the incidences of design changes. The time and cost performance of building projects are significantly determined by the ability of clients, consultants, and contractors to efficiently manage preventable changes. It is evident that all three primary stakeholders in a building project (client, consultant, and contractor) need to improve their existing practices if they want to ensure on-time and on-budget delivery of future projects.

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

The current scope of study is limited to building projects in Malaysia. A comparative study of other countries would be beneficial in understanding the relative causes and effects involved, possibly extended to civil engineering (infrastructure) projects. Case studies are also needed to identify the indirect effects of design changes and the resultant rework involved.

Disclosure statement

No potential conflict of interest is reported by the authors.

Acknowledgements

Special gratitude is also extended to those industrial practitioners who have responded to and contributed their valuable input in this research through their time and effort.

References

Abdul-Rahman, H., Berawi, M. A., Berawi, A. R., Mohamed, O., Othman, M., & Yahya, I. A. (2006). Delay mitigation in the Malaysian construction industry. *Journal of Construction Engineering and Management*, *132*(2), 125–133.

Abdul-Rahman, H., Wang, C., & Yap, J. B. H. (2016). Impacts of design changes on construction project performance: Insights from a literature review. *Journal of Quantity Surveying & Construction Business*, *7*(1), 31–54.

Abdullah, M. R., Rahman, I. A., & Azis, A. A. A. (2010). Causes of delay in MARA management procurement construction projects. *Journal of Surveying, Construction & Property*, *1*(1), 123–138.

Aibinu, A. A., & Odeyinka, H. A. (2006). Construction delays and their causative factors in Nigeria. *Journal of Construction Engineering and Management*, *132*(7), 667–677.

Al-Kharashi, A., & Skitmore, M. (2009). Causes of delays in Saudi Arabian public sector construction projects. *Construction Management and Economics*, *27*(1), 3–23.

Alaghbari, W., Kadir, M. R. A., Salim, A., & Ernawati. (2007). The significant factors causing delay of building construction projects in Malaysia. *Engineering, Construction and Architectural Management*, *14*(2), 192–206.

Ali Memon, M., Ting, H., Ramayah, T., Chuah, F., & Cheah, J.-H. (2017). A review of the methodological misconceptions and guidelines to the application of structural equation modeling: A Malaysian scenario. *Journal of Applied Structural Equation Modeling*, *1*(1).

Alinaitwe, H., Apolot, R., & Tindiwensi, D. (2013). Investigation into the causes of delays and cost overruns in Uganda's public sector construction projects. *Journal of Construction in Developing Countries*, *18*(2), 33–47.

Alnuaimi, A. S., Taha, R. A., Al Mohsin, M., & Al-Harthi, A. S. (2010). Causes, effects, benefits, and remedies of change orders on public construction projects in Oman. *Journal of Construction Engineering and Management*, *136*(5), 615–622.

Arain, F. M., & Pheng, L. S. (2005). The potential effects of variation orders on institutional building projects. *Facilities*, *23*(11/12), 496–510.

Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management*, *24*(4), 349–357.

Aziz, R. F. (2013). Ranking of delay factors in construction projects after Egyptian revolution. *Alexandria Engineering Journal*, *52*(3), 387–406.

Bagaya, O., & Song, J. (2016). Empirical study of factors influencing schedule delays of public construction projects in Burkina Faso. *Journal of Management in Engineering*, *32*(5), 5016014.

Bonhomme-Delprato, D. (2008). Pricing cumulative impacts of differing site conditions and design changes in construction. *Cost Engineering*, *50*(3), 13–16.

Burati, J. L., Farrington, J. J., & Ledbetter, W. B. (1992). Causes of Quality Deviations in Design and Construction. *Journal of Construction Engineering and Management*, *118*(1), 34–49.

Chan, D. W. M., & Kumaraswamy, M. M. (1997). A comparative study of causes of time overruns in Hong Kong construction projects. *International Journal of Project Management*, *15*(1), 55–63.

Chang, A. S. T. (2002). Reasons for cost and schedule increase for engineering design projects. *Journal of Management in Engineering*, *18*(1), 29–36.

Chang, A. S. T., Shih, J. S., & Choo, Y. S. (2011). Reasons and costs for design change during production. *Journal of Engineering Design*, *22*(4), 275–289.

Cheng, Y. M. (2014). An exploration into cost-influencing factors on construction projects. *International Journal of Project Management*, *32*(5), 850–860.

Chua, Y. P. (2013). *Mastering Research Statistics*. Shah Alam, Malaysia: McGraw-Hill Education.

Cox, I. D., Morris, J. P., Rogerson, J. H., & Jared, G. E. (1999). A quantitative study of post contract award design changes in construction. *Construction Management and Economics*, *17*(4), 427–439.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed method approaches* (4th ed.). Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J. W. L., & Clark, V. L. P. (2011). The nature of mixed methods research. *Designing and Conducting Mixed Methods Research*, 1–18.

Dainty, A., Moore, D., & Murray, M. (2006). *Communication in construction: theory and practice*. London: Taylor & Francis.

Davis, P., Love, P., & Baccarini, D. (2008). *Report: Building Procurement Methods*. *CRC Construction Innovation (Research Project No. 2006-034-C-02)*. Brisbane, Australia.

Department of Statistics Malaysia. (2016). *Quaterly construction statistics, fourth quater 2016*.

Doloi, H. (2009). Analysis of pre-qualification criteria in contractor selection and their impacts on project success. *Construction Management and Economics*, *27*(12), 1245–1263.

Doloi, H. (2013). Empirical analysis of traditional contracting and relationship agreements for procuring partners in construction projects. *Journal of Management in Engineering*, *29*(3), 224–235.

Doloi, H., Sawhney, A., Iyer, K. C., & Rentala, S. (2012). Analysing factors affecting delays in Indian construction projects. *International Journal of Project Management*, *30*(4), 479–489.

El-Razek, M. E. A., Bassioni, H. A., & Mobarak, A. M. (1995). Causes of delay in large building construction projects in Egypt. *Journal of Management in Engineering*, *11*(2), 45–50.

El-Razek, M. E. A., Bassioni, H. A., & Mobarak, A. M. (2008). Causes of delay in large building construction projects. *Journal of Construction Engineering and Management*, *134*(11), 831–841.

Faridi, A., & El-Sayegh, S. (2006). Significant factors causing delay in the UAE construction industry. *Construction Management and Economics*, *24*(11), 1167–1176.

Flanagan, J. C. (1954). The critical incident technique. *Psychological Bulletin*, *51*(4).

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2017). *A primer on partial least squares structural equation modeling (PLS-SEM)* (2nd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Hamzah, N., Khoiry, M. A., Arshad, I., Badaruzzaman, W. H. W., & Tawil, N. M. (2012). Identification of the causes of construction delay in Malaysia. *World Academy of Science, Engineering and Technology*, *72*(12), 312–317.

Han, S., Love, P., & Peña-Mora, F. (2013). A system dynamics model for assessing the impacts of design errors in construction projects. *Mathematical and Computer Modelling*, *57*(9–10), 2044–2053.

Hanna, A. S., Camlic, R., Peterson, P. a., & Lee, M.-J. (2004). Cumulative Effect of Project Changes for Electrical and Mechanical Construction. *Journal of Construction Engineering and Management*, *130*(6), 762–771.

Hindmarch, H., Gale, A., & Harrison, R. (2010). A proposed construction design change management tool to aid in making informed design decisions. In C. Egbu (Ed.), *Procs 26th Annual ARCOM Conference* (pp. 21–29). Leeds, UK: Association of Researchers in Construction Management.

Howick, S., Ackermann, F., Eden, C., & Williams, T. (2009). Delay and disruption in complex projects. In *Complex Systems in Finance and Econmetrics* (pp. 116–135). New York: Springer.

Hwang, B.-G., & Yang, S. (2014). Rework and schedule performance: A profile of incidence, impact, causes and solutions. *Engineering, Construction and Architectural Management*, *21*(2), 190–205.

Hwang, B. G., & Low, L. K. (2012). Construction project change management in Singapore: Status, importance and impact. *International Journal of Project Management*, *30*(7), 817–826.

Hwang, B. G., Zhao, X., & Goh, K. J. (2014). Investigating the client-related rework in building projects: The case of Singapore. *International Journal of Project Management*, *32*(4), 698–708.

Ibbs, W. (2005). Impact of change's timing on labor productivity. *Journal of Construction Engineering and Management*, *131*(November), 1219–1223.

Ibbs, W., & Liu, M. (2005). System dynamic modeling of delay and disruption claims. *Cost Engineering*, *47*(6), 12–16.

Ikediashi, D., Ogunlana, S., & Alotaibi, A. (2014). Analysis of project failure factors for infrastructure projects in Saudi Arabia: A multivariate approach. *Journal of Construction in Developing Countries*, *19*(1), 35–52.

Isaac, S., & Navon, R. (2013). A graph-based model for the identification of the impact of design changes. *Automation in Construction*, *31*, 31–40.

Josephson, P.-E., Larsson, B., & Li, H. (2002). Illustrative benchmarking rework and rework costs in Swedish construction industry. *Journal of Management in Engineering*, *18*(2), 76–83.

Kakitahi, J. M., Alinaitwe, H. M., Landin, A., & Mone, S. J. (2016). Impact of construction-related rework on selected Ugandan public projects. *Journal of Engineering, Design and Technology*, *14*(2), 238–251.

Kaliba, C., Muya, M., & Mumba, K. (2009). Cost escalation and schedule delays in road construction projects in Zambia. *International Journal of Project Management*, *27*(5), 522–531.

Kaming, P. F., Olomolaiye, P. O., Holt, G. D., & Harris, F. C. (1997). Factors influencing construction time and cost overruns on high-rise projects in Indonesia. *Construction Management and Economics*, *15*(1), 83–94.

Kartam, N. A., Al-Daihani, T. G., & Al-Bahar, J. F. (2000). Professional project management practices in Kuwait: issues, difficulties and recommendations. *International Journal of Project Management*, *18*(4), 281–296.

Kazaz, A., Ulubeyli, S., & Tuncbilekli, N. A. (2012). Causes of delays in construction projects in Turkey. *Journal of Civil Engineering and Management*, *18*(3), 426–435.

Kerzner, H. R. (2013). *Project management: A systems approach to planning, scheduling, and controlling.* (11th ed.). New Jersey, USA: John Wiley & Sons.

Kikwasi, G. J. (2013). Causes and effects of delays and disruptions in construction projects in Tanzania. In *Australasian Journal of Construction Economics and Building - Conference*

Series (Vol. 1, pp. 52–59).

Knight, K., & Fayek, A. R. (2002). Use of fuzzy logic for predicting design cost overruns on building projects. *Journal of Construction Engineering and Management*, *128*(6), 503–512.

Kothari, C. (2004). *Research methodology: Methods and techniques*. *New Age International* (2nd ed.). New Delhi, India: New Age International Publishers.

Koushki, P. A., Al Rashid, K., & Kartam, N. (2005). Delays and cost increases in the construction of private residential projects in Kuwait. *Construction Management and Economics*, *23*(3), 285–294.

Larsen, J. K., Shen, G. Q., Lindhard, S. M., & Brunoe, T. D. (2015). Factors affecting schedule delay, cost overrun, and quality level in public construction projects. *Journal of Management in Engineering*, *32*(1), 4015032.

Le-Hoai, L., Lee, Y. D., & Lee, J. Y. (2008). Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. *KSCE Journal of Civil Engineering*, *12*(6), 367–377.

Li, Y., & Taylor, T. (2014). Modelling the impact of design rework on transportation infrastructure construction project performance. *Journal of Construction Engineering and Management*, *140*(9), 4014044.

Lisse, S. (2013). System Dynamics for Outsourcing Construction Services. *International Journal of Construction Engineering and Management*, *2*(3), 53–61.

Love, P. E. ., & Sohal, A. S. (2003). Capturing rework costs in projects. *Managerial Auditing Journal*, *18*(4), 329–339.

Love, P. E. D., Edwards, D. J., & Irani, Z. (2008). Forensic project management: An exploratory examination of the causal behavior of design-induced rework. *IEEE Transactions on Engineering Management*, *55*(2), 234–247.

Love, P. E. D., Frani, Z., & Edwards, D. J. (2004). A rework reduction model for construction projects. *IEEE Transactions on Engineering Management*, *51*(4), 426–440.

Lucko, G., & Rojas, E. M. (2010). Research validation: Challenges and opportunities in the construction domain. *Journal of Construction Engineering and Management*, *136*(January), 127–135.

Marzouk, M. M., & El-Rasas, T. I. (2014). Analyzing delay causes in Egyptian construction projects. *Journal of Advanced Research*, *5*(1), 49–55.

Memon, A. H., Abdul Rahman, I., & Abdul Aziz, A. A. (2012). The cause factors of large project's cost overrun: a survey in the southern part of Peninsular Malaysia. *International Journal of Real Estate Studies (INTREST)*, *7*(2), 1–15.

Memon, A. H., Rahman, I. A., Abdullah, M. R., Aziz, A. A. A., Rahman, A. I., Razaki, A. M., & Aziz, A. A. A. (2011). Time overrun in construction projects from the perspective of project management consultant (PMC). *Journal of Surveying, Construction & Property*, *2*(1), 54–66.

Memon, A. H., Rahman, I. A., Faris, M., & Hasan, A. (2014). Significant causes and effects of variation orders in construction projects. *Research Journal of Applied Sciences, Engineering and Technology*, *7*(21), 4494–4502.

Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). San Francisco, CA: Jossey-Bass.

Mohamad, M., Nekooie, M., & Al-Harthy, A. (2012). Design changes in residential reinforced concrete buildings: The causes, sources, impacts and preventive measures. *Journal of Construction in Developing Countries*, *17*(2), 23–44.

Mpofu, B., Godfrey, E., Moobela, O. C., & Pretorious, A. (2017). Profiling causative factors leading to construction project delays in the United Arab Emirates. *Engineering , Construction and Architectural Management*, *24*(2), 346–376.

Muhwezi, L., Acai, J., & Otim, G. (2014). An assessment of the factors causing delays on building construction projects in Uganda. *International Journal of Construction Engineering and Management*, *3*(1), 13–23.

Nguyen, T. P., & Chileshe, N. (2015). Revisiting the construction project failure factors in Vietnam. *Built Environment Project and Asset Management*, *5*(4), 398–416.

Nurul, A. J., Aminah, M. Y., Syuhaida, I., & Chai, C. S. (2016). Public construction projects performance in Malaysia. *Journal of Southeast Asian Research*, *2016*, 1–29.

Odeh, A. M., & Battaineh, H. T. (2002). Causes of construction delay: Traditional contracts. *International Journal of Project Management*, *20*, 67–73.

Ogunlana, S. O., Promkuntong, K., & Jearkjirm, V. (1996). Construction delays in a fastgrowing economy: Comparing Thailand with other economies. *International Journal of Project Management*, *14*(1), 37–45.

Olawale, Y. A., & Sun, M. (2010). Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice. *Construction Management and Economics*, *28*(5), 509–526.

Oppenheim, A. N. (1992). *Questionaire design, interviewing, and attitude measurement*. London: Pinter.

Oyewobi, L. O., Abiola-Falemu, O., & Ibironke, O. T. (2016). The impact of rework and organisational culture on project delivery. *Journal of Engineering, Design and Technology*, *14*(2), 214–237.

Rosenfeld, Y. (2013). Root-cause analysis of construction-cost overruns. *Journal of Construction Engineering and Management*, *140*(1), 4013039.

Ruqaishi, M., & Bashir, H. A. (2013). Causes of delay in construction projects in the oil and gas industry in the Gulf Cooperation Council Countries : A case study. *Journal of Management in Engineering*, *31*(3), 1–8.

Sambasivan, M., & Yau, S. W. (2007). Causes and effects of delays in Malaysian construction industry. *International Journal of Project Management*, *25*(5), 517–526.

Shehu, Z., Endut, I. R., Akintoye, A., & Holt, G. D. (2014). Cost overrun in the Malaysian construction industry projects: A deeper insight. *International Journal of Project Management*, *32*(8), 1471–1480.

Shohet, I. M., & Frydman, S. (2003). Communication patterns in construction at construction manager level. *Journal of Construction Engineering and Management*, *129*(5), 570–577.

Simpeh, E. K., Ndihokubwayo, R., Love, P. E. D., & Thwala, W. D. (2015). A rework probability model: a quantitative assessment of rework occurrence in construction projects. *International Journal of Construction Management*, *15*(2), 109–116.

Suleiman, I. J., & Luvara, V. G. M. (2016). Factors influencing change of design of building projects during construction stage in Dar-es- Salaam Tanzania. *International Journal of Construction Engineering and Management*, *5*(4), 93–101.

Sun, M., & Meng, X. (2009). Taxonomy for change causes and effects in construction projects. *International Journal of Project Management*, *27*(6), 560–572.

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Sweis, G., Sweis, R., Hammad, A. A., & Shboul, A. (2008). Delays in construction projects: The case of Jordan. *International Journal of Project Management*, *26*(6), 665–674.

Tawil, N. M., Khoiry, M. A., Arshad, I., Hamzah, N., Jasri, M. F., & Badaruzzaman, W. H. W. (2013). Factors contribute to delay project construction in higher learning education case study UKM. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(11), 3112–3116.

Thyssen, M. H., Emmitt, S., Bonke, S., & Kirk-Christoffersen, A. (2010). Facilitating client value creation in the conceptual design phase of construction projects: A workshop approach. *Architectural Engineering and Design Management*, *6*(1), 18–30.

Williams, T., Eden, C., Ackermann, F., & Tait, A. (1995). The effects of design changes and delays of project costs. *Journal of the Operational Research Society*, *46*(7), 809–818.

Wu, C. H., Hsieh, T. Y., & Cheng, W. L. (2005). Statistical analysis of causes for design change in highway construction on Taiwan. *International Journal of Project Management*, *23*(7), 554–563.

Wu, C., Hsieh, T., Cheng, W., & Lu, S. (2004). Grey relation analysis of causes for change orders in highway construction. *Construction Management and Economics*, *22*(5), 509–520.

Yana, A. A. G. A., Rusdhi, H. A., & Wibowo, M. A. (2015). Analysis of factors affecting design changes in construction project with Partial Least Square (PLS). *Procedia Engineering*, *125*, 40–45.

Yang, J.-B., & Wei, P.-R. (2010). Causes of delay in the planning and design phases for construction projects. *Journal of Architectural Engineering*, *16*(2), 80–83.

Yang, J. Bin, Chu, M. Y., & Huang, H. M. (2013). An empirical study of schedule delay causes cased on Taiwan's litigation cases. *Project Management Journal*, *44*(3), 21–31.

Yap, J. B. H., Abdul-Rahman, H., & Wang, C. (2017). Collaborative model: Managing design changes with reusable project experiences through project learning and effective communication. *International Journal of Project Management*, *35*(7), 1253–1271.

Yap, J. B. H., Low, P. L., & Wang, C. (2017). Rework in Malaysian building construction: Impacts, causes and potential solutions. *Journal of Engineering, Design and Technology*, Accepted Article. https://doi.org/https://doi.org/10.1108/JEDT-01-2017-0002

Ye, G., Jin, Z., Xia, B., & Skitmore, M. (2014). Analyzing causes for reworks in construction projects in China. *Journal of Management in Engineering*, *31*(6), 1–9.

Yogeswaran, K., Kumaraswamy, M. M., & Miller, D. R. A. (1998). Claims for extensions of time in civil engineering projects. *Construction Management and Economics*, *16*(3), 283–293.

Yong, Y. C., & Mustaffa, N. E. (2012). Analysis of factors critical to construction project success in Malaysia. *Engineering, Construction and Architectural Management*, *19*(5), 543–556.

CAPTIONS TO TABLES AND FIGURES

Tables

1: Design changes as a major factor of project delays and cost overruns

2: Causal effects of design changes to project performance

3: Quantum of schedule delay and cost increase arising from design changes and rework

4: Factors causing design changes from past studies

5: Demographic profile of respondents

6: Analysis methods employed for the ranking of attributes in construction management research

7: Frequency statistic of cost increase and schedule growth from design changes

8: Cronbach's coefficient α values for all causes categories

9: Ranking of causes (based on overall)

10: Average percentage of cost overruns (based on overall)

11: Importance index and ranking (based on overall)

12: 2-way ANOVA for cause categories and role groups

13: Pearson's correlation coefficient for category of causes

Figures

1: Profiles of different factor categories for RII

2: Profiles of different factor categories for Avg%

3: Profiles of different factor categories for IMP.I

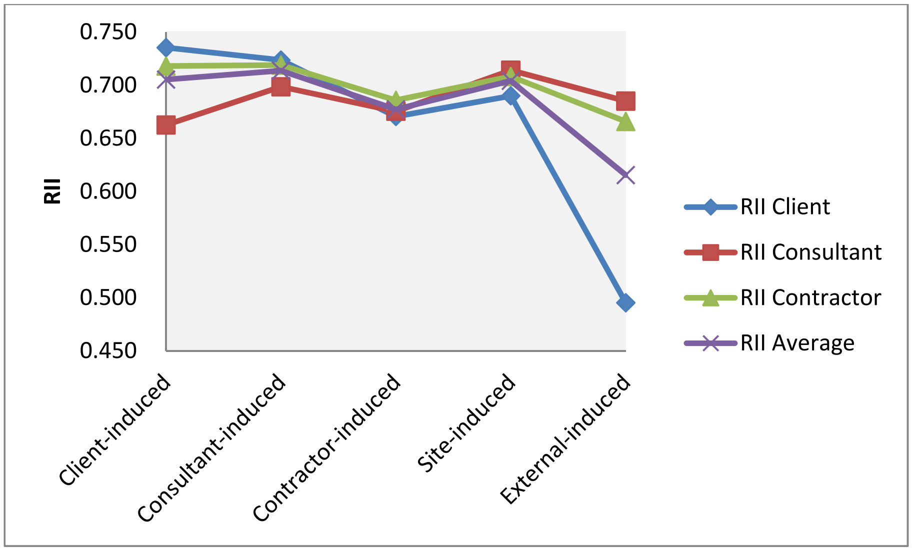

Figure 1. Profiles of different factor categories for RII

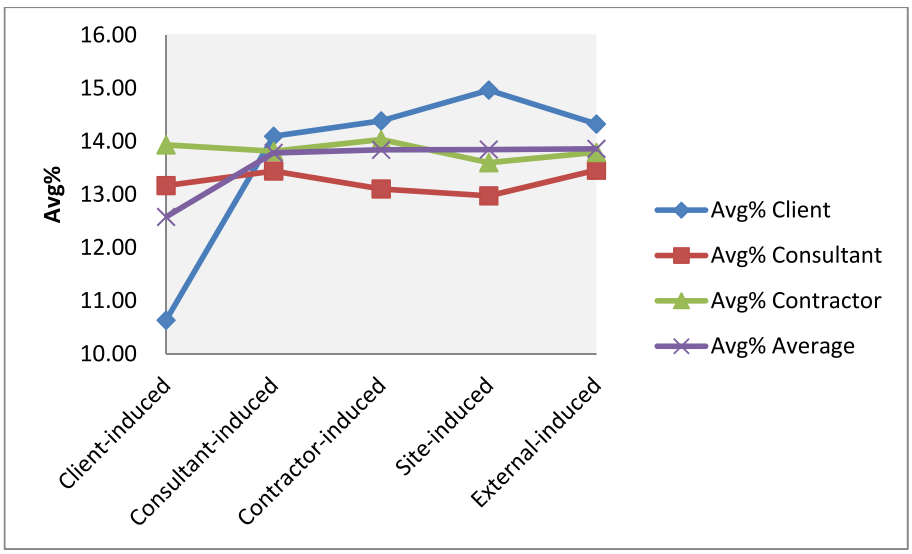

Figure 2. Profiles of different factor categories for Avg%

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

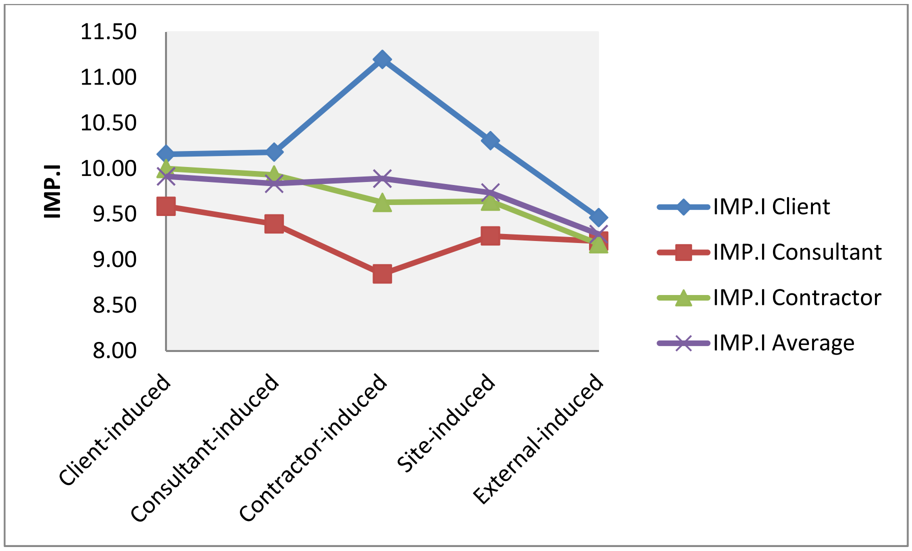

Figure 3. Profiles of different factor categories for IMP.I

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 1. Design changes as a major factor responsible for project delays and cost overruns

Source	Location of study
Aziz (2013); El-Razek, Bassioni, & Mobarak (1995)	Egypt
Kaming, Olomolaiye, Holt, & Harris (1997)	Indonesia
Rosenfeld (2013)	Israel
Sweis et al. (2008)	Jordan
Koushki, Al Rashid, & Kartam (2005)	Kuwait
Memon, Rahman, Faris, & Hasan (2014; Tawil et al. (2013)	Malaysia
Aibinu & Odeyinka (2006)	Nigeria
Alnuaimi, Taha, Al Mohsin, & Al-Harthi (2010)	Oman
Assaf & Al-Hejji (2006); Ikediashi, Ogunlana, & Alotaibi (2014)	Saudi Arabia
Cheng (2014); Wu, Hsieh, & Cheng (2005); Yang, Chu, & Huang (2013)	Taiwan
Kikwasi (2013)	Tanzania
Kazaz, Ulubeyli, & Tuncbilekli (2012)	Turkey
Mpofu et al. (2017)	UAE
Muhwezi, Acai, & Otim (2014)	Uganda
Olawale & Sun (2010); Williams, Eden, Ackermann, & Tait (1995)	UK
Hanna, Camlic, Peterson, & Lee (2004); Ibbs (2005)	USA
Le-Hoai, Lee, & Lee (2008); Nguyen & Chileshe (2015)	Vietnam
Kaliba, Muya, & Mumba (2009)	Zambia

Table 2. Causal effects of design changes on project performance

Implications for project performance		Source
Rework	Additional efforts	Abdul-Rahman et al. (2016); Cox, Morris, Rogerson, & Jared (1999); Han, Love, & Peña-Mora (2013); Hwang, Zhao, & Goh (2014); Isaac & Navon (2013); Josephson, Larsson, & Li (2002); Lisse (2013); Love, Edwards, & Irani (2008); Simpeh, Ndihokubwayo, Love, & Thwala (2015); Sun & Meng (2009); Ye et al. (2014)
Time	Increased duration	Abdul-Rahman et al. (2016); Howick, Ackermann, Eden, & Williams (2009); Hwang & Low (2012); Shohet & Frydman (2003); Suleiman & Luvara (2016); Sun & Meng (2009)
Cost	Increased cost	Abdul-Rahman et al. (2016); Cox et al. (1999); Hwang & Low (2012); Ibbs & Liu (2005); Knight & Fayek (2002); Love & Sohal (2003); Sun & Meng (2009)

Table 3. Quantum of schedule delay and cost increase arising from design changes and rework

Source	Country	Schedule delay	Cost increase
Cox et al. (1999)	UK	-	5-8%
Chang (2002)	Taiwan	69%	24.8%
Chang et al. (2011)	Taiwan	-	8.5%
Burati et al. (1992)	USA	-	12.4%
Li & Taylor (2014)	USA	-	13.0%
Kakitahi, Alinaitwe, Landin, & Mone (2016)	Uganda	8.4%	4.5%
Hwang et al. (2014)	Singapore	3.3 weeks	7.1%

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 4. Factors from past studies causing design changes

Ref	Cause	Group
1	Change of requirement/specification	Client-induced
2	Value engineering (cost savings, alternative materials)	
3	Unclear client's brief	
4	Addition/Omission of scopes	
5	Additional requirements (add-on features)	
6	Desire to use new technology/materials	
7	Change of financial status (funding of project)	
8	Slow decision-making	
9	Change of use of building	
10	Driven by market demand (sales)	
11	Lack of coordination among various professional disciplines/consultants	Consultant-induced
12	Poor understanding of client's needs	
13	Insufficient soil investigation (SI) prior to design	
14	Erroneous/discrepancies in design documents	
15	Design omissions/incomplete drawings	
16	Outdated design (new technology/construction method)	
17	Modification to design (improvement)	
18	Current design too expensive	
19	Constructability ignored in design process (difficult to build)	
20	Compliance to quality requirements (CONQUAS 21, QCLASSIC)	
21	Non-compliance with authority requirements	
22	Request to use available materials	Contractor-induced
23	Alternative construction methods for schedule acceleration (i.e. use of metal formwork, IBS)	
24	To suit subcontractors' design/requirements	
25	Improving buildability (ease of construction)	
26	Shortage of materials (resources not availability)	
27	Rectify construction mistakes	
28	Improve quality of works (defective)	
29	Improve safety and health aspects (temporary structures, sequence of works)	
30	Shop drawings coordination due to discrepancies	
31	Skill shortage in certain trades (labour)	
32	Unforeseen ground conditions (geotechnical issues)	Site-induced
33	Site safety considerations (soil erosion, scaffolding, site access)	
34	Clashes with adjacent structures	
35	Undetected underground utilities	
36	Changes in government regulations, laws and policies	External-induced
37	Problem with adjacent properties	
39	Economic conditions (i.e. changes in tax structure, interest rates, exchange rates)	
39	Local authority planning permission requirements	

Table 5. Demographic profile of respondents

Parameter	Categories	Clients	Consultants	Contractors	Total	Frequency (%)
Designation level	Executive	36	98	40	174	51.5
	Manager	28	25	23	76	22.5
	Senior Manager	18	22	14	54	16.0
	Director	3	29	2	34	10.1
Highest academic qualification	Diploma	9	5	7	21	6.2
	Bachelor degree	53	120	56	229	67.8
	Master degree	22	44	16	82	24.3
	Ph.D.	1	5	0	6	1.8
Years of relevant working experience (years)	1 to 5	16	59	31	106	31.4
	6 to 10	22	33	13	68	20.1
	11 to 15	21	24	14	59	17.5
	16 to 20	16	23	9	48	14.2
	Over 20	10	35	12	57	16.9
Sector of building projects frequently involved	Private projects	53	118	57	228	67.5
	Government projects	32	56	22	110	32.5
Category of building projects frequently involved	Residential	36	71	38	145	42.9
	Non-residential	24	43	18	85	25.1
	Social Amenities	7	9	2	18	5.3
	Infrastructure	18	51	21	90	26.6

Table 6. Analysis methods used to rank attributes

Source (in chronological order)	Attributes types	Valid responses collected	Response rate (%)	Method of analysis	Cross-compare groups of respondents	Location of study
Mpofu et al. (2017)	Delay factors	208	41.6	Relative importance index (RII)	Yes	UAE
Bagaya & Song (2016)	Delay factors	140	70.0	Importance index (IMP.I)	Yes	Burkina Faso
Muhwezi et al. (2014)	Delay factors	52	82.5	Relative importance index (RII)	No	Uganda
Ye et al. (2014)	Rework causes	277	65.2	Mean value	No	China
Kikwasi (2013)	Delay factors	43	66.7	Relative importance index (RII)	No	Tanzania
Doloi, Sawhney, Iyer, & Rentala (2012)	Delay factors	77	70.0	Relative importance index (RII)	No	India
Olawale & Sun (2010)	Cost and time control inhibiting factors	110	44.0	Relative importance index (RII)	No	UK
Yang & Wei (2010)	Delay factors	95	79.2	Relative importance index (RII)	No	Taiwan
Le-Hoai et al. (2008)	Cost overruns and delay factors	87	30.5	Importance index (IMP.I)	Yes	Vietnam
Sweis et al. (2008)	Delay factors	91	82.7	Mean value	Yes	Jordan
Alaghbari et al. (2007)	Delay factors	78	17.3	Mean score	No	Malaysia
Sambasivan & Yau (2007)	Delay factors and effects	150	75.0	Relative importance index (RII)	Yes	Malaysia
Assaf & Al-Hejji (2006)	Delay factors	57	39.6	Importance index (IMP.I)	Yes	Saudi Arabia
Chan & Kumaraswamy (1997)	Delay factors	147	37.0	Relative importance index (RII)	Yes	Hong Kong

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management,
available online: https://doi.org/10.1080/17452007.2017.1384714

Table 7. Frequency statistic of cost increase and schedule growth from design changes

Quantum of schedule growth			Quantum of cost increment		
Range	Number of respondents	Frequency (%)	Range	Number of respondents	Frequency (%)
Less than 5%	27	8.0	Less than 5%	29	8.6
5.1% to 10%	86	25.4	5.1% to 10%	82	24.3
10.1% to 15%	108	32.0	10.1% to 15%	109	32.2
15.1% to 20%	70	20.7	15.1% to 20%	67	19.8
20.1% and above	47	13.9	20.1% and above	51	15.1

Table 8. Cronbach's coefficient α values for all causes categories

Category of causes	Number of items	Cronbach's α
Client-related	10	0.78
Consultant-related	11	0.81
Contractor-related	10	0.83
Site-related	4	0.69
External-related	4	0.68
Overall	39	0.94

Table 9. Ranking of causes (based on overall)

Ref.	Causes of design changes	Clients (N = 85) RII	Clients (N = 85) Rank	Consultants (N = 174) RII	Consultants (N = 174) Rank	Contractors (N = 79) RII	Contractors (N = 79) Rank	Overall (N = 338) RII	Overall (N = 338) Rank
1	*Client-induced causes*								
1.01	Value engineering (cost savings, alternative materials)	0.798	4	0.802	1	0.797	3	0.800	1
1.02	Change of requirement/specification	0.816	2	0.772	4	0.797	3	0.789	3
1.03	Addition/Omission of scopes	0.793	5	0.769	5	0.797	3	0.782	4
1.04	Additional requirements (add-on features)	0.781	6	0.768	6	0.777	7	0.773	5
1.05	Slow decision-making	0.751	12	0.760	7	0.752	10	0.756	9
1.06	Change of financial status (funding of project)	0.696	21	0.723	14	0.646	34	0.698	19
1.07	Unclear client's brief	0.706	19	0.689	22	0.678	21	0.691	20
1.08	Driven by market demand (sales)	0.759	10	0.692	20	0.628	36	0.683	23
1.09	Change of use of building	0.652	29	0.657	30	0.628	36	0.649	32
1.10	Desire to use new technology/materials	0.602	38	0.651	31	0.678	21	0.645	33
2	*Consultant- induced causes*								
2.01	Lack of coordination among various professional disciplines/consultants	0.821	1	0.790	2	0.782	6	0.796	2
2.02	Erroneous/discrepancies in design documents	0.805	3	0.738	12	0.815	1	0.773	7
2.03	Design omissions/incomplete drawings	0.772	7	0.745	9	0.810	2	0.767	8
2.04	Modification to design (improvement)	0.656	28	0.741	10	0.752	10	0.749	10
2.05	Non-compliance with authority requirements	0.732	13	0.702	17	0.694	19	0.708	15
2.06	Current design too expensive	0.718	16	0.707	16	0.686	20	0.705	16
2.07	Constructability ignored in design process (difficult to build)	0.706	19	0.669	27	0.709	16	0.688	21
2.08	Insufficient soil investigation (SI) prior to design	0.673	25	0.678	25	0.676	24	0.676	25
2.09	Poor understanding of client's needs	0.729	14	0.647	33	0.658	32	0.670	27
2.10	Compliance to quality requirements (CONQUAS 21, QCLASSIC)	0.621	36	0.637	35	0.666	29	0.640	35
2.11	Outdated design (new technology/construction method)	0.624	35	0.630	38	0.661	31	0.636	36
3	*Contractor- induced causes*								
3.01	Shop drawings coordination due to discrepancies	0.755	11	0.716	15	0.754	9	0.735	11
3.02	Rectify construction mistakes	0.715	17	0.736	13	0.727	13	0.728	13
3.03	Improving buildability (ease of construction)	0.696	21	0.701	19	0.714	14	0.703	17

Table 9. *(Continued)*

Ref.	Causes of design changes	Clients (N = 85) RII	Rank	Consultants (N = 174) RII	Rank	Contractors (N = 79) RII	Rank	Overall (N = 338) RII	Rank
3.04	Alternative construction methods for schedule acceleration (i.e. use of metal formwork, IBS)	0.673	25	0.702	17	0.732	12	0.702	18
3.05	Improve quality of works (defective)	0.694	23	0.687	24	0.678	21	0.687	22
3.06	Request to use available materials	0.687	24	0.689	22	0.668	28	0.683	23
3.07	Shortage of materials (resources not availability)	0.656	28	0.651	31	0.673	25	0.657	31
3.08	Improve safety and health aspects (temporary structures, sequence of works)	0.631	32	0.636	36	0.671	27	0.643	34
3.09	Skill shortage in certain trades (labour)	0.614	37	0.640	34	0.633	35	0.632	38
3.10	To suit subcontractors' design/requirements	0.584	39	0.597	39	0.608	39	0.596	39
4	*Site- induced causes*								
4.01	Unforeseen ground conditions (geotechnical issues)	0.765	8	0.779	3	0.770	8	0.773	5
4.02	Undetected underground utilities	0.722	15	0.747	8	0.699	17	0.730	12
4.03	Site safety considerations (soil erosion, scaffolding, site access)	0.626	33	0.669	27	0.699	17	0.665	28
4.04	Clashes with adjacent structures	0.647	30	0.661	29	0.666	29	0.659	30
5	*External- induced causes*								
5.01	Local authority planning permission requirements	0.711	18	0.740	11	0.714	14	0.727	14
5.02	Changes in government regulations, laws and policies	0.661	27	0.692	20	0.648	33	0.674	26
5.03	Problem with adjacent properties	0.626	33	0.676	26	0.673	25	0.663	29
5.04	Economic conditions (i.e. changes in tax structure, interest rates, exchange rates)	0.645	31	0.632	37	0.628	36	0.634	37

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 10. Average percentage of cost overruns (based on overall)

Ref.	Causes of design changes	Clients (N = 85) Avg%	Rank	Consultants (N = 174) Avg%	Rank	Contractors (N = 79) Avg%	Rank	Overall (N = 338) Avg%	Rank
1	*Client-induced causes*								
1.01	Unclear client's brief	14.10	21	13.60	7	14.06	17	13.82	8
1.02	Slow decision-making	14.31	15	13.17	22	14.27	7	13.70	15
1.03	Addition/Omission of scopes	13.92	25	13.28	14	14.08	16	13.64	17
1.04	Desire to use new technology/materials	14.24	16	13.26	17	13.62	27	13.54	22
1.05	Change of financial status (funding of project)	13.73	30	13.23	20	14.26	8	13.53	24
1.06	Change of requirement/specification	13.87	29	13.31	13	13.61	28	13.53	25
1.07	Additional requirements (add-on features)	13.60	33	13.01	32	14.08	15	13.41	31
1.08	Driven by market demand (sales)	13.44	35	13.14	26	14.15	13	13.40	33
1.09	Change of use of building	13.68	31	12.88	33	13.59	29	13.21	36
1.10	Value engineering (cost savings, alternative materials)	13.35	36	12.80	36	13.62	26	13.12	39
2	*Consultant- induced causes*								
2.01	Insufficient soil investigation (SI) prior to design	14.97	4	13.38	11	14.17	11	13.96	4
2.02	Lack of coordination among various professional disciplines/consultants	13.87	27	13.97	2	13.99	18	13.95	5
2.03	Poor understanding of client's needs	14.15	19	13.95	3	13.63	25	13.95	6
2.04	Current design too expensive	13.97	23	13.42	9	14.67	4	13.81	10
2.05	Non-compliance with authority requirements	14.24	17	13.62	5	13.48	32	13.75	12
2.06	Compliance to quality requirements (CONQUAS 21, QCLASSIC)	15.66	2	13.25	18	13.09	38	13.75	13
2.07	Erroneous/discrepancies in design documents	13.89	26	13.60	6	13.69	22	13.71	14
2.08	Outdated design (new technology/construction method)	13.21	39	13.17	23	14.46	5	13.50	26
2.09	Design omissions/incomplete drawings	13.33	37	13.17	24	14.15	12	13.46	27
2.10	Constructability ignored in design process (difficult to build)	14.21	18	13.09	29	13.20	36	13.42	29
2.11	Modification to design (improvement)	13.58	34	13.23	20	13.42	34	13.21	37
3	*Contractor- induced causes*								
3.01	Improve safety and health aspects (temporary structures, sequence of works)	13.97	23	13.42	9	14.35	6	14.46	1
3.02	Shortage of materials (resources not availability)	14.84	7	13.72	4	15.12	1	14.36	2
3.03	Rectify construction mistakes	14.53	11	13.34	12	14.72	2	13.94	7

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 10. *(Continued)*

Ref.	Causes of design changes	Clients (N = 85) Avg%	Rank	Consultants (N = 174) Avg%	Rank	Contractors (N = 79) Avg%	Rank	Overall (N = 338) Avg%	Rank
3.04	Skill shortage in certain trades (labour)	15.59	3	13.03	30	13.91	19	13.81	9
3.05	Improve quality of works (defective)	14.00	22	13.10	28	14.18	10	13.57	19
3.06	To suit subcontractors' design/requirements	14.41	12	13.28	15	13.29	35	13.54	21
3.07	Improving buildability (ease of construction)	13.26	38	13.43	8	13.54	31	13.42	30
3.08	Shop drawings coordination due to discrepancies	13.63	32	12.87	34	14.10	14	13.38	34
3.09	Alternative construction methods for schedule acceleration (i.e. use of metal formwork, IBS)	14.97	5	12.55	38	13.68	23	13.37	35
3.10	Request to use available materials	14.65	10	12.29	39	13.47	33	13.14	38
4	*Site- induced causes*								
4.01	Clashes with adjacent structures	16.07	1	13.24	19	12.66	39	13.76	11
4.02	Unforeseen ground conditions (geotechnical issues)	14.89	6	12.85	35	13.84	20	13.58	18
4.03	Undetected underground utilities	14.10	20	13.03	31	14.25	9	13.53	23
4.04	Site safety considerations (soil erosion, scaffolding, site access)	14.80	8	12.78	37	13.65	24	13.46	28
5	*External- induced causes*								
5.01	Economic conditions (i.e. changes in tax structure, interest rates, exchange rates)	13.87	28	14.29	1	14.71	3	14.29	3
5.02	Local authority planning permission requirements	14.41	13	13.16	25	13.58	30	13.56	20
5.03	Changes in government regulations, laws and policies	14.32	14	13.11	27	13.12	37	13.40	32
5.04	Problem with adjacent properties	14.71	9	13.27	16	13.76	21	13.70	16

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 11. Importance index and ranking (based on overall)

Ref.	Causes of design changes	Clients (N = 85) IMP.I	Rank	Consultants (N = 174) IMP.I	Rank	Contractors (N = 79) IMP.I	Rank	Overall (N = 338) IMP.I	Rank
1	*Client-induced causes*								
1.01	Change of requirement/specification	11.32	3	10.28	2	10.85	7	10.68	2
1.02	Addition/Omission of scopes	11.04	5	10.22	4	11.23	2	10.66	3
1.03	Value engineering (cost savings, alternative materials)	10.65	7	10.27	3	10.86	6	10.50	6
1.04	Additional requirements (add-on features)	10.63	8	9.99	8	10.94	4	10.37	7
1.05	Slow decision-making	10.74	6	10.00	7	10.73	8	10.35	8
1.06	Unclear client's brief	9.95	24	9.36	18	9.54	24	9.54	17
1.07	Change of financial status (funding of project)	9.56	29	9.57	14	9.21	30	9.45	18
1.08	Driven by market demand (sales)	10.20	17	9.09	20	8.88	33	9.16	27
1.09	Desire to use new technology/materials	8.58	37	8.62	31	9.24	28	8.73	35
1.10	Change of use of building	8.91	35	8.47	34	8.53	36	8.58	38
2	*Consultant- induced causes*								
2.01	Lack of coordination among various professional disciplines/consultants	11.39	1	11.03	1	10.94	5	11.10	1
2.02	Erroneous/discrepancies in design documents	11.17	4	10.04	5	11.16	3	10.59	4
2.03	Design omissions/incomplete drawings	10.29	15	9.81	11	11.46	1	10.32	9
2.04	Modification to design (improvement)	10.32	13	9.81	10	10.09	13	9.89	11
2.05	Non-compliance with authority requirements	10.42	9	9.56	15	9.35	26	9.73	15
2.06	Current design too expensive	10.02	23	9.49	16	10.07	14	9.73	16
2.07	Insufficient soil investigation (SI) prior to design	10.08	19	9.08	21	9.58	21	9.44	19
2.08	Poor understanding of client's needs	10.32	12	9.03	24	8.97	32	9.35	23
2.09	Constructability ignored in design process (difficult to build)	10.03	22	8.76	29	9.36	25	9.23	26
2.10	Compliance to quality requirements (CONQUAS 21, QCLASSIC)	9.73	26	8.44	36	8.72	35	8.80	34
2.11	Outdated design (new technology/construction method)	8.23	39	8.29	38	9.55	22	8.58	37
3	*Contractor- induced causes*								
3.01	Rectify construction mistakes	10.39	11	9.81	9	10.69	9	10.16	10
3.02	Shop drawings coordination due to discrepancies	10.29	14	9.22	19	10.64	11	9.84	14
3.03	Shortage of materials (resources not availability)	9.74	25	8.92	27	10.18	12	9.44	20

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 11. *(Continued)*

Ref.	Causes of design changes	Clients (N = 85) IMP.I	Clients (N = 85) Rank	Consultants (N = 174) IMP.I	Consultants (N = 174) Rank	Contractors (N = 79) IMP.I	Contractors (N = 79) Rank	Overall (N = 338) IMP.I	Overall (N = 338) Rank
3.04	Improving buildability (ease of construction)	9.23	32	9.42	17	9.67	18	9.43	21
3.05	Alternative construction methods for schedule acceleration (i.e. use of metal formwork, IBS)	10.07	20	8.81	28	10.01	15	9.39	22
3.06	Improve quality of works (defective)	9.72	27	9.01	25	9.62	20	9.32	24
3.07	Improve safety and health aspects (temporary structures, sequence of works)	8.81	36	8.53	33	9.62	19	9.29	25
3.08	Request to use available materials	10.07	21	8.46	35	9.00	31	8.98	32
3.09	Skill shortage in certain trades (labour)	9.57	28	8.34	37	8.80	34	8.73	36
3.10	To suit subcontractors' design/requirements	8.41	38	7.92	39	8.07	39	8.07	39
4	*Site- induced causes*								
4.01	Unforeseen ground conditions (geotechnical issues)	11.39	2	10.01	6	10.65	10	10.50	5
4.02	Undetected underground utilities	10.19	18	9.74	13	9.96	16	9.87	12
4.03	Clashes with adjacent structures	10.40	10	8.75	30	8.43	38	9.06	30
4.04	Site safety considerations (soil erosion, scaffolding, site access)	9.26	31	8.55	32	9.54	23	8.95	33
5	*External- induced causes*								
5.01	Local authority planning permission requirements	10.24	16	9.74	12	9.69	17	9.85	13
5.02	Problem with adjacent properties	9.21	33	8.97	26	9.27	27	9.08	28
5.03	Economic conditions (i.e. changes in tax structure, interest rates, exchange rates)	8.94	34	9.04	23	9.23	29	9.06	29
5.04	Changes in government regulations, laws and policies	9.47	30	9.07	22	8.51	37	9.03	31

This is an Accepted Manuscript of an article published on 4 May 2018 by Taylor & Francis in Architectural Engineering and Design Management, available online: https://doi.org/10.1080/17452007.2017.1384714

Table 12. 2-way ANOVA for cause categories and role groups

Source of variation	SS	df	MS	F	P-value	F crit
RII						
Cause categories	0.007	4	0.002	11.337	0.002	3.838
Role groups	0.000	2	0.000	0.161	0.854	4.459
Error	0.001	8				
Total	0.008	14				
Avg%						
Cause categories	0.098	4	0.024	0.251	0.923	3.838
Role groups	2.984	2	1.492	13.162	0.003	4.459
Error	0.907	8				
Total	3.988	14				
IMI.I						
Cause categories	0.975	4	0.244	6.230	0.014	3.838
Role groups	1.208	2	0.604	15.442	0.002	4.459
Error	0.313	8				
Total	2.496	14				

Table 13. Pearson's correlation coefficient for category of causes

	Causes	Client-consultant	Client-Contractor	Consultant-Contractor
RII	Client-induced	**0.885***	**0.737***	**0.874***
	Consultant-induced	**0.897***	**0.829***	**0.854***
	Contractor-induced	**0.923***	**0.886***	**0.892***
	Site-induced	**0.981***	0.789	0.832
	External-induced	0.807	0.677	0.900
Avg%	Client-induced	**0.639***	0.142	0.338
	Consultant-induced	0.035	-0.466	0.031
	Contractor-induced	-0.234	0.108	0.566
	Site-induced	0.567	**-0.984***	-0.609
	External-induced	-0.811	-0.630	**0.952***
IMP.I	Client-induced	**0.917***	**0.838***	**0.918***
	Consultant-induced	**0.841***	0.508	**0.761***
	Contractor-induced	0.624	**0.704***	**0.861***
	Site-induced	0.772	0.431	0.793
	External-induced	0.934	0.419	0.629

Note: * Significant at $p<0.05$.