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Design Changes in Residential Reinforced Concrete Buildings: The Causes, Sources, Impacts and Preventive Measures

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Abstract: Design changes are common in building projects. Design changes are almost inevitable during the lifecycle of a project; however, design change can be minor or major according to the result. Identifying the source and impact of each design change in the construction lifecycle could help manage all of the design changes associated with a project. Furthermore, such management of changes could help to define preventive measures and actions. A complete survey was conducted using interviews and questionnaires with professionals in three main groups involved in reinforced concrete building projects; all of the sources, causes and impacts were defined by their level of importance. Corrective and preventive actions were measured to avoid as many design changes as possible in this research. The results of this research encourage the implementation of preventive actions by the professionals involved in low-rise reinforced concrete building projects.

Keywords: Design changes, Delay in construction, Modification in design, Residential buildings, Consultancy

INTRODUCTION

Engineering design changes in reinforced concrete buildings are common in the construction industry; in many cases, these changes lead to excessive claims and disputes. A design change is defined as any change in the design or construction of a project after the contract is awarded and signed. Such changes are related not only to matters in accordance with the provision of the contract but also changes to the work conditions (Baxendale and Schofield, 1996; Burati, Farrington and Led, 1992). These changes are defined as any additions, omissions or adjustments made to the original scope of work after a contract is awarded (Akinsola et al., 1997; Turner, 1984). Many studies have attempted to classify changes as formal or informal (Gilbreath, 1992), direct or constructive (Fisk and Reynolds, 2000), or required or elective (Construction Industry Institute, 1994). Formal changes are generally identified before they come in effect, based on a planned and deliberated choice by the owner and documented before they are executed by a formal instruction to change or modify the agreed scope of work. Informal changes are the ones often identified after the fact and are based on unexpected event and unplanned choice by the owner. In direct changes, the owner directs the consultant or the contractor to do works that are not specified in the original contract or the owner increases/decreases the specified scope of work which, in turn, leads to modification to the design documents. Constructive changes, on the other hand, are an informal act resulting in modification to the

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work caused by act or failure to act by the owner that increases the cost and/or time to perform certain activities. In addition, in some studies, design changes have been classified based on their nature and origin (Construction Industry Institute, 1995; Defence Construction Canada, 1992). To obtain a comprehensive evaluation and to manage design changes, one must first assign the sources, causes and impacts of the change. Furthermore, prevention and minimising should be measured to avoid design changes when possible.

The federal construction council revealed the client's representative as the most significant source of excessive changes in construction (Federal Construction Council, 1983). Although there are no similar results in the literature for major sources of design change, the client and the architects within design teams are two main sources of design changes, both in cost and in the number of changes (Bromilow, 1970; Choy and Sidwell, 1991). A review of previous studies indicates that clients are the main sources of design change (Bromilow, 1970; Kelvin, 1999; Al-Dubaisi, 2000; Ssegawa et al., 2003; Motawa, Anumba and El-Hamalawi, 2006). However, some authors have indicated that design teams are the main sources of design change (Choy and Sidwell, 1991; McDermott and Dodd, 1984; Hibberd, 1982).

Various causes of changes have been identified by many researchers in different regions. Extra and non-compulsory work by clients has been proposed to be the cause of change by researchers (Wilson, 1982; Kirby et al., 1988; Diekmann and Nelson, 1992; Austin et al., 2002). Poor communication and a lack of proper design briefing have been introduced as other causes in the literature (McDermott and Dodd, 1984; Caballero et al., 2002; Lutz, Hancher and East, 1990). The causes have been introduced as design deficiency and errors (Kirby, Furry and Hiks, 1988; Diekmann and Nelson, 1992; Lutz, Hancher and East, 1990; Bubshait, Al-Said and Abolnour, 1998). Furthermore, site condition contracts, conflicts and incomplete information are further causes for changes that have been indicated by researchers (Kirby, Furry and Hiks, 1988; Lutz, Hancher and East, 1990; Mokhtar, 2002; Ogunlana, Promkuntong and Jearkjirm, 1996; Essex, 1996; Love et al., 2002; Motawa, Anumba and El-Hamalawi, 2006). Another researcher, Emmitt (2001), mentioned the specification of building material as an important cause of design changes. Ssegawa et al. (2003) highlighted the financial aspect as a main cause. Amr A.G. Hassanein studied claims and change in order management. The author defined causes as a deficient contract from the public sector, a lack of contract awareness by the site team, or oral changes to orders from an owner. The study introduced a phenomenon called "fear of the consultant", where claim and documentation procedures and the lack of a unified quantification of change orders are other change causes and problems in Egypt (Hassanein and Waleed, 2008). The most common causes of design changes recommended by each researcher are presented in Table 1.

Although design changes are widely accepted from all of the participants in the construction industry, the design changes do affect the outcome of the project. Quality level, on-time completion and an allocated budget are three principles for a successful project diverted by design changes (Chan and Kumaraswamy, 1994; Frimpong, Oluwoye and Crawford, 2003). Trickey and Hackett (2001) identified the challenges of change and established the value of "change" itself; the effects of change on other work, losses and expenses were directly attributable to execution of the changes.

Table 1. The Causes of Design Changes as Identified in Literature

	Extra Work by Client	Poor Communication and Lack of Proper Design Briefing	Design Deficiency and Errors	Site Condition	Contract Conflict and Incomplete Information	Specification of Materials	Value Engineering	Adopt New Technology	Financial Difficulties	Unforeseen Condition (same as weather...)	Lack of Appropriate Equipment	Defective Workmanship	Safety Consideration	New Government Regulations	Lack of Unified System for Change Order	Fear of the Consultant
Wilson [18]	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mcdermott [16]	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leonard [31]	–	–	R	–	–	–	–	–	–	R	–	–	–	–	–	–
Kirby et al. [19]	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–
Lutz et al. [23]		R	R	–	R	–	–	–	–	–	–	–	–	–	–	–
Gilbreath [5]	R	–	R	R	R	R	R	R	R	R	R	R	R	R	–	–
Diekmann and Nelson [20]	R	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–
Ogunlana and Promkuntong [26]	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–
Essex [27]	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–
Yogeswaran [32]	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–
Mokhtar [25, 33, 34]	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–
Bubshait et al. [24]	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–
Emmitt [29]	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–
Love Et al. [28]	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–
Caballero et al. [22]	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Austin [21]	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–
Al-Dubasis [14]	R	R	R	R	R	R	R	R	R	R	R	R	R	R	–	–
Ssegawa et al. [15]	–	–	R	R	–	–	–	–	R	R	–	–	–	–	–	–
Amr A.G. Hassanein [30]	R	–	R	–	R	–	–	–	–	–	–	–	–	–	R	R

R = Recommended by researcher

A broad range of study was conducted that indicated three major categories for design changes: impact on cost, impact on time and impact on productivity (Burati, Farrington and Led, 1992; Akinsola et al., 1997; Construction Industry Institute, 1994; Al-Dubaisi, 2000; Love et al., 2002; Leonard, Fazio and Moselhi, 1988; Chang, 2002; Moselhi, Leonard and Fazio, 1991; Hester, Kuprenas and Chang, 1991; Thomas and Napolitan, 1995; Wang, 2008). Design changes are inevitable in any building project and frequently lead to disputes among the concerned parties. The management of design changes is an important tool to reduce the risk of disputes that may arise at later stages. The construction process involves several disciplines, which tend to work independently. Creating a design team requires a shared understanding (Anumba, 2000; Valkenburg, 1998). Some recent studies have described the use of collaborative tools for managing design changes and proposed new approaches based on techniques for coordinating design information. These practices accommodate design changes and present a collaborative information model using the environment (Kolarevic et al., 2000; Bubshait, Al-Said and Abolnour, 1998; Mokhtar, 1998; Mokhtar, Bedard and Fazio, 1998; Peltonen et al., 1993). Hegazy, Zaneldin and Grierson (2001) also present an information model for managing design changes. Effective design and frequent report meetings are conducted in a successful design process (Austin, Baldwin and Steele, 2000; Kuprenas, 2003). A parametric coordinator and other collaborative or knowledge-based systems have also been presented by researchers (Soh and Wang, 2000; Zaneldin, Hegazy and Grierson, 2001; Hew, Fisher and Awbi, 2001).

Residential reinforced concrete buildings are ordinary construction utilising current technology in urban areas. Most of the owners and clients of these buildings are normal citizens who assume that the construction's original cost is the final fee. Most of the clients in this situation do not accept excessive claims for design changes; however, frequently there are numerous factors that lead to design changes.

The issue of managing design changes has not been given much attention, despite its importance in engineering design practice. Identification of the most significant corrective actions and/or preventive measures can be used as a basis for managing design changes to prevent any future disputes by owners and clients. In addition, managing design changes can help parties achieve optimum satisfaction in a construction project.

This study was conducted to formulate practical procedures for the assessment of structural design changes by identifying the sources, causes and impacts of design changes on residential reinforced concrete buildings. Furthermore, the study establishes corrective action and preventive measures to minimise avoidable design changes. Figure 1 illustrates the approach of this research regarding the streamlining of the process.

METHODOLOGY

To achieve the study objectives, previous studies related to the current study were collected. The authors conducted a literature review of design change factors and investigated the processes in the construction industry. It was essential to provide a comprehensive background on the principle of design changes in residential reinforced concrete buildings, that is, the sources, causes and impacts on the lifecycle of the project and attempts to manage these changes were observed.

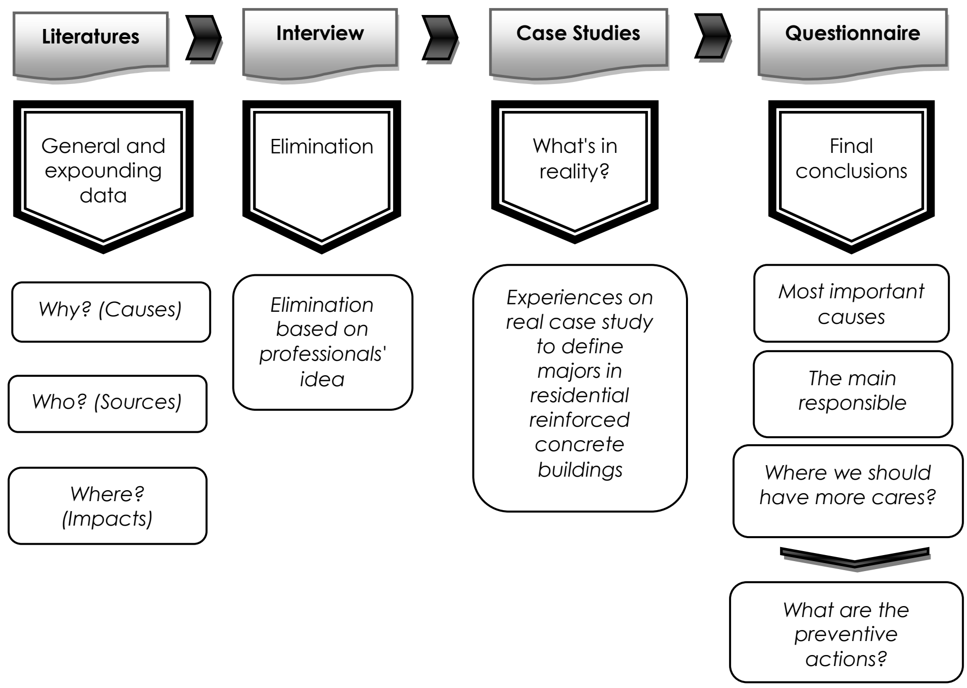

Figure 1. The Stream Line of This Study

Interviews

Interviews with professionals were conducted as a recognised form of qualitative research. In this research, the intention of the interviews was to obtain preliminary opinions on the extent of the research problems. Three groups were assumed to be required construction project parties: clients, consultants and contractors. Eleven semi-closed questions were prepared for four professionals from each project party. The selected clients were from a governmental organisation heavily involved in the construction industry. The contractors and consultants were also selected from a top-level company involved extensively in building construction.

Case Studies

Three case studies were investigated for this research. The projects, all medium-sized reinforced concrete buildings, were initiated during the last eight years. The purpose of the selected case study was to provide in-depth knowledge and a better understanding of the factors and size of the research problem.

Questionnaires

The questionnaires were developed to obtain professional opinions on the causes, sources and impacts of structural design changes on a reinforced concrete construction project. The possible corrective and preventive actions were measured to minimise avoidable design changes.

Pilot questionnaires were developed and tested by six respondents from the mentioned groups. The final questionnaire was presented in six parts using the Likert (ordinal) scale (Table 2). The questionnaire was distributed among consultants, clients and contractors with more than 10 years of experience. A total of 42 questionnaires were distributed and 27 were completed and returned. The response rate was 59.5%, which was reasonable for this type of study.

Table 2. Ranking System for the Questionnaire, Using Likert Scale

Sections and Questions	Q
Rate 1	Disagree
Rate 2	Slightly agree
Rate 3	Agree in average
Rate 4	Mostly agree
Rate 5	Strongly agree

The data collected by the questionnaire survey were analysed using the mean score (MS) terminology; the MS of each factor was computed by the following formula (Chan and Kumaraswamy, 1996):

$$MS = \sum {(f \times s)}/{N_f} \left(1 \le MS \le 5\right) \quad (1)$$

where,
f = frequency of responses to each score for each factor;
s = score given to each factor as ranked by the respondents; and
N_f = total number of responses concerning that factor.

To combine the opinions of the participating groups to determine the level of each factor's significance, a weighted average (WA) for each of the factors was obtained from the following expression (Chan and Kumaraswamy, 1996):

$$WA = \sum \frac{n}{N_g} \times MS\left(1 \le WA \le 5\right) \quad (2)$$

where,
n = number of responses for each group;
N_g = total number of responses for the three participating groups (N_g = 52); and
MS = corresponding mean score for that group with respect to each factor.

The MS and WA could be further interpreted based on each respondent's rating. To achieve this, MS and WA can be split into discrete categories as follows (Majid and McCafer, 1997):

Least	$1.0 \leq$ MS or WA < 1.5
Less	$1.5 \leq$ MS or WA < 2.5
Average	$2.5 \leq$ MS or WA < 3.5
High	$3.5 \leq$ MS or WA < 4.5
Highest	$4.5 \leq$ MS or WA ≤ 5.0

Similar categories could be established for other ranking classifications and the computed MS and WA from the analysis could then be converted to the above categories.

The agreement between the rankings of any two groups, for any given number of factors, needed to be tested. Spearman correlation analysis was used to test such agreements. This method is a commonly used tool for measuring the association between groups, two by two. The expression for calculating the Spearman's correlation coefficient was as follows (Mendenhall, Reimuth and Beaver, 1993):

$$r_s = 1 - \frac{6 \times \sum d_i^2}{f_n \times (f_n - 1)} \qquad (-1 \leq r_s \leq +1) \tag{3}$$

where,
d_i = the difference between the rank given by one group and the rank given by another group; and
f_n = the total number of factors ranked by any two groups for any given category.

In the above expression, a maximum rank correlation coefficient of +1 indicated perfect linear correlation, while a minimum value of –1 indicated negative correlation. In the case of a zero value, no correlation existed.

To test the rank correlation coefficient (the null hypothesis, H_0), a two-tailed t-statistic test was used for this study at a significance level of 5%. H_0 occurs when two groups of participants in the construction did not agree on the ranking of important factors; otherwise, H_1 is accepted. However, in this study, the value 0.362 obtained a significance level of slightly less than 5% for most situations.

RESULTS AND DISCUSSION

Interviews

The data obtained from interviews show clearly that projects are unlikely to be completed without design changes. The nature and complexity of the work require a degree of design changes. Professionals believe that projects with repetitive design and detail experience fewer and less extensive changes than non-repetitive projects.

Regarding the interviews, clients are the most common source of design changes in reinforced concrete buildings. Many clients lack the ability to visualise the proposed works from detailed drawings until they see them built. Moreover, to enhance the quality of the work and the extent of performance, the client often changes the specifications in the construction industry. Financial obligation is introduced as another factor that forces clients to modify the scope of the work, use alternative materials, or adopt different construction methods.

Furthermore, a lack of coordination between members of the design team can affect the buildability of the project and the conformity of the elements. An unclear scope of work is also considered to be a common cause of design changes, especially for fast-track projects. To save time, there are cases in which the construction work is started before the completion of the design. Unexpected site conditions due to improper site investigation and the lack of a feasibility study at the proposed site are another cause highlighted by the interviewees.

Although consultants, contractors and clients spend much effort to ensure the completion of work within the allocated time and budget, design changes deviate from these essential goals. Respondents cited major delays as an impact of design changes because these changes redistribute the planning of material, the allocation of resources and the completed portions of the project. The delay caused by a design change could also significantly affect the cost of a project. In addition, productivity, efficiency and momentum are influenced and slowed by design changes. Moreover, there is a common interest among professionals to build good relationships with each other and to work in harmony to achieve a successful project; design changes can create an adverse atmosphere and can lead to frustration and disputes among the professionals involved.

Case Studies

The reason for using three case studies is to provide actual examples of the negative aspects of design changes (especially cost and time). The causes and sources for each of the three case studies are listed in Table 3; the extent of the effects of each cause on the project is indicated by the percentage and how frequently it occurs. Table 4 shows the precise impact of the design changes on each case study by the end of the project by the percentage of increase in cost and time.

Table 4. Value of Design Changes Impact in Each Case Study

	Case Study 1	Case Study 2	Case Study 3
Increase in design fee	137.56%	189.76%	55.20%
Increase in supervision fee	284.30%	65.00%	60.00%
Increase in design time	195.00%	484.60%	146.50%
Increase in supervision time	126.50%	29.20%	60.00%
Increase in construction time	120.60%	20.80%	44.80%

Table 3. Design Changes Related Causes and Sources with Their Effect

Main Causes	Case Study 1			Case Study 2			Case Study 3		
	Occurrence Frequency	Main Source(s)	Percentage of Original Fee	Occurrence Frequency	Main Source(s)	Percentage of Original Fee	Occurrence Frequency	Main Source(s)	Percentage of Original Fee
Modification to the design	5	Client	37.63	6	Client	31.09	5	Client	11.39
Introduction of new work	7	Client	90.02	6	Client	107.3	2	Client	26.11
Lack of coordinate	3	Interior designer	6.94	2	Interior designer & service engineer	1.83	4	Interior designer and service engineer	6.22
Improper site investigation	1	Sub-consulta nt	2.97	3	Client & structural eng.	49.54	2	Contractor and structural eng.	3.52
Inadequate design	–	–	–	–	–	–	1	Client	7.66
Alternative construction method	–	–	–	–	–	–	1	Contractor	0.3
Total causes	16	–	137.56	17	–	189.76	15	–	55.2

The first case study consists of three main residential complex buildings with basements and ground floors. The second case study consists of three main concrete buildings with ground floors and seven secondary concrete buildings with one floor. The last case study consists of main residential complex concrete buildings and four secondary buildings with one or two floors. The primary causes of design changes as identified from the case studies, were:

1. Modification of the original design,
2. Introduction of new work,
3. Lack of coordination among members of the design team,
4. Unexpected site conditions,
5. Alternative construction method, and
6. An inadequate design.

There are further causes that were identified both in the literature review and in the interviews that did not contribute to the design changes in the case studies. One of the possible reasons for limiting the causes was that only major design changes, or new work that included a reasonable fee, were considered valid design change claims. Furthermore, many design changes were covered by complementary agreements or under the original contract document.

Causes, Sources and Impact of Design Changes from the Questionnaires

The responses to the questionnaires were provided with a list of causes of design changes attributable to each group involved in the construction project. The first section of the questionnaire was conducted to establish the category and ranking of each cause of the client-initiated design changes according to their significance level as perceived by the clients, consultants and contractors. Seven possible causes were identified in previous parts of the questionnaire as attributable to the client. The MS and rankings (R) for each cause are presented in Table 5.

As can be seen from the table, clients, consultants and contractors "mostly agree" that the clients are likely to "modify the original design". This factor is considered the most common cause of clients wanting design changes, with a weighted average mean score of 4.175. In addition, "addition of new work/scope" is the next important factor, with a weighted average mean score of 4.037. Based on the Spearman correlation analysis, there is clear agreement in the rankings of the clients and those of the contractors, with $r_s = 0.786$ when the value 0.362 gives a significance level of slightly less than 5% for most situations.

In the second section of the questionnaire, five common causes were identified as reasons for consultant-initiated design changes. Table 5 also stipulates the MS and R for each cause as perceived by the participating groups.

The weighted average MS "inconsistent information", "discrepancy with contract document" and "insufficient details of existing site condition" are the three most common causes of design changes attributable to the consultants. By applying the Spearman correlation analysis, the r_s of 0.9 indicated a reasonable correlation with the ranking of the factors.

Table 5. Mean Scores (MS) and Ranks (R) for Causes of Design Changes

Cause(s)	Clients		Consultants		Contractors		Weighted Average	
	MS	R	MS	R	MS	R	MS	R
1. Due to Clients								
a) Additions of new works/ scopes (not part of original scope)	4.273	2	3.778	2	4.000	1	4.037	2
b) Omission of works/ scopes (reduction on original scopes)	3.000	3	2.333	7	2.857	4	2.741	6
c) Modifications to the original design (changes within the original scope)	4.454	1	3.889	1	4.105	1	4.175	1
d) Unclear initial design brief (e.g. the extent of the scopes, requirements, details etc.)	2.909	4	3.333	3	3.571	3	3.222	3
e) Desire to use alternative material/new technology (may require different details and coordination with suppliers)	2.818	5	3.000	4	2.286	7	2.741	5
f) Desire to use better specification (e.g. to extend the life of the structure or for better performance etc., may require different design detail)	2.818	6	2.778	5	2.714	5	2.778	4
g) Insufficient background of proposed site (e.g. possibility of underground facilities, previous structures, previous site condition etc.)	2.400	7	2.667	6	2.714	5	2.570	7
2. Due to Consultants								
a) Improper design /part of design improvement (e.g. to rectify design mistakes, to adopt better detailing, to simplify the design for easy construction etc.)	2.909	3	2.556	4	2.571	3	2.704	4

(continued on next page)

Table 5 (*continued*)

Cause(s)	Clients		Consultants		Contractors		Weighted Average	
	MS	R	MS	R	MS	R	MS	R
b) Inconsistent information in drawings (e.g. structural detail does not match architectural detail etc.)	3.364	1	2.667	2	4.000	1	3.297	1
c) Discrepancy between contracts documents (e.g. drawings or specification, Bill of Quantities etc.)	3.091	2	2.667	2	2.857	2	2.889	2
d) Lack of insufficient geotechnical investigation or wrong interpretation of the findings (e.g. un-expected rock layers, loose soil, high water table etc.)	2.545	4	2.444	5	1.857	5	2.333	5
e) Insufficient detail of existing site condition (e.g. clashes with underground facilities, clashes with adjacent structures, flooding condition at site, etc.)	2.545	4	3.111	1	2.571	3	2.740	3
3. Due to Contractors								
a) To use available material	3.000	3	3.444	1	2.143	5	2.926	3
b) To use alternative construction methods to save time	2.727	4	3.000	3	3.000	1	2.889	4
c) To use alternative construction methods to save money	3.364	1	2.889	4	2.857	2	3.074	1
d) To rectify construction mistakes	3.182	2	3.142	2	2.429	3	2.973	2
e) To improve the quality of works at site	2.182	5	2.444	5	2.400	4	2.185	5

Table 5 presents the MS and R, for design changes attributable to the contractors in the third part of the questionnaire. These data are extracted from the opinions of the questionnaire respondents. Using an alternative construction method is the most common cause for design changes attributable to the contractors. The ranks, obtained from the weighted average mean score, indicate the level of importance of each cause cited by all three groups.

The clients, consulting engineers, contractors and specialised design members all initiated design changes of different magnitudes. Table 6 shows the sources that normally cause design changes in the construction industry. All of the participating groups agreed on the significance level of each source, shown in the following rankings (from most significant to least significant):

1. Clients,
2. Members of the design team,
3. Consultant engineers, and
4. Contractors.

Table 6. Mean Scores (MS) and Ranks (R) for Sources of Design Changes

Sources(s)	**Clients**		**Consultants**		**Contractors**		**Weighted Average**	
	MS	R	MS	R	MS	R	MS	R
Clients	4.455	1	4.444	1	4.429	1	4.445	1
Consultant engineers	3.091	3	2.667	3	2.714	3	2.852	3
Contractors	2.000	4	2.222	4	2.143	4	2.111	4
Design members (e.g. interior designers, acoustic engineers etc.)	4.091	2	3.000	2	4.143	2	3.741	2

The relationship between the level of significance for each factor and the impact of the design changes is shown in Table 7. This part of study aims at establishing general knowledge for professionals in the construction industry on the negative aspects of design changes to minimise avoidable design changes later.

It is clear from Table 7 that the three participating groups do not agree on the most important factor that leads to design changes. Factors that "lead to loss of productivity and efficiency due to interruption and out-of-sequence work" were ranked highest by the contractors, with a mean score of 4.857. The contractors "strongly agreed" on this factor as having the most important impact on design changes. The impact on labour productivity caused by this factor is a major concern to contractors, especially when the changes arise during the construction stages. The clients considered "increase in design fee" to be the most important factor and thus, they gave it the highest rank, with a mean score of 4.454. The clients might have ranked this factor as the highest because the highest fee is associated with altering the original design. "Delay construction progress" was given the highest rank by the consultants, with a mean score of 4.44. Thus, the consultants "mostly agree" on the ranking of this factor. Although the consultants have no direct impact on this factor, they ranked delays the highest, possibly because their experience has proven that the majority of projects are delayed significantly. A statistical test was performed on the factors that are related to the effects of design changes. The value of 0.733 for r_s indicates a reasonable correlation with the ranking of the factors. However, clients versus contractors and consultants versus contractors do not agree significantly on the ranking because the null hypothesis H_0 is accepted for both groups. Figure 2 presents a summary of the results based on the highest ranking in each category.

Table 7. Mean Scores (MS) and Ranks (R) for Impacts of Design Changes

Impacts(s)	Clients		Consultants		Contractors		Weighted Average	
	MS	R	MS	R	MS	R	MS	R
Increase design fee	4.454	1	3.778	2	3.286	7	3.926	3
Increase construction cost	4.182	2	3.667	4	3.714	6	3.889	5
Delay design progress	4.091	3	4.444	1	3.857	5	4.248	1
Delay construction progress	4.000	4	3.556	5	4.571	2	4.000	2
Increase chances for material waste due to re-work operations	3.132	7	3.778	2	4.000	4	3.572	6
Lead to loss of productivity and efficiency due to interruption and out of sequence works	3.727	5	3.444	6	4.857	1	3.926	4
Lead to loss of motivation and momentum to re-do work	3.091	7	3.444	6	4.286	3	3.518	7
Increase chances for design mistakes	2.636	9	2.556	9	2.429	9	2.556	9
Decrease quality of works	2.000	10	2.111	10	2.143	10	2.074	10
Increase chances for frustration, strain the relation, and build-up bad atmosphere among concerned people	3.273	6	3.222	8	3.286	7	3.259	8

Corrective Actions and Preventive Measures in the Questionnaire Survey

One of the main objectives of this research was to identify the most significant corrective action or preventive measure that could be recommended to affected professionals in the construction industry; these factors are important to minimise avoidable design changes. The majority of the corrective actions and/or preventive measures that could be implemented to minimise design changes were presented in the interviews with professionals. These actions were specifically conducted for this study and were reported as required corrective actions and/or preventive measures, along with their mean scores and ranks, as perceived by the participating groups. Table 8 presents the factors that are important to avoid expensive design changes.

As shown in Table 8, the clients, consultants and contractors considered "allocating sufficient time at the initial design stage to implement the client's idea properly and to finalise the requirements of the proposed work" as the most important factor that needed to be addressed to avoid expensive design changes. The professionals "strongly agreed" on the highest rank of this factor, with a weighted average score of 4.629. In many cases, clients do not comprehend the basic requirements of the project until they observe them in the late design stage or during construction. This problem is, in most cases, caused by the failure to brief clients on the progress of the design work and to discuss any technical problems or alternative opinions that deviate from the clients' requirements. Moreover, many clients do not involve themselves much at the design stage because they are too busy or they do not believe they have the technical experience; clients expect their ideas to be implemented with minimum time and discussion. In addition, there are cases in which construction work starts before the completion of the design. For such cases, consultants come under pressure to provide working drawings quickly to contractors to avoid delaying the progress at the site. Most importantly, consulting engineers should understand their clients' requirements and be able to implement them correctly. If consultants have doubts, they should clear such doubts promptly with their clients.

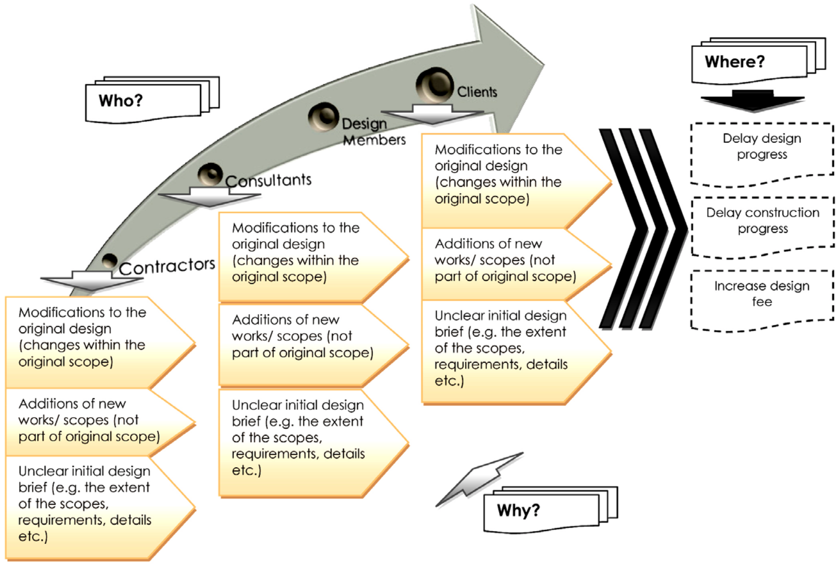

Figure 2. Summary of the Results

Furthermore, clients should appoint consulting engineers who have sufficient experience in the field to be able to conduct their work professionally. Unqualified consultants may not be able to realise the clients' ideas or may be able to develop only limited design criteria that are not in line with clients' requirements.

The questionnaire item, "allocating sufficient time and funds at initial planning stage for feasibility studies, site investigations, detailing existing site conditions and highlighting any site restrictions to avoid unexpected circumstances", was scored second highest by both of the clients. The clients indicated they "strongly agree" with the ranking and the consultants indicated they "mostly agree" with the rank, with mean scores of 4.545 and 4.431, respectively. The contractors indicated they "mostly agree" to give this factor the third highest rank, with a mean score of 4.429.

Feasibility studies and site investigations and details are critical because they normally define the basic requirements of work that need to be developed further. This information provides alternative options and highlights any technical problems or restrictions to the work with solutions to such potential problems at the initial stage of a project. Feasibility studies also provide an approximation of the cost of work so that clients are aware of the required funding. Site investigations reveal critical design parameters such as the type and details of the underlying soil stratus.

Table 8. Mean Scores (MS) and Ranks (R) for Corrective Actions and/or Preventive Measures of Design Changes

Actions(s)	Clients		Consultants		Contractors		Weighted Average	
	MS	R	MS	R	MS	R	MS	R
Allocating sufficient time at the initial design stage to implement clients' ideas properly and to finalise the requirements of the proposed work	4.636	1	4.444	1	4.857	1	4.629	1
Allocating sufficient time and funds at the initial planning stage for feasibility studies, site investigations, detailing the existing site conditions and highlighting any site restrictions to avoid unexpected circumstances	4.545	2	4.431	2	4.429	3	4.477	2
Involving specialised professionals at early planning stage for any extraordinary and/or unfamiliar works that may require special design arrangement	4.091	7	3.889	6	4.571	2	4.148	5
Briefing and discussing with clients or their representatives in regular intervals the progress of the work and highlight any potential difficulties/concerns as early as possible	4.364	4	3.772	9	4.134	7	4.107	6
Advising clients at early stages of any potential impacts that may result from each proposed change in particular on fee and time aiming to minimise the changes	4.273	6	3.918	5	4.418	4	4.192	4
Engaging an experience coordinator/project director to represent the client which eases the design process and transmission of information to the design members but may influence fee if not taken into consideration	3.941	8	3.667	10	3.857	9	3.828	9
Setting up at the initial design stage a proper method of coordination which was to be reviewed on a regular basis to make any adjustment if deemed necessary	4.351	5	3.778	8	4.143	6	4.106	7
A simple communication channel and better method for transmission of information would improve the efficiency of coordination and approval process	3.818	10	3.864	7	3.827	10	3.836	8

(*continued on next page*)

Table 8 (*continued*)

Actions(s)	Clients		Consultants		Contractors		Weighted Average	
	MS	R	MS	R	MS	R	MS	R
A proper personnel evaluation and assigning responsibilities accordingly would assist assigning the right responsibility to the right personnel	3.545	12	3.556	12	3.571	12	3.555	12
Providing a clear and comprehensive design brief at an early stage	4.500	3	4.222	3	4.200	5	4.330	3
For each project, more effort is required to review the clauses of contract documents with reference to drawings in order to eliminate/reduce the inconsistency and deficiency between the documents	3.900	9	4.000	4	3.286	13	3.774	10
An improvement to the working atmosphere and job satisfaction would increase the spirits and motivation of people and hence to the quality of the work produced	3.200	13	3.642	11	3.726	11	3.484	13
Centralising responsibility for overseeing proper coordination between clients, design members, and contractors	3.600	11	3.222	13	4.000	8	3.578	11

A sequential detailed design is based on the optimum options and solutions associated with the feasibility studies and site investigations. In many cases, in an attempt to save time, major decisions and detailed designs start before the results of feasibility studies and site investigations are received. Furthermore, clients sometimes believe that the benefits of conducting feasibility studies and site investigations do not justify the cost of such requirements. Clients sometimes prefer to accept the risk of unexpected circumstances by saving money on these items, which in turn increases the chances of design changes at late stages in the project.

It is also worth mentioning that "providing a clear and comprehensive design brief at an early stage" to minimise the design changes was ranked third by the participating groups, with a weighted average of 4.330. Design changes occur because of unclear design briefs and in many instances, these changes lead to disputes, which invariably address details that did not exist in the scope of the original design. For large-scale projects, more-detailed design briefs are normally available for the major elements of the work, with less concentration on the secondary elements. It is also common in the construction industry to leave small elements without design briefs, allowing consultants to claim extra money to design them later. Thus, it is essential to define precisely the scope of the work and to provide comprehensive details on the required services during the design/tender stage, which in turn reduces the chances of modifying the original design scope.

Table 9 presents the results of the statistical test that was conducted on this group of corrective actions and preventive measures to minimise the design changes. The Spearman's correlation coefficients ratio, r_s, and t-statistics indicate significant agreement in the rankings; hence, the null hypothesis H_0 is rejected for the three groups.

Table 9: Test for Agreement on the Ranking for Corrective Actions and/or Preventive Measures of Design Changes

Groups	Spearman's Coeff. Rho. (r_s)	t-statistics (calculated)	t-statistics (t table)	Reject H_0
Client and consultants	0.775	4.067		Yes
Client and contractors	0.797	4.377	2.201	Yes
Consultants and contractors	0.599	2.481		Yes

Note: Coeff. Rho. = Coefficients ratio

CONCLUSION

Almost all projects undergo various modifications and changes, not only at the design stage but also during construction. These changes have numerous impacts during the lifecycle of a project, which might be minor or major according to the result of the change. Design changes are on-going problems that continue to raise concerns in the construction industry. Defining the causes, sources and impacts of design changes in residential reinforced concrete buildings could help all of the parties involved in the construction project find mutual solutions to claims and avoid disputes.

Clients are recognised as a major source of design changes. "Modifications to the original design", "addition of new work/scope" and "unclear initial design brief" were three major causes of design changes attributable to the client in the view of contractors, consultants and clients. The next most significant source of design changes was the "design team", followed by consultant engineers. "Inconsistent Information", "discrepancy with contract document" and "insufficient details of existing site condition" were the three most common causes of design changes attributed to consultants and members of the design team. Contractors received the lowest rank for initiating design changes in the construction industry; three major relevant causes were "to use alternative construction methods to save money", "to rectify construction mistakes" and "to use available material".

In conclusion, the most common impacts of design changes were explored and defined. Compared with the results of previous studies, the results of this study indicated that delays in design and construction and increasing the cost are the most common and important impacts of design changes. However, there were other impacts introduced in this study that were rated high by clients, contractors and consultants.

Finally, in this paper, the most significant corrective actions and/or preventive measures that could establish boundaries and attempt to minimise avoidable design changes were identified. Furthermore, guidelines were recommended to be implemented by professionals involved in reinforced concrete building projects.

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