Factors leading to design changes in Jordanian construction projects

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Abstract

Purpose – The problem of design changes in the construction industry is common worldwide, and the Jordanian market is no exception. The purpose of this paper is to identify the factors causing design changes in construction projects in Jordan in both the public and private sectors. Furthermore, this research will examine the effect of these factors on project's performance during the construction phase.

Design/methodology/approach – This research commences by identifying the factors causing design changes in construction projects worldwide through an intensive literature review. The identified factors were then filtered to those applicable to the Jordanian construction market based on the results obtained from a questionnaire survey and real case construction projects. In total, 252 professionals from the Jordanian construction industry and 10 completed and/or ongoing construction projects in different parts of Jordan were compared.

Findings – The results find that the top major factors affecting design changes are owner's requirements; design errors and omissions and value engineering. The research also studies and documents the impacts of design changes on project cost, schedule and quality.

Originality/value – The results obtained from this research will assist the construction professionals representing owners, consultants and contractors in applying control measures to minimize the occurrence of the identified factors causing design changes and to mitigate their sever impacts on projects in terms of cost, schedule and quality.

Keywords Design changes, Project performance, Construction industry, Jordan

Paper type Research paper

1. Introduction

The construction industry plays a vital role in the socioeconomic development of any country with the products and activities of the industry directly influencing the achievement of the national socioeconomic improvement goals by providing infrastructure, facilities and employment (Myers, 2013).

Construction has been considered a dynamic industry which is constantly facing uncertainties in its budgets, processes and technology. These uncertainties combined with other factors such as project complexity and the increased involvement of stakeholders; contribute to the difficulty in managing any construction project and the resultant time and cost overruns (Halpin, 2011; Chan *et al.*, 2004).

Despite the fact that there have been improvements in the management of the construction industry, the problems of cost and time overruns are still critical and prevailing issue in the industry (Parvan *et al.*, 2012). It is widely acknowledged that design changes form one of the most significant factors affecting construction projects performance irrespective of its size, complexity and/or duration.

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Even with good management practices; the impact of design changes still present a significant problem with its cost impact varying between 5 and 15% of total construction costs. (Hao *et al.*, 2008; Bekr, 2015; Ibbs, 2012) highlighted that around two-thirds of the costs due to design changes could have been avoided, which brings us to the question as to why controlling the design changes in construction projects remains such a problem?

Therefore, this research not only focuses on identifying causes of design changes but also proposes possible precautions and preventive measures to minimize the occurrence of design changes. However it is worth mentioning that this research is applicable to the building construction sector only, whereas other sectors such as civil engineering sector and industrial sector are not applicable to the research.

2. Literature review

Changes in construction projects usually occur to modify or correct the design, or scope of work (Alnuaimi *et al.*, 2010). One of the most common types of change in the construction industry is the "Design Change" (Mohamad *et al.*, 2012). Design changes would inevitably affect a project's key success principles, namely, cost, time and quality (Le Hoai *et al.*, 2008; Owalabi *et al.*, 2014). Meanwhile, project performance is assessed and evaluated by a set of indicators/factors which can be viewed as budget, schedule, quality, shareholder satisfaction and owner–contractor relationship. Of these indicators: cost, time and quality are considered tangible and easily measured; thus, providing a clear indication of the status of the project (Memon *et al.*, 2014; Chan *et al.*, 2004).

Many studies extracted from the developed countries that examined design changes and project performance; the first study is the construction of the Sydney Opera House where the continuous and excessive design changes were the main contributor to the 1400% cost overrun suffered through its 16-years construction period (Flyvbjerg *et al.*, 2004). The second study, which is based on four case studies from California, estimated the percentages of overruns that were associated with design changes to be 25% in cost, and around 70% in time from the original contracts (Chang, 2002). The third research study by Orangi *et al.*, 2011 which stated the causes of delay of the Victoria-based Australian pipeline projects. The fourth study by Olawale and Sun, 2010 investigated the cost overruns in UK's construction industry, and highlighted design changes as the major factor among the 21 no. main factors that contributed to project overruns.

Whereas in a study by Gajewska *et al.*, 2011 on the factors leading to cost overrun in Sweden, the findings excluded design changes as a major factor cause, and claimed that delay in decision-making, inaccurate estimation and incompetence contractors were the most influencing factors of cost overrun in construction projects. Also a study by Doloi, 2011 that aimed at identifying the causes of cost overrun in Australia, concluded that improper planning, complexity of design, methods of construction and deficiencies in planning and scheduling at the tender stage were the most recognized factors in Australia.

Compared to the developing countries, the first study examined the causes of cost and time overruns in building projects in Vietnam, based on a structured questionnaire from 87 construction experts from Vietnam. This study showed that inadequate supervision, owners' and contractors' financial problems, and design changes were the most frequent factors causing project overruns. Similarly from Nigeria, two studies conducted by Owalabi *et al.*, 2014; Sanni and Hashim, 2013 agreed on the factors leading to time overruns in Nigerian construction projects; which included improper documentation, market changes, project complexity and continuous changes in governmental regulations. However the effect of design changes was not addressed as a delay contributing factor. Another research in Cambodia by Peansupapa and Cheangb, 2015 that focused on the change issues and cost conflicts associated with cost overruns between project's parties, found design changes by owner to be a vital cause leading to cost conflicts. Also practitioners in Malaysian construction industry acknowledged design changes as a major concern of the industry (Abdul-Rahman *et al.*, 2006), the case of Kuala Lumpur International Airport 2 (KLIA2) that much affected the project performance in Malaysia.

A similar study in Malaysian residential buildings by Mohamad *et al.*, 2012 claimed that the client-related factors were found to be the most influencing factors of design changes, followed by the design team, and the lowest rank was received by the contractor-related factors. Their study also mentioned the impacts on project performance which causes overrun and delays on cost and time, respectively.

Another study by Ravisankar *et al.*, 2014 which studied the causes of delay in construction projects in India stated that design changes by owner as one of the most important factors leading to delays along with several factors mentioned in the paper. However, neither of the studies conducted by Singh, 2011 and Shanmuganathan and Baskar, 2015 indicated design changes as a direct causative factor of cost overrun in India and agreed that the main factor was initiating the construction process prior to completing the design.

Several studies were conducted in the Middle Eastern countries. A study by Alnuaimi *et al.*, 2010 on the public projects in Oman ranked client modifications and design changes as the most causative factors of variation orders in Omani public construction projects. More in the same vein, a similar study done in Saudi Arabia by Homaid *et al.*, 2009 concluded that the main impact of change orders is on the project's budget, and identified the scope changes by the owner as the main factor leading to the variation orders. Moreover, the results from a study in Gaza Strip by Enshassi *et al.*, 2010 indicated that the factors related to the consultant were ranked as the most important causes of variations and that change in design is the most important. These findings were supported by Albhaisi, 2016 who found that changes of design by the owner were ranked as the main causative factor of variation orders in construction projects in Gaza.

Five studies were concluded in the Jordanian industry by researchers and commentators; Samarah and Bekr, 2016 aimed to identify the most important causes of delay in Jordanian construction projects and its impact, using a survey from a sample of 23 contractors and 17 consultants. The main factors were found to be: contractor's financial status, design changes by owner, shortage in labor, poor site management and supervision, and owner's financial capability. These findings supported a previous study by Al-Momani (2000), on the same subject.

Many studies have also investigated causes of cost overruns. For instance, Sweis and others in (2013) investigated the causative factors of cost overruns in the Jordanian construction industry, and the public projects in specific, found that design changes, contractor's poor experience in similar projects, and project location were considered the main variables causing cost overruns. Another study by Abu Hammad *et al.* 2010 conducted in Jordan, noted that additional work/direct change orders by client ranked as the prime main factor causing cost overruns. A similar study by Bekr, 2015 named schedule delay (time overrun) and frequent design changes as the main causes. These findings were recently confirmed and supported by Al-Hazim *et al.*, 2017. Another study by Abdalla and Battainehm, 2002 concluded the main factors impacting the performance as: the agreement among contractors and consultants, inadequate contractor experience, and funding and labor productivity with no mention made of design changes as a contributing factor to delays.

There has been no comprehensive studies on the problem of design changes in the Jordanian construction industry prior to this research; moreover, previous studies from Jordan on construction projects performance have been limited in their scope and focusing on specific attributes that are causing cost and time overruns and uncertainties in construction projects in general. This research aims toward adding more knowledge, particularly in Jordan, about the factors causing design changes in construction projects and providing some proposed recommendation to minimize the occurrence of these design change factors.

In view of the above, it is essential that research studies be conducted to identify the causative factors of design changes in the Jordanian market in general and the same to be complemented with actual case studies from the market to provide a practical analysis and findings. This observation provide the underlying motivation for future studies to fill the gap in knowledge on the major causes of design changes in the Jordanian construction projects and its impacts on the project's performance.

Review of literature focused on research identifying the main factors affecting performance of construction projects in different countries worldwide, and then extracting those factors that eventually will lead to design changes. The results of the literature review are summarized in Table 1 below.

3. Research methodology

The aim of this research is to identify the causes of design changes and analyze its effects to enhance the control over its occurrence in construction projects. To achieve this aim, this paper has three objectives:

(1) Identifying major factors leading to design changes in construction projects;

(2) Investigate the impacts of design changes factors on project performance;

(3) Propose possible precautions and preventive measures to minimize the occurrence of design changes using the data gathered on the causing factors and their level of severity, as well as probable methods to reduce its negative impact.

The method adopted for data collection was determined based on the type of information needed to achieve the research objectives, depending on the source and availability of the data (Robson, 2002). Hence, there was a need for different types of research methods to be implemented. A mixed-method approach whereby a combination of qualitative and quantitative techniques is used has become generally preferred and is known as triangulation method (Creswell, 2003; Neuman, 2006). This method is used to test the research proposition of the data collection and evaluation stage, to achieve the research aims and objectives.

The qualitative techniques used for collecting the research data were based on the literature review and structured interviews. Interviews were conducted using seven key selected practitioners from the construction industry in Jordan to discuss different issues on design change factors and their effects on construction project's performance

As a result of these interviews certain comments and modifications were introduced to customize the collected factors according to the Jordanian construction market to be later used in the questionnaire survey. This resulted in introducing two additional factors that are frequently observed in construction projects in Jordan and lead to design changes; which are related to the requirements by the end users of the facility and the operator's requirements. On the other hand, there was a need to remove irrelevant or repetitive factors such as type of contract and poor labor productivity.

The quantitative technique used for collecting the research data were based on the questionnaire that was prepared based on the final list of design change factors which was analyzed from the reviewed case studies and through the questionnaire. The questionnaire was distributed using the online survey method.

Collected data targeted basically the consultants working in the supervision field, first and second grade registered firms, and first and second firms specialized in buildings and clients, and client's representatives all in public and privet sectors.

The sample size was determined based on Yamane (1967) sample size equation: [$n = N/(1 + Ne2)$], where, n is the sample size, e is the margin of error, N is the population size.

Factor	Reference
Owner-related factors	
Owners requirement	Alwi *et al.* (2002); Al-Najjar (2008); Elinwa and Joshua (2001); Mohamad *et al.* (2012); Albhaisi (2016); Sunday (2010); Memon *et al.* (2014); Kaliba and Mumba (2009); Peansupap and Cheangb (2015); Staiti (2015); Memon *et al.* (2014); Oladapo (2007); Sweis *et al.* (2013); Kaming *et al.* (1997); Lokhande and Ahmed (2015); Ogunlana *et al.* (1996); Chan *et al.* (2002); Odeh *et al.* (2002); Abudul-Rahman *et al.* (2006); Chimwaso (2001); El-Razek *et al.* (2008); Mezher and Tawil (1998); Assaf *et al.* (1995); Samarah and Bekr (2016); Mohamad *et al.* (2012); Olawale and Sun (2010); Jergeas and Ruwanpura (2010); Le-Hoai *et al.* (2008); Albhaisi (2016); Memon *et al.* (2014); Staiti (2015); Sweis *et al.* (2013); Al-Momani (2000); Lokhande and Ahmed (2015); Alwi *et al.* (2002)
Cost saving by owner	Lokhande and ahmed (2015); Al-Najjar (2008); Sunday (2010); Memon *et al.* (2014)
Value engineering	Lokhande and ahmed (2015); Staiti (2015); Halwatura and Ranasinghe (2013)
Late involvement of specialists	Aibinu *et al.* (2006)
Design and consultant-related factors	
Design errors and omissions	Al-Momani (2000); Lokhande and ahmed (2015); Alwi *et al.* (2002); Al-Najjar (2008); Enshassi *et al.* (2010); Abudul-Rahman *et al.* (2006); Chimwaso (2001); Long *et al.* (2004); Assaf *et al.* (1995); Samarah & Bekr (2016); Mohamad *et al.* (2012); Memon *et al.* (2014); Albhaisi (2016); Sunday (2010); Memon *et al.* (2014); Peansupap and Cheangb (2015); Staiti (2015)
Discrepancies in contract documents	Lokhande and Ahmed (2015); Alwi *et al.* (2002); Odeh *et al.* (2002); Alghbari *et al.* (2007); Mohamad *et al.* (2012); Albhaisi (2016); Sunday (2010); Staiti (2015); Memon *et al.* (2014)
Poor coordination between design disciplines	Lokhande and Ahmed (2015); Ogunlana *et al.* (1996); Elinwa and Joshua (2001); Odeh *et al.* (2002); Yang *et al.* (2013); Abudul-Rahman *et al.* (2006); Chimwaso (2001); Frimpong *et al.* (2003); Faridi and El-Sayegh (2006); Samarah and Bekr (2016)
Incomplete design at tender stage	Peansupap and Cheang (2015); Al-Najjar (2008); Ogunlana *et al.* (1996); Alghbari *et al.* (2007); Chimwaso (2001); Long *et al.* (2004); Aibinu *et al.* (2006); Assaf *et al.* (1995)
External factors	
Unforeseen conditions	Alwi *et al.* (2002); Mohamad *et al.* (2012); Sunday (2010); Staiti (2015)
Constructability	Alwi *et al.* (2002); Al-Najjar (2008); Odeh *et al.* (2002); Samarah and Bekr (2016); Mohamad *et al.* (2012); Albhaisi (2016); Peansupap and Cheang (2015)
Market requirements	Albhaisi (2016); Sanni and Hashim (2013); Owolabi *et al.* (2014)
Regulatory requirements	Sweis *et al.* (2013); Lokhande and Ahmed (2015); Alwi *et al.* (2002); Ogunlana *et al.* (1996); Odeh *et al.* (2002); Enshassi *et al.* (2003); Alghbari *et al.* (2007); Chimwaso (2001); Alaryan *et al.* (2014); Albhaisi (2016); Sunday (2010); Peansupap and Cheang (2015)
Technological requirements or changes	Lokhande and Ahmed (2015); Al-Najjar (2008); Chimwaso (2001); Long *et al.* (2004); Samarah and Bekr (2016); Alaryan *et al.* (2014); Albhaisi (2016); Staiti (2015); Oladapo (2007); Halwatura and Ranasinghe (2013)
Unavailability of materials	Lokhande and Ahmed (2015); Alwi *et al.* (2002); Ogunlana *et al.* (1996); Odeh *et al.* (2002); Enshassi *et al.* (2003); Alghbari *et al.* (2007); Faridi and El-Sayegh (2006); Samarah and Bekr (2016); Enshassi (2009); Albhaisi (2016); Staiti (2015)

Table 1. Design change factors as identified by previous literature

Using a confidence level of 95% for the quota sampling based on Kish, 1965 sampling technique and the population size is determined earlier as (1120), using the above equation, the sample size needed is 286 respondents.

The questionnaire was sent using a web-based form to 610 practitioners, the number of questionnaires that were returned and completed was 252 with a response rate of 42%, the sample then characterized by sector (private and public), role (Client, Consultant Contractor), years of experience of the participant and the position held by the participant.

Out of the 252 respondents, 109 were engineers from consultation firms, 99 were from contracting firms, while 44 were representing the owner's side. 24% of the respondents were from the public sector and 76% of the respondents were from the private sector. More than 60% of the participants had more than seven years of experience, while 35% of the respondents held managerial positions, whether from the owner, contractor or consultants sides, which increased the level of reliability of the gathered data.

To achieve better comprehensiveness and variation, five aspects were considered to select the case studies, namely, project value and scope, geographical location, the function or type of the project, type of contract and project delivery method, and type of client (public or private). In terms of project value, a minimum of JOD 7*m* was selected as this represents the medium to large scaled projects. Such projects are characterized by having a better documentation and demonstration of the phenomena associated with the construction industry. Cases were selected among various locations in Jordan, from the north, center and south regions with different types of building functions (residential, educational, commercial, governmental, etc. . .). Moreover, three main types of construction contracts (remeasured, lump sum and engineering procurement contracts (EPC)), different types of project delivery methods (design–bid–build, design–build and design–build–operate projects) and type of client (public or private) were considered. Another source of information regarding design changes in the case studies which is the documentary data such as the change order logs, monthly reports and project documents.

Ten case studies were discussed, comprising actual projects within the Hashemite Kingdom of Jordan whose construction is still in progress or completed in the last seven years. The selected projects differed in their characteristics as shown in Table 2, which summarizes the 10 cases in terms of characteristics and findings. Additionally, the cases were distributed between north, middle and south regions of Jordan, six out of the 10 cases were from the private sector, while the remaining four are public projects, and the base contract amounts of the cases varied between JD 7.4*m* and JD 140*m*.

To answer this study questions and hypotheses, the following statistical methods were used:

(1) Mean, standard deviation and percentage mean (relative weight frequency index).

(2) Pearson's correlation coefficients to measure the degree of correlation as well to study the relation between variables.

(3) Cronbach's alpha coefficient and split-half coefficient to determine the consistency of questionnaires' items.

(4) T-test to determine the difference between the categories of the categorical variables (two categories).

(5) One-way ANOVA to study the effect of categorical variables (three or more categories) on some numerical variables.

(6) Multicollinearity test and multiple linear regression was used by the researcher to test the impact of the design change factors, considering the design change factors as independent variables, and the three dependent variables being the (cost, time and quality).

The research methodology is elaborated through a methodology map. Figure 1 represents the research framework of this study.

Table 2. Summary of cases data

Case	Project type	Sector	Contract type	Location	Original contract value (JD)	Cost overrun from design changes	Main design change factors with cost implications	Time overrun	Factors leading to design changes with quality implications
A	H	PV	LS	Amman	139,677,868	14.4%	Owners requirement Value engineering Late involvement of owner's specialists	58%	Cost saving Owners requirement Operator's requirements Value engineering
B	C	PV	RM	Amman	29,437,259	12%	Owners requirement Value engineering	53%	Cost saving Owners requirement Value engineering
C	R	PV	RM	Aqaba	14,192,018	71%	Owners requirement	113%	Owners requirement
D	R	PV	LS	Aqaba	59,157,635	10%	Owners requirement Changes in market requirements	0%	Cost saving requirement Changes in market requirements
E	C	PV	RM	Amman	19,143,224	10%	Owners requirement Regulatory requirements	69%	Owners requirement
F	C	PV	RM	Amman	60,214,240	33%	Owners requirement Regulatory requirements Design errors and omissions	80%	Owners requirement
G	T	PB	EPC	Aqaba	48,449,035	25%	Owners requirement Operator's requirements	12%	Owners requirement Operator's requirements Changes in market requirements
H	E	PB	RM	Aqaba	21,468,925	13%	Owners requirement Regulatory requirements	51%	Cost saving Owners requirement Value engineering
I	E	PB	RM	Amman and Zarqa	14,258,112	9%	Cost saving Owners requirement Value engineering Design errors and omissions	0%	Cost saving Owners requirement Operator's requirements Value engineering
J	E	PB	RM	Irbid	7,483,448	12%	Operator's requirements Value engineering Owners requirement	39%	Cost saving Owners requirement Operator's requirements Value engineering

Note(s): Project Type: H: Hospitality, R: Residential, C: Commercial, T: Transportation, E: Educational
Sector: PV: Private, PB: Public
Contract Type: LS: Lump Sum, RM: Remeasured, EPC: Engineer, Procure and Construct

4. Data analysis and discussion

The reliability of the measurement instrument was evaluated through the use of Cronbach's (1951) coefficient alpha (α) using SPSS software. The values of Cronbach's alpha (α) for each construct used in the questionnaire survey revealed a very good reliability. In general, the values of Cronbach's alpha (α) ranged between (0.743) and (0.846).

Content validity was not evaluated numerically, instead it was subjectively judged and evaluated by academics and industry practitioners; moreover, the selection of the measurement elements were based on an exhaustive review of the relevant literature. Pearson's correlation coefficient was calculated to test the construct validity of the research instrument; the *p*-values were found to be less than 0.05, indicating that the correlation coefficients of all the fields are significant at $\alpha = 0.05$.

According to the statistical analysis, the design change factor "Incomplete design at tender stage" was ranked the first as it recorded the highest mean (3.762) while the design change "Technological requirements" had the lowest mean according to the data analysis (2.254).

The methodology of using the frequency index has been used before by Sweis *et al.*, 2013 and Le-Hoai *et al.*, 2008 to rank factors of cost overruns through calculating the weighted indexes of the importance and frequency of cost overrun factors.

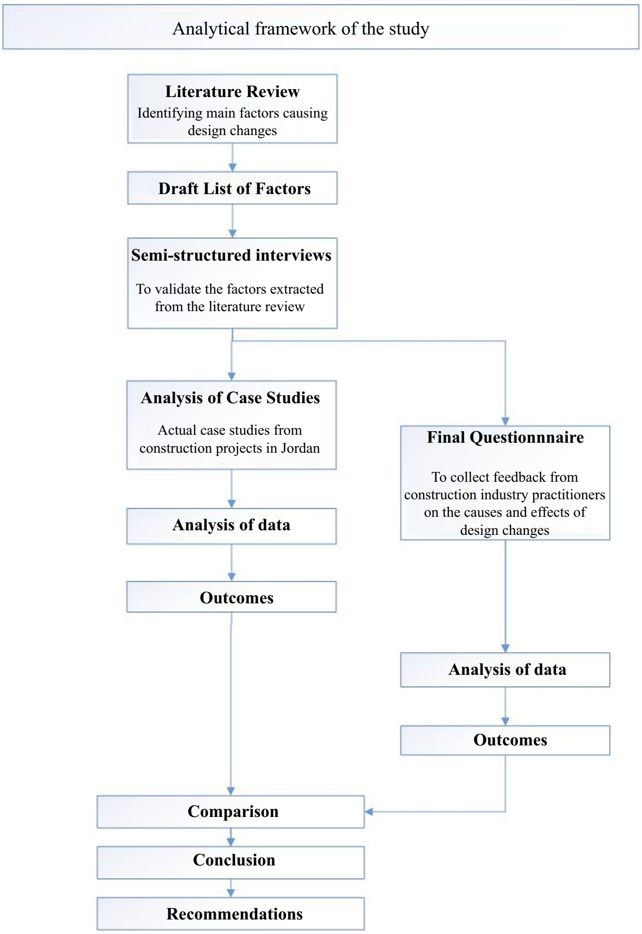

Figure 1.
Research framework for this study

5. Case study analysis

Due to the confidentiality nature of the projects discussed and evaluated here, the main information regarding each project including project names and identities of the different project parties was not revealed and the projects will just be referred to as only "Project A", "Project B" and so on. These cases were analyzed independently to determine the impact of design changes on project performance .The analysis of the case studies will be limited to only the approved final variation orders. Then classified the listed variation orders into two categories, namely, Design Change (DG) and Others (O) with only those classified as (DG) selected for further analysis.

Fourteen design change factors were identified from the analysis of the 10 case studies, and the occurrence of each factor in the cases, regardless of the impact of the factor.

The conducted analysis of the said data included the determination of the percentage from the overall issued project variation orders, identification of the factors contributing to the design changes, determination of the cost impact as a percentage of the original contract price, determination of the time impact as a percentage of the project contact time of completion as well as the effect on overall project quality as maintained, increased and/or reduced.

The most common factor was the owner's requirements, as it has been noticed in all of the 10 cases, followed by the design errors and omissions, and regulatory requirements, as these two factors had appeared in 90% of the analyzed projects. Whereas cost saving, value engineering and operator's requirements were the only cases which had an operator involved within the projects entities; hence, all the projects that had a specialized operator involved, registered design changes were seen as a result of the operators requirements.

6. Devolving and testing hypothesis

In conjunction with the research objectives, a number of research hypotheses were developed and tested as follows:

6.1 Comparison between public and private sector viewpoints related to factors ranking

Hypothesis 1

H0. Assessment of the factors causing design changes and their impacts on construction projects in Jordan are similar in the public and private sectors.

H1. Assessment of the factors causing design changes and their impacts on construction projects in Jordan differ in the public and private sectors.

T-test was used to test Hypothesis 1 as shown in Table 3 which lists the results of the independent samples test and its related significance at 0.05 level:

All calculated significance levels indicates a failure to reject the null hypothesis (study hypothesis) as the values were >0.05 meaning that there are no statistical differences in assessing the design change factors between the private and public sectors.

6.2 Comparison between owners, consultants and contractors viewpoints related to factors ranking

The one-way ANOVA is used to determine whether there are any significant differences between the means of two or more independent (unrelated) groups. To test the degree of agreement between the owners, consultants and contractors in ranking the design change factors, the following hypothesis was tested:

Hypothesis 2

H0. Assessment of factors causing design changes and their impacts on construction projects in Jordan is mutually agreed among contractors, consultants and clients.

Table 3.
T-test (independent samples test) results according to the sector variable (public and private)

		Sig.	Sig. (2-Tailed)	Mean difference	95% confidence interval of the difference Lower	Upper
Cost-savings	Equal variances assumed	0.979	0.404	0.1240	−0.1682	0.4161
	Equal variances not assumed		0.412	0.1240	−0.1744	0.4223
Owners-requirements	Equal variances assumed	0.421	0.019	0.3583	0.0586	0.6580
	Equal variances not assumed		0.021	0.3583	0.0555	0.6612
Operators-requirements	Equal variances assumed	0.702	0.495	0.1125	−0.2119	0.4369
	Equal variances not assumed		0.468	0.1125	−0.1933	0.4183
Late-involvement-specialists	Equal variances assumed	0.502	0.414	−0.1365	−0.4651	0.1922
	Equal variances not assumed		0.406	−0.1365	−0.4611	0.1882
Value-engineering	Equal variances assumed	0.486	0.280	−0.1781	−0.5020	0.1457
	Equal variances not assumed		0.259	−0.1781	−0.4895	0.1333
End-user	Equal variances assumed	0.252	0.866	−0.0271	−0.3428	0.2886
	Equal variances not assumed		0.858	−0.0271	−0.3258	0.2716
Design-errors	Equal variances assumed	0.721	0.634	0.0802	−0.2513	0.4117
	Equal variances not assumed		0.638	0.0802	−0.2571	0.4176
Discrepancies	Equal variances assumed	0.735	0.462	−0.1271	−0.4669	0.2127
	Equal variances not assumed		0.474	−0.1271	−0.4782	0.2240
Incomplete-design	Equal variances assumed	0.393	0.759	−0.0500	−0.3699	0.2699
	Equal variances not assumed		0.745	−0.0500	−0.3534	0.2534
Constructability	Equal variances assumed	0.317	0.088	−0.2656	−0.5712	0.0400
	Equal variances not assumed		0.080	−0.2656	−0.5639	0.0327
Market-requirements	Equal variances assumed	0.666	0.839	−0.0354	−0.3777	0.3068
	Equal variances not assumed		0.835	−0.0354	−0.3715	0.3007
Regulatory	Equal variances assumed	0.131	0.493	0.1219	−0.2278	0.4715
	Equal variances not assumed		0.470	0.1219	−0.2112	0.4550
Unforeseen	Equal variances assumed	0.685	0.604	−0.0917	−0.4389	0.2556
	Equal variances not assumed		0.604	−0.0917	−0.4412	0.2578
Tech0logical	Equal variances assumed	0.307	0.698	−0.0604	−0.3662	0.2454
	Equal variances not assumed		0.673	−0.0604	−0.3436	0.2227
Unavailability-of-materials	Equal variances assumed	0.703	0.907	−0.0229	−0.4072	0.3614
	Equal variances not assumed		0.908	−0.0229	−0.4147	0.3689

H1. Assessment of factors causing design changes and their impacts on construction projects in Jordan widely differ among contractors, consultants and clients.

Table 4 shows the results of the one-way ANOVA test, and its related significance at 0.05 levels. All of the calculated significance values indicated that we failed to reject the null hypothesis (study hypothesis) as the values were less than 0.05, except for two out of the 15 factors, meaning that there are no statistical differences in assessing the design change factors among the clients, consultants and contractors except for two factors which are "Late involvement of Owner's specialists" and "Design errors and omissions".

The factor "Late involvement of Owner's specialists" has been highly ranked by most respondents from the owner's side in most of the cases. This is due to: the owner postpones the involvement of certain specialists until later stages which might be after the construction phase had started, and the involved specialist that might have additional requirements which were not included in the original design which will impose changes and modifications and in some cases it results in rework.

On the other hand, the factor "Designs errors and omissions" was highly ranked by respondents from the contractor's side. The main cause is the lack of quality of the design documents which clearly can be concluded from Love *et al.*, 2009 According to the values shown in Table 5, there has been an agreement in ranking the highest six factors among the 15 main factors for both sectors, however different ranking orders were made.

Multiple linear regression was used to test the impact of the design change factors, considering the design change factors as independent variables, and the three dependent variables being the cost, time and quality. Two tests have been used to check the adequacy of the data for multiple linear regression; the normality distribution of the independent variable and the multicolinearity among the independent variables. The values of skewness indicate that the data distributions are close to the normal distribution as the values were ranging between (±1).

Variance inflation factors (VIF) is used to describe the existence of multicollinearity (correlation between predictors) in a regression analysis. The VIF results mentioned in Table 6 below ranged between (1.548) for the design change factor "Unavailability of materials" and (1.221) for the design change factor "Value engineering".

Anova Design change factor	*F*	Sig.
Cost saving by the owner	1.279	0.28
Owners requirement	0.222	0.802
Operator's requirements	0.423	0.656
Late involvement of owner's specialists	3.944	0.021
Value engineering	0.934	0.394
End-user requirements	1.186	0.307
Design errors and omissions	3.275	0.039
Discrepancies in contract documents	0.473	0.624
Incomplete design at tender stage	0.142	0.867
Improve constructability	1.043	0.354
Changes in market requirements	0.52	0.595
Regulatory requirements	2.319	0.101
Unforeseen conditions	1.116	0.329
Technological requirements	0.253	0.776
Unavailable materials	1.411	0.246

Table 4. One-way ANOVA for comparing the means of design changes factors according to the role variable

Table 5.
Highest ranked factors as seen by the different projects roles

Design change factors	Clients				Consultants				Contractors			
	Mean	SD	Frequency index	Rank	Mean	SD	Frequency index	Rank	Mean	SD	Frequency index	Rank
Late involvement of owner's specialists	3.84	1.14	76.82	1	3.321	1.128	66.24	4	3.333	1.088	66.74	5
Incomplete design at tender stage	3.841	0.888	76.82	2	3.752	1.123	75.04	1	3.737	1.157	74.74	1
Owner's requirement	3.386	0.895	67.72	3	3.44	1.049	68.8	3	3.505	1.091	70.1	3
Cost saving by the owner	3.341	0.776	66.82	4	3.56	1.031	71.2	2	3.364	1.054	67.28	4
Design errors and omissions	3.182	1.225	63.64	5	3.229	1.16	64.58	5	3.586	1.04	71.72	2
Value engineering	3.136	0.905	62.72	6	3.138	1.158	62.76	6	3.333	1.143	66.66	6

6.3 Impact of factors causing design change on project's cost

Multiple linear regression was used to test the impact of the design change factors on the project's cost, using stepwise method. The differences in the impact on cost between various design change factors was tested using the following hypothesis:

Hypothesis 3

H0. The impacts of design changes on project cost significantly differ for varying design change factors.

H1. The impacts of design changes on project cost do not significantly differ for varying design change factors.

The results of multiple linear regression showed that 11 (out of 15) design change factors impacting the project cost were accepted in the regression model as shown above in Table 7, where a value of (67.6%) for R2 is considered to be good. The significance value of the indicator *F* was (0.000) which suggests the acceptance of the model (the sig value was <0.05), therefore the independents in the model could be accepted (statistically). It can be seen that the design change factor "Owners-Requirements" recorded the highest impact value of (β = 0.114) while the design change factors "Unforeseen Conditions, Cost Savings by the Owner, Improving the Constructability of the Project" recorded the least impact value of (β = 0.047), all beta coefficient values obtained are considered statistically important as they were <0.05 which is shown by the significance level (that is related to the *t*-test).

Based on the significance value related to *F*-test, the null hypothesis is rejected and alternative one is accepted.

The additional cost that resulted from design changes in each case was analyzed. For each case, the factors that had an impact on the cost were selected, the impact was calculated as a percentage from the base contract amount, and the contribution of each factor to the total cost of design changes in the project.

As a result from the case studies; the owner's requirement has been the main contributing factor to the cost of design changes in 9 out of 10 of the cases, followed by the value engineering, as this factor has been identified in 5 out of 10 cases as a factor leading to design changes with a significant cost impact. The effect of the design changes that resulted from market requirement had a sever effect on the project's cost and caused 53% of the additional cost of design changes in this project. Despite other factors that had cost implications in 9 out of 10 cases their cost impact found to be small in relevance of the other factors' impact. These

Design change causes	Tolerance	VIF
Cost savings by the owner	0.750	1.333
Owner's requirements	0.714	1.400
Operator's requirements	0.754	1.326
Late involvement of owner's specialists	0.815	1.227
Value engineering	0.819	1.221
End-user requirements	0.724	1.381
Design errors and omissions	0.721	1.387
Discrepancies in contract documents	0.692	1.446
Incomplete design at tender stage	0.813	1.230
Improving the constructability of the project	0.789	1.267
Changes in market requirements	0.692	1.445
Regulatory requirements	0.659	1.518
Unforeseen conditions	0.773	1.293
Technological requirements	0.761	1.313
Unavailability of materials	0.646	1.548

Table 6. Colinearity diagnosis for the design change factors using VIF and tolerance tests

Design change factor	Model goodness indicators r	R^2	F	Sig(f)	B	Coefficients s.e	t	Sig(t)
Impact of design change factors on the project cost								
Owners-requirements	0.822	0.676	45.45	0.000	0.114	0.019	6.077	0.000
Incomplete design at tender stage					0.085	0.019	4.612	0.000
Unavailability-of-materials					0.064	0.017	3.723	0.000
Value-engineering					0.063	0.019	3.293	0.001
Design errors and omissions					0.056	0.019	2.906	0.004
Changes in market requirements					0.055	0.018	3.126	0.002
Technological requirements					0.055	0.020	2.742	0.007
Regulatory requirements					0.051	0.019	2.706	0.007
Unforeseen conditions					0.047	0.019	2.505	0.013
Cost savings by the owner					0.047	0.019	2.427	0.016
Improving the constructability of the project					0.047	0.019	2.427	0.016
Impact of design change factors on the project duration								
Regulatory requirements	0.794	0.631	37.25	0.000	0.090	0.022	4.071	0.000
End-user requirements					0.083	0.022	3.770	0.000
Incomplete design at tender stage					0.067	0.021	3.156	0.002
Late involvement of owner's specialists					0.067	0.023	2.954	0.003
Unavailability of materials					0.066	0.020	3.317	0.001
Design errors and omissions					0.066	0.020	3.317	0.001
Changes in market requirements					0.065	0.022	2.987	0.003
Discrepancies in contract documents					0.062	0.022	2.859	0.005
Improving the constructability of the project					0.060	0.020	2.940	0.004
Owners-requirements					0.060	0.020	2.940	0.004
Technological requirements					0.057	0.023	2.444	0.015
Impact of design change factors on the project quality								
Cost savings by the owner	0.579	0.335	20.55	0.000	0.141	0.034	4.162	0.000
End-user requirements					0.129	0.035	3.709	0.000
Value-engineering					0.087	0.033	2.685	0.008
Unavailability of materials					0.077	0.028	2.750	0.006
Design errors and omissions					0.073	0.034	2.171	0.031
Discrepancies in contract documents					0.065	0.033	1.975	0.049

Table 7.
Multiple linear regression for testing the impact of design change factors on the project cost, duration and quality

findings are summarized in Table 8 which shows factors that caused the design changes with the highest cost implications.

6.4 Impact of factors causing design change on project's duration

The differences in the impact on time between various design change factors was tested using the following hypothesis:

Hypothesis 4

H0. The impacts of design changes on project time significantly differ for varying design change factors.

H1. The impacts of design changes on project time do not significantly differ for varying design change factors

The results of multiple linear regression shown in Table 7 above indicated that 11 (out of 15) design change factors impacting the project duration were accepted in the regression model, where a value of (63.1 %) for R^2 is considered to be good. It can be seen that the design change

Design change factor		Case A	B	C	D	E	F	G	H	I	J
Additional total cost of design changes		14.4%	15.5%	75%	31%	9.6%	12%	25%	20%	14.4%	14.2%
Main factors leading to design	Cost saving									25%	
	Owners requirement	32%	65%	97%	43%	66%	60%	65%	62%	13%	
	Operator's requirements							22%			23%
	Late involvement of owner's specialists	16%									
	Value engineering	21%	14%						13%	31%	49%
	Design errors and omissions						28%				
	Changes in market requirements				53%			7%			
	Regulatory requirements					25%			17%		

Table 8. Main design change factors with the highest cost implications from the cases

factor "Regulatory Requirements" recorded the highest impact value of (0.090) while the design change factor "Technological Requirements" recorded the least impact value of (0.057). Based on the sig value related to F-test, the null hypothesis is rejected.

As for the 10 cases that were analyzed, the time overrun was identified as a percentage of the original contract duration. The reasons of the delays were either extracted directly from the registered time claims and project documents, or obtained by direct interviews. It was noted that the main common factors among the cases were disrupting the sequence of works and in putting the progress on hold and time wasted in coordinating the new changes and requirements between all parties.

6.5 Impact of factors causing design change on project's quality

The differences in the impact on quality between various design change factors were tested using the following hypothesis:

Hypothesis 5

H0. The impacts of design changes on project quality significantly differ for varying design change factors.

H1. The impacts of design changes on project quality do not significantly differ for varying design change factors.

The results of multiple linear regression shown in Table 7 above indicated that six (out of 15) design change factors impacting the project quality were accepted in the regression model, where a value of (33.5%) for R2 is considered to be low. It can be seen that the design change factor "Cost Savings by the Owner" recorded the highest impact value of (0.141) while the design change factor "Discrepancies in contract documents" recorded the least impact value of (0.065).

The analysis of the case studies in terms of quality was done by examining the effect of each design change, and assessing whether the design change affected the quality positively or negatively, or had no impact on the quality standards compared to the original design with respect to the variation orders.

Results of the analysis show that the impact on quality was associated with the factors that are involved in changes to the scope or functions of the project, or changes to the materials used, with the intention of the owner and the operator to improve the end product of the design.

Value engineering has a positive impact on quality. On the other hand, changes made on the design with the purpose of reducing the cost have shown negative impacts on quality.

The analysis of the cases assessed the frequency or level of occurrence of the factors in each case, owner requirements was the main factor to appear as a cause of design changes during the construction phase, which was involved in more than 50% of the total number of variation orders that involved design changes, followed by the design errors and omissions and the value engineering.

The impact ranking of design change factors on cost, time and quality were identified to assess the impact of each factor of the design change. The ranking of the factors based on the average cost impact from case studies was tested. It was not possible to assess the time impact of each design change factor due to lack of sufficient documentation. It can be attributed that design changes are usually accompanied with delays due to: disrupting the sequence of works and putting the progress on hold, delay in issuing the revised issued for construction drawings implementing the design change, and delays due to permits and authorities' approvals and time wasted in coordinating the new changes and requirements between all parties.

Factors with the highest impact on the project's cost were found to be the owner's requirement and the changes in market requirements, while the factors with the least significant impact were the poor coordination between design disciplines and unavailability of materials.

The quality impact ranking of design change factors was evaluated and examined earlier, three main factors were found to have a positive impact on quality, and these were as follows: owner's requirement, value engineering and operator's requirements, while two factors found to be having a negative impact on the quality which were cost saving and changes in market requirements.

It can be seen from Figure 2 that the factors "design errors and omissions" and "unavailability of materials", were found to be affecting the main three performance aspects all together according to the analysis of the questionnaire data.

Figure 3 demonstrates the relationship between the cost and quality negative impacts of the main design change factors as per the case studies.

In order to assess whether there is a difference between the results of the two methods in ranking the factors, Spearman rank test was used. The results of the test indicated that there are no significant differences. It can be seen from Table 9, which shows the difference between the rankings in terms of frequency, that some factors had a significant difference in ranking. Such differences can be attributed to the documentation and justifications of the variation orders issued.

7. Conclusion

The first objective of this research which is identifying the main factors leading to design changes during the construction phase of the project was achieved using two different methods: statistical analysis of a survey questionnaire data that was collected from 252 professionals from different construction sectors, and by analyzing real case studies of construction projects in Jordan.

The analysis of the questionnaire data was conducted in order to rank the causative factors of design changes from the perspectives of private and public sectors.

The compatibility between the different construction parties and sectors were tested using T-test and one-way ANOVA. This has been followed by applying the multiple linear regression tests to investigate the severity of each factor on cost, time and quality, separately. Accordingly, the overall view point ranking obtained.

The second objective of this research was to investigate the impacts of design changes factors on project performance, the factors were ranked based on their effect on cost, time and quality. Furthermore, the top factors affecting these three aspects were selected; these are as follows: design errors and omissions, unavailability of materials, incomplete design at tender

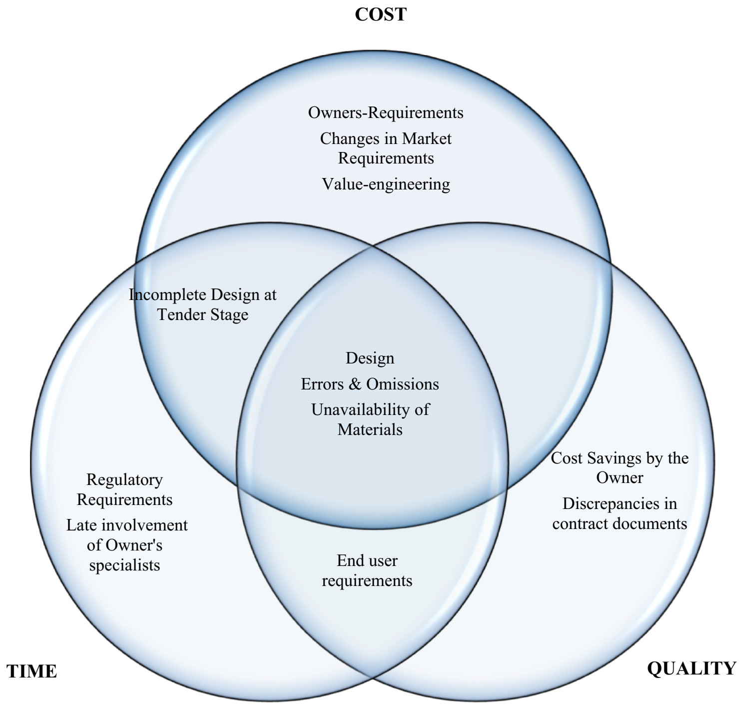

Figure 2.
Relationship between cost, quality and time negative impacts of main design change factors

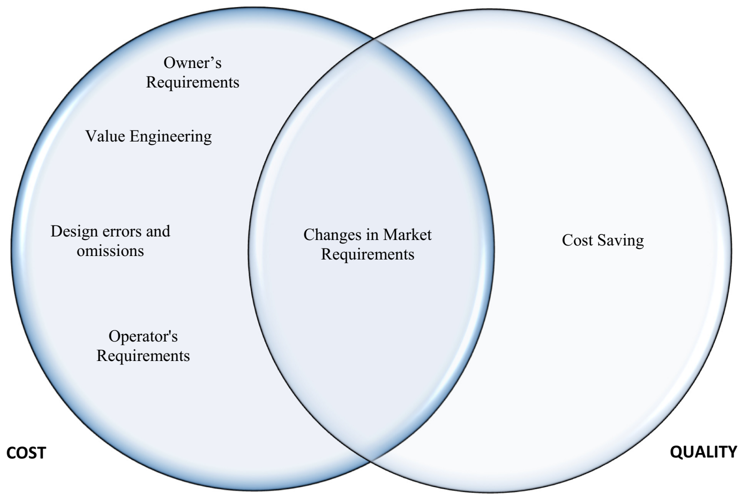

Figure 3.
Relationship between quality and cost negative impacts of main design change factors as per the case studies analysis

Table 9.
Comparison between questionnaire analysis and case studies analysis

Design change factors	Rank as per questionnaire data analysis	Rank as per case studies
Incomplete design at tender stage	1	7
Owner's requirements	2	1
Cost savings by the owner	3	5
Late involvement of owner's specialists	4	8
Design errors and omissions	5	2
Value engineering	6	3
Operator's requirements	7	6
Regulatory requirements	8	4
Unavailability of materials	9	12
Unforeseen conditions	10	11
Changes in market requirements	11	9
Improving the constructability of the project	12	N/A
Discrepancies in contract documents	13	11
End-user requirements	14	10
Technological requirements	15	N/A

stage, end-user requirements, owner's requirements, value-engineering and regulatory requirements. Similarly, the factors identified from the case studies with the most influence and severe impact on the performance indices were: owner's requirements, changes in market requirements, value engineering, design errors and omissions, operator's requirements and cost saving by the owner.

Although there were differences in ranking the main factors between the questionnaire analysis and the real case studies as shown above, three causative factors of design changes were common between the two which are: "Design errors and omissions", "Owner's requirements" and "Value engineering".

The "owner's requirement" was identified as the main contributor of the cost overrun caused by design changes in nine out of ten real case studies as well as from the expert's feedback obtained during interviews, although only ranked as fifth by those responding to the conducted survey .

The results and conclusions reached in this research corresponded with the results established from similar studies conducted in other developing countries as shown in Table 10.

8. Recommendation

The research findings form a number of lessons to be learned which construction organizations and industry clients should address if design changes are to be reduced.

Table 10.
Similar findings from developing countries

#	Factor causing design changes	Similar studies
1.	Design errors and omissions	Vidalis *et al.* (2002); Love *et al.* (2009); Mohammad *et al.* (2012)
2.	Owner's requirements	Koushki *et al.* (2005), Love *et al.* (2009); Al-Najjar (2008); Mohammad *et al.* (2012)
3.	Regulatory requirements	Sweis *et al.* (2013); Peansupap and Cheang (2015)
4.	Incomplete design at tender stage	Vidalis *et al.* (2002); Al-Najjar (2008); Peansupap and Cheang (2015)
5.	Unavailability of materials	Peansupap and Cheang (2015); Chen (2015)
6.	End-user requirements	Love *et al.* (2009)

These include

(1) When selecting design consultants (architects and engineers), clients are advised to pay more attention to the quality of the previous designs, the understanding of the firm to the needs and requirements of the client, and the firm's capability to meet the project design time and cost constraints.

(2) Clients and consultants may consider getting the contractor and operator (Facility Manager) involved earlier in the design phase.

(3) Structured change management control should be implemented resulting in the clear impact assessment of each change in terms of cost, time and quality prior to issuing the change order

(4) The construction industry in Jordan may consider the "Building information modelling" software, which will control and significantly minimize the project and design related factors; design errors and omissions.

(5) Undertaking market assessments and feasibility studies along with economic studies prior to the design phase.

In view of the limited research studies done on the subject of design changes in Jordan specifically and in developing countries in general, the research methodology followed in this study can be well replicated by other researchers from other parts of the world, especially the case study's method to determine specific factors during the construction phase of the project, and integrate the outcomes with the findings of this study.

The research presented in this study has tackled a number of subjects that are worthy of further investigation. These include

(1) Developing causal models that can be used to describe the factors that lead to design changes so that responsibility can be assigned.

(2) Examine the design related issues that influences design changes during construction.

(3) Develop a systematic methodology to assess the indirect impact of design changes in terms of cost, time and quality.

To sum up, this research provided valuable insights and findings that can be further analyzed by researchers in order to either validate the research outcomes or to focus on the main factors to find possible remedies.

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