Journal of Civil Engineering and Architecture 17 (2023) 57-72
doi: 10.17265/1934-7359/2023.02.001

Causes, Effects, and Control Measures of Construction Change Orders in the U.S.

Ahmed Redha Gheraba[1], Clifford B. Fedler[1], Debajyoti Pati[1], Marcelo Schmidt[1], Mukaddes Darwish[1], Ali Nejat[1] and Bill Wade[2]

1. Department of Civil, Environmental, and Construction Engineering, Texas Tech University, Box 41023. Lubbock, TX 79409, USA

2. Facilities, Planning, and Management, Southern Methodist University, 6116 N. Central Expressway Ste 808. Dallas TX 75206, USA

Abstract: Change orders have a significant impact on many aspects of construction projects. They are known to be the primary cause of litigation in the construction industry. Change orders are almost inevitable due to the uniqueness of each project from many perspectives, such as the type of building, complexity of the design, human factors, and the available resources. Change orders are the formal mechanism to implement design changes during the execution phase. These changes are usually the outcome of lack of visualization by the owner, misunderstanding, miscommunication between different parties involved in the project, shortage in resources, and other factors. This research aims to investigate and rank causes, effects, and control measures of change orders in the construction industry in the U.S. This research presents the results of a questionnaire surveying owners, contractors, and consultants. A total of 123 industry professionals in the Architecture, Engineering, and Construction (AEC) field, with either significant or final decision-making authority on reviewing, issuing, and approving change orders responded to the survey. Results indicated that owners are the primary source followed by consultants and contractors, respectively. Some of the more important control measures identified in this research are collaboration and visualization technologies.

Key words: Construction change orders, architectural visualization, decision making process, construction management, construction technology, BIM, interior environmental design, virtual reality.

1. Introduction

The complexity and uniqueness of construction projects makes it almost impossible to complete any project without changes [1]. Change orders are the result of a combination of factors leading to a deviation from the original scope of work [2]. Construction projects include several phases from strategic planning to the project closeout. The main parties involved in a construction project are usually owner(s), constant(s) and contractor(s). These major players are required to make critical design and budgetary decisions throughout the entire project lifecycle. Most of the important design and financial decisions are made prior to completing and issuing the construction documents. In many instances decisions are made based on assumption, personal experience, and imagination. There are many reasons that might trigger change orders during the construction phase of a project. The reasons might vary from project to project, depending on the nature of the project (residential, commercial, healthcare, etc.), the complexity of the architectural program, and the engineering systems integrated in the project. Sadi and Sadiq [3] stated that it rarely happens that a construction project is completed within the specified schedule. The reasons can be, but not limited to: the performance of parties involved, resources availability, environmental conditions, involvement of other parties, and contractual relations. Change orders usually result in disputes and dissatisfactions between all involved parties due to the delay in schedule and the additional cost [4]. In this study, change orders are defined as any

Corresponding author: Ahmed Redha Gheraba, Ph.D., research fields: Decision making process in the AEC industry, virtual reality application in the design and construction field, artificial intelligence and machine learning in construction, the build environment and human behavior.

deviation from the original scope of work during the construction phase that may impact the overall project budget or schedule [5].

1.1 Research Objective

The aim of this study is to investigate and rank the causes, effects, and control measures of change orders in the United Stated of America.

1.2 Research Questions

(1) What are the most important change order causes?

(2) What are the most important change orders effects?

(3) What are the most important control measures that should be implemented to minimize change orders in construction projects?

(4) Who is the main responsible player for causing change orders?

(5) Does the implementation of Building Information Modeling (BIM) help in minimizing change orders?

(6) Does the implementation of Virtual Reality (VR) technology help in minimizing change orders?

1.3 Research Scope

This research encompasses the following design disciplines, architecture, civil engineering, mechanical engineering, electrical engineering, interior design, and audio-visual building technologies. The sampling frame for consultants and design professionals was the American Institute of Architects (AIA), the American Society of Civil Engineers (ASCE), and a random selection of design companies. The scope of the research also includes general contractors and sub-contractors from different trades. The survey was sent to a random selection of top 100 GCs in the U.S. as well as the Associated General Contractors (AGC) of North America. The scope of the research also included owners and owners' representatives; the survey was distributed to members of the Association of Physical Plant Administrators (APPA). The survey was also sent to a list of randomly selected universities and health care institutions physical plant departments.

2. Method

2.1 Instruments

To identify the most important change orders causes, their effects, and the potential control measures, a survey was designed based on literature findings in the AEC field, mostly in complex public projects.

First, a thorough literature review was conducted to identify all factors triggering change orders as well as their effects and the potential control measures. Second, the survey draft was organized as follows: demographic information, change orders causes, effects, and control measures.

The initial survey was then presented to experts in the AEC field to collect feedback on both content and technical language of the survey. The initial survey was presented only to experts with a minimum of twenty years of experience. All of the participants were either registered architects or professional engineers holding key positions within their organizations with significant or final decision-making authority on issuing, reviewing, and approving change orders.

The change order section of the survey is mainly composed of Internal Environment (IE) factors known as owner, consultant, and contractor. Other factors are also included in the causes section, such as Input Factor (IF) and Exogenous Factor (EF). The IF factors identified are labor, material and equipment, while the EF factors are weather and new regulations.

The same strategy was implemented for the change orders effects section—this section comprised five effects that emerged from pertinent scholarly literature as well as the AEC expert's input and recommendations. The identified effects are delay in schedule, delay in payments, decrease in productivity of workers, decrease in quality of work, and increase in the overall cost of the project.

The control measure section included eight of the most relevant control measures found in the literature review and recommended by the AEC expert. BIM and VR were also added to this section.

The next section of the survey comprised two sets of questions, both intended to assess familiarity and experience in using BIM and VR, presented as follows: Are you familiar with the BIM delivery process?

If the participant answers NO, then they will skip to the next sets of questions. If the respondent's answer is YES, then they were asked: How familiar are they with the BIM delivery process? And, how often have they used BIM in the past five years? Answers to both questions are recorded on five-point Likert scales that will be explained in detail on the data analysis section.

The second set of questions on VR familiarity and experience is slightly different from the first set. If the respondent's answer is YES to the first question which is: Are you familiar with the VR technology used in the AEC industry? Then the respondents will be given the opportunity to indicate their level of familiarity on a Likert scale, the respondents will then be asked if they have used VR in the past five years.

The final section of the survey included one open-ended question asking respondents to outline the most important measures that should be implemented in order to minimize and prevent change orders in construction projects.

2.1.1 Survey Validity and Reliability

The validity of this research lays on the quality of its instruments, more precisely on how well instruments measure what they intended to measure. Hence, the questionnaire was designed to extract meaningful information relevant to answering the research questions. Coefficient of correlation between questions and outcome variables in each section of the survey indicated a high level of logic matching between respondents toward the questionnaire.

The construct validity in this research is mainly concerned with how well the survey measures what it was designed to measure. The research team tried to minimize the threats to construct validity by avoiding the following:

- Hypothesis guessing: no clues were given to the respondent to guess what the research desired end-result is.
- Bias: all parties normally involved in a construction project were included in the research.
- Research expectations: no desired effect was mentioned in the survey.

The survey was designed to answer all the research questions and represent all facets of the given constructs. Furthermore, the survey was reviewed by experts to complete missing items for an optimum coverage of the addressed objective.

The research used the same questionnaire structure in many peer reviewed journal articles addressing similar questions to this research. All AEC experts confirmed that the survey "appears" to measure what is it intended to measure.

All the research variables have been represented by appropriate criterion in the questionnaire. The review phase of the questionnaire revealed that the survey has a good predictive validity as most of the questions expressed a good degree of operationalization that can measure the same constructs in the final survey.

This research was designed and intended to include all design disciplines, construction delivery methods, and all major parties involved in construction projects—this was achieved through a stratified random sampling strategy by defining the theoretical population, which is all AEC professional representing owners, consultants, and contractors. The accessible population was defined by selecting the appropriate sampling frame as discussed earlier.

To ensure all subparts of the survey measure the same characteristic, Cronbach's alpha was used to check for internal consistency.

Principal Components Analysis (PCA) with varimax rotation was used for both causes and control measures sections of the survey as a grouping and data reduction tool. It has been reported that there are no strict rules regarding sample size for PCA, and empirical research has revealed that adequate sample size is partly determined by the nature of the data [6, 7]. In factor analysis, "strong data" means homogeneously high communalities without cross loadings, in addition to several variables loading strongly on each factor [8, 9].

The 123 sample subjects were analyzed via PCA at a 6:1 and 12:1 subject to item ratios for causes and control measures, respectively. The results of the factor analysis produced four factors, and all the items loaded on the correct factors. For example, in the causes section of the survey, all owner related causes loaded together on a single factor, all consultant related causes loaded together on a single factor, all contractor related causes loaded together on a single factor, and all the other causes loaded in a single factor, with the exception of one item that cross loaded incorrectly which was the "undefined scope". These results are perfectly in line with the data as shown in Table 1 and Table 2.

2.1.1.1 Factor Analysis Output for Change Orders Causes

Nineteen questions relating to change order's causes factors were analyzed using PCA with varimax (orthogonal) rotation. The analysis produced four factors explaining a total of 62.33% of the variance for the entire set of variables. Factor 1 was labeled other as it relates to labor; equipment; material testing; new regulation; safety; weather; and construction procedures. This first factor explained 35% of the variance. The second factor derived was related to contractors. This factor was labeled as such due to the high loadings by the following factors: errors made by the contractor, unfamiliarity and or negligence of the existing condition; poor planning by the contractor; inaccurate cost estimate; unforeseen conditions. The variance explained by this factor was 10%. Factor 3 was labeled consultants as it relates to poor construction drawings and lack of details, errors and omissions in design, and conflict between contract documents such as construction drawings vs. specifications. This factor explained 9% of the variance. Factor 4 was labeled owner as it relates to change in scope by owner, change in design by owner, and owner's change in schedule. This factor explained 7% of the variance.

The communalities of the variables included are rather high overall with one variable (safety consideration) having a small amount of variance (39%) in common with the other variables in the analysis. This indicates that the variables chosen for this analysis are only strongly related with each other. The KMO and Bartlett's Test of Sphericity both indicate that the set of variables are strongly and adequately related for factor analysis. Practically, this means that we have identified four clear patterns of response among "causes, effects, and control measures of changes orders" respondents.

2.1.1.2 Factor Analysis Output for Change Orders Control Measures

Ten questions relating to change order's control measures factor were analyzed using PCA with varimax (orthogonal) rotation. The analysis produced three factors explaining a total of 64.61% of the variance for the entire set of variables. Factor 1 was collaborative review as it relates to collaboration between all parties at all project stages, review of the design by all parties, and review of change orders by knowledgeable individuals. This first factor explained 33% of the variance. The second factor derived was related to change order's procedures. This factor was labeled as such due to the high loadings by the following factors: any change order should be addressed by knowledgeable individuals, change order procedure should be explained in the contract document, and scope of change should be made clear. The variance explained by this factor was 18%. Factor 3 was labeled organizational methods and collaborative technologies as it relates to WBS, BIM, and VR. This factor explained 11% of the variance.

Table 1

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin measure of sampling adequacy		0.823
Bartlett's test of sphericity	Approx. Chi-square	962.805
	df	171
	Sig.	0

Rotated Component Matrix	Component 1	2	3	4	Communalities
1. Lack of appropriate construction equipment	0.795				0.633
2. Insufficient and/or inaccurate materials testing	0.747				0.797
3. New regulations	0.745				0.83
4. Safety consideration	0.672				0.397
5. Weather conditions	0.67				0.548
6. Lack of skilled labor	0.637				0.795
7. Change in construction procedure	0.547				0.416
8. Errors made by contractor		0.796			0.623
9. Unfamiliarity and/or negligence of the existing condition		0.779			0.554
10. Poor planning by the contractor		0.736			0.63
11. Inaccurate cost estimate		0.615			0.637
12. Unforeseen conditions		0.598			0.517
13. Poor construction drawings and lack of details			0.899		0.74
14. Errors and omissions in design by the design team			0.853		0.613
15. Conflict between contract documents (construction drawings vs. specifications)			0.581		0.569
16. Change of the project scope by owner				0.88	0.739
17. Change in design by owner				0.78	0.571
18. Owner's change in schedule				0.66	0.606

PCA

Comp	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	6.672	35.114	35.114	6.672	35.114	35.114	3.979	20.942	20.942
2	2	10.525	45.638	2	10.525	45.638	3.444	18.128	39.07
3	1.728	9.097	54.735	1.728	9.097	54.735	2.26	11.893	50.963
4	1.444	7.597	62.333	1.444	7.597	62.333	2.16	11.37	62.333
5	0.943	4.963	67.296						
6	0.884	4.654	71.95						
7	0.806	4.241	76.191						
8	0.758	3.988	80.179						
9	0.586	3.082	83.261						
10	0.501	2.638	85.9						
11	0.477	2.51	88.41						
12	0.433	2.278	90.688						
13	0.386	2.031	92.719						
14	0.294	1.549	94.268						
15	0.287	1.51	95.779						
16	0.223	1.175	96.953						
17	0.208	1.095	98.049						
18	0.198	1.04	99.088						
19	0.173	0.912	100						

Extraction Method: PCA.

Table 2

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin measure of sampling adequacy		0.751
Bartlett's test of sphericity	Approx. Chi-square	355.17
	df	45
	Sig.	0

Rotated Component Matrix	Component 1	Component 2	Component 3	Communalities
1. Contract documents should be reviewed by all parties involved in the project—gray areas should be highlighted, clarified, and agreed upon prior to construction	0.722	0.087	0.158	0.554
2. Owner, design professionals, and contractor should be involved in all project phases	0.712	0.229	-0.04	0.561
3. Any change order should be addressed and negotiated by knowledgeable individuals	0.823	0.067	0.054	0.685
4. Change orders procedures should be explained in the contract documents	0.488	0.087	0.515	0.51
5. The scope of change should be made clear and issued by the design professionals	0.392	-0.09	0.637	0.567
8. BIM should be implemented in all project phases	0.201	0.873	-0.07	0.809
9. Immersive VR technology should be implemented during the design phase	0.068	0.895	0.052	0.808
10. WBS (work breakdown structure) should be used in complex projects	0.126	0.792	0.051	0.646

Total Variance Explained

Comp	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.388	33.878	33.878	3.388	33.878	33.878	2.752	27.517	27.517
2	1.883	18.834	52.712	1.883	18.834	52.712	2.29	22.897	50.414
3	1.191	11.906	64.618	1.191	11.906	64.618	1.42	14.204	64.618
4	0.898	8.985	73.603						
5	0.677	6.766	80.37						
6	0.51	5.103	85.473						
7	0.465	4.646	90.119						
8	0.41	4.1	94.219						
9	0.347	3.473	97.692						
10	0.231	2.308	100						

Extraction Method: PCA.

The communalities of the variables included are rather high overall with one variable. This indicates that the variables chosen for this analysis strongly related with each other. The KMO and Bartlett's Test of Sphericity both indicate that the set of variables are strongly and adequately related for factor analysis. Practically, this means that we have identified three clear patterns of response among "causes, effects, and control measures of changes orders" respondents.

Internal consistency: causes a subscale that consisted of 19 items (α = 0.88), which means good internal consistency and is an indicator of the reliability of this survey section.

Cronbach's alpha for the other's related causes: The other's subscale consisted of 7 items (α = 0.86), which is a strong indicator of the reliability of this group of questions used to measure the owner's causes construct.

Cronbach's alpha for contractor's related causes: The contractor's subscale consisted of 5 items (α = 0.81), this means that this section fulfills a good internal consistency, which is an indicator of the good reliability of these questions.

Cronbach's alpha for consultant's related causes: The consultant's subscale consisted of 3 items (α = 0.80), this means that this section of the survey satisfies a good internal consistency.

Cronbach's alpha for the effects: the effects subscale consisted of 5 items (α = 0.74), this means good internal consistency, which is an indicator of the reliability of this survey section.

Cronbach's alpha for the control measures: the control measures subscale consisted of 10 items (α = 0.74), this means a good internal consistency, which is an indicator of the reliability of this survey section.

Cronbach's alpha for factor 1 collaborative review: this subscale of the control measures survey consisted of 3 items (α = 0.75), this means that this section of the survey satisfies a good internal consistency.

Cronbach's alpha for factor 2 change orders procedures and execution guidelines: This subscale of the control measures survey consisted of 2 items (α = 0.55), which is an indicator of the weak internal consistency between this subscale question. This might be due to the low numbers of items included in this subscale to measure the procedures and execution construct.

Cronbach's alpha for factor 3 organizational methods and collaborative technologies: the organizational methods and collaborative technologies subscale consisted of 3 items (α = 0.83), this good internal consistency, which is an indicator of the reliability of this group of questions used to measure the organizational methods and collaborative technologies construct.

The work outlined in this section is of utmost importance for the validation of the measurement tool used in this research. The literature review that addressed the same topic and used similar tools, only reported results of internal consistency, as opposed to using the exploratory factor analysis to provide evidence that the subscale questions truly belong to their groups or subscales.

2.2 Data Collection

The questionnaire was distributed to a random sample of AEC professionals representing owners, consultants, and contractors. A total of 123 AEC professionals completed the survey, more than 90% of the respondents indicated that they have either a significant or final decision-making authority on issuing, reviewing, and approving change orders, which can be interpreted as an indicator of profound understanding of all change orders aspects. The responses were collected through an online survey questionnaire.

The questionnaire is divided into six sections. Section one is related to demographics and general information on the respondents, section two includes causes of change orders, section three includes effects of change orders, section four lists the proposed control measures to minimize and eliminate change orders, section five measures the participants' familiarity with VR and BIM, and finally section six is an open-ended question asking participants to propose and outline the most important control measures from their perspective and according to their professional experience. All the causes, effects and control measures were selected from the prominent literature and experts' recommendations.

The "causes, effects, and control measures" survey was sent to entities representing owners, contractors, and consultants in the United States of America, such as the AIA, ASCE, APPA, and the Associated General Contractor of North America. Simultaneously, the survey was sent to a list of top 100 contractor and consulting firms. The survey was also sent to a list of Physical Plant departments of higher education and health care institutions. Responses were collected via an electronic survey tool.

2.3 Data Analysis

2.3.1 Ranking of Causes by Relative Importance Index (RII)

The Relative Importance Index technique is not only used to rank causes, but also to determine the contribution of each cause by itself as well as in combination with other causes on triggering change orders. Furthermore, Johnson and Le Breton [10] indicated that RII helps in determining the contribution of a particular variable on making predictions regarding a criterion variable, both by itself and in combination with other predictor variables. In this section RII, is used to rank causes as well as to predict the contribution of each cause in triggering change orders.

The RII formula used in this study is:

$$\mathrm{RII} = \frac{\sum W}{A * N}$$

- W is the weight given to each cause by the respondents and ranges from 1 to 5 (where "1" is "Very rarely" and "5" is "Very frequently");
- A is the highest weight (i.e. 5 in this case);
- N is the total number of respondents.

2.3.2 Chi Square for Goodness of Fit Test by RII

Chi Square is performed to check if the responses are significantly different (Tables 3 and 4). The logic of this test is to compare the proportion of observed or actual cases relative to the expected proportion of cases. For example, the expected frequency for the 113 respondents over 5 categories ranging from strongly agree to strongly disagree will be approximately 22 respondents for each of the 5 categories and the responses are equally distributed. This can be interpreted as non-significant as the observed data equal the expected data—which is not the case in this section of the questionnaire. Chi-square results for all the responses were statistically significant, $p < 0.05$, meaning that all recorded responses are significantly different from the expected responses.

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

O: the frequencies observed

E: the expected frequencies

Table 3 Ranking of change orders by RII.

Causes	N	Mean	SD	Variance	χ^2	RII	Rank
Change in design by owner	113	3.9	0.963	0.909	χ^2 (4, N = 113) = 3.9, p = 0.05	0.78	1
Change of the project scope by owner	113	3.51	1.053	0.997	χ^2 (4, N = 113) = 3.51, p = 0.05	0.70	2
Unforeseen conditions	113	3.35	0.823	0.547	χ^2 (4, N = 113) = 3.35, p = 0.05	0.67	3
Errors and omissions in design by the design team	113	3.13	1.013	0.979	χ^2 (4, N = 113) = 3.13, p = 0.05	0.63	4
Poor construction drawings and lack of details	113	2.96	1.101	1.215	χ^2 (4, N = 113) = 2.96, p = 0.05	0.59	5
Owner's change in schedule	113	2.88	1.108	1.141	χ^2 (4, N = 113) = 2.88, p = 0.05	0.58	6
Poor planning by the contractor	112	2.76	0.961	0.876	χ^2 (4, N = 112) = 2.76, p = 0.05	0.55	7
Conflict between contract documents	113	2.67	1.089	1.044	χ^2 (4, N = 113) = 2.67, p = 0.05	0.53	8
Inaccurate cost estimate	113	2.62	1.167	1.255	χ^2 (4, N = 113) = 2.62, p = 0.05	0.52	9
Errors made by contractor	111	2.54	0.942	0.844	χ^2 (4, N = 111) = 2.54, p = 0.05	0.51	10
Weather conditions	113	2.4	1.005	0.849	χ^2 (4, N = 113) = 2.4, p = 0.05	0.48	11
Unfamiliarity and/or negligence of the existing condition	112	2.3	1.03	0.955	χ^2 (4, N = 112) = 2.3, p = 0.05	0.46	12
Change in construction procedure	111	2.15	0.886	0.694	χ^2 (4, N = 111) = 2.15, p = 0.05	0.43	13
New regulations	112	2.01	0.963	0.881	χ^2 (4, N = 112) = 2.01, p = 0.05	0.40	14
Insufficient and/or inaccurate materials testing	111	1.95	0.883	0.77	χ^2 (3, N = 111) = 1.95, p = 0.05	0.39	15
Lack of skilled labor	112	1.89	0.924	0.829	χ^2 (3, N = 112) = 1.89, p = 0.05	0.38	16
Safety consideration	112	1.84	0.766	0.549	χ^2 (3, N = 112) = 1.84, p = 0.05	0.37	17
Lack of appropriate construction equipment	111	1.65	0.782	0.574	χ^2 (4, N = 111) = 1.65, p = 0.05	0.33	18

Table 4 Ranking of change order causes by group of factors and PCA results.

	Causes	N	Mean	SD	Variance	χ^2	RII	Rank
Owner	Change in design by owner	113	3.9	0.963	0.909	χ^2 (4, N = 113) = 3.9, p = 0.05	0.78	1
	Change of the project scope by owner	113	3.51	1.053	0.997	χ^2 (4, N = 113) = 3.51, p = 0.05	0.70	2
	Owner's change in schedule	113	2.88	1.108	1.141	χ^2 (4, N = 113) = 2.88, p = 0.05	0.58	6
Consultant	Errors and omissions in design by the design team	113	3.13	1.013	0.979	χ^2 (4, N = 113) = 3.13, p = 0.05	0.63	4
	Poor construction drawings and lack of details	113	2.96	1.101	1.215	χ^2 (4, N = 113) = 2.96, p = 0.05	0.59	5
	Conflict between contract documents	113	2.67	1.089	1.044	χ^2 (4, N = 113) = 2.67, p = 0.05	0.53	8
Contractor	Unforeseen conditions	113	3.35	0.823	0.547	χ^2 (4, N = 113) = 3.35, p = 0.05	0.67	3
	Poor planning by the contractor	112	2.76	0.961	0.876	χ^2 (4, N = 112) = 2.76, p = 0.05	0.55	7
	Inaccurate cost estimate	113	2.62	1.167	1.255	χ^2 (4, N = 113) = 2.62, p = 0.05	0.52	9
	Errors made by contractor	111	2.54	0.942	0.844	χ^2 (4, N = 111) = 2.54, p = 0.05	0.51	10
	Unfamiliarity and/or negligence of the existing condition	112	2.3	1.03	0.955	χ^2 (4, N = 112) = 2.3, p = 0.05	0.46	12
Other	Weather conditions	113	2.4	1.005	0.849	χ^2 (4, N = 113) = 2.4, p = 0.05	0.48	11
	Change in construction procedure	111	2.15	0.886	0.694	χ^2 (4, N = 111) = 2.15, p = 0.05	0.43	13
	New regulations	112	2.01	0.963	0.881	χ^2 (4, N = 112) = 2.01, p = 0.05	0.40	14
	Insufficient and/or inaccurate materials testing	111	1.95	0.883	0.77	χ^2 (3, N = 111) = 1.95, p = 0.05	0.39	15
	Lack of skilled labor	112	1.89	0.924	0.829	χ^2 (3, N = 112) = 1.89, p = 0.05	0.38	16
	Safety consideration	112	1.84	0.766	0.549	χ^2 (3, N = 112) = 1.84, p = 0.05	0.37	17
	Lack of appropriate construction equipment	111	1.65	0.782	0.574	χ^2 (4, N = 111) = 1.65, p = 0.05	0.33	18

2.3.3 Ranking of Causes by Responsibility

The ranking of different parties involved in a project relied on comparing the calculated means as well as the RII of each group (Table 5).

Table 5 Ranking of change orders by responsibility of each party involved in the project.

Causes	Mean	RII	Rank
Owner	3.43	0.69	1
Consultant	2.92	0.58	2
Contractor	2.71	0.54	3
Other	1.98	0.40	4

2.3.4 Ranking of Effects by RII

This technique is not only used to rank effects of change orders (Table 6), but also to determine the contribution of each effect by itself as well as in combination with other effects on construction projects.

2.3.5 Chi Square for Goodness of Fit Test by Responsibility

Chi-square results for all the responses were statistically significant, $p < 0.05$, meaning that all recorded responses are significantly different from the expected responses.

Table 6 Ranking of change order's effects on construction projects.

Effects	N	Mean	SD	Variance	χ^2	RII	Rank
Increase in the overall cost of the project	112	4.32	0.80	0.634	χ^2 (4, N = 112) = 4.32, p = 0.05	0.86	1
Delay in schedule	113	4.05	0.80	0.64	χ^2 (4, N = 113) = 4.05, p = 0.05	0.81	2
Delay in payments	111	3.59	1.04	1.08	χ^2 (4, N = 111) = 3.59, p = 0.05	0.71	3
Decrease in productivity of workers	113	3.23	0.96	0.929	χ^2 (4, N = 113) = 3.23, p = 0.05	0.64	4
Decrease in quality of work	113	2.84	0.91	0.832	χ^2 (4, N = 113) = 2.84, p = 0.05	0.56	5

2.3.6. Ranking of Control Measures by RII

This technique is not only used to rank change orders control measures, but also to determine the contribution of each control measure by itself as well as in combination with other measures to eliminating and reducing the number of change orders in construction projects (Table 7).

Table 7 Ranking of change order's control measures by RII.

Control measures	N	Mean	SD	Variance	χ^2	RII	Rank
Contract documents should be reviewed by all parties involved in the project—gray areas should be highlighted, clarified, and agreed upon prior to construction	113	4.65	0.563	0.317	χ^2 (3, N = 112) = 4.65, p = 0.05	0.93	1
Any change order should be addressed and negotiated by knowledgeable individuals	113	4.6	0.527	0.277	χ^2 (2, N = 112) = 4.46, p = 0.05	0.92	2
Owner, design professionals, and contractor should be involved in all project phases	113	4.52	0.628	0.395	χ^2 (2, N = 112) = 4.52, p = 0.05	0.90	3
Change orders procedures should be explained in the contract documents	113	4.52	0.599	0.359	χ^2 (2, N = 112) = 4.52, p = 0.05	0.90	4
The scope of change should be made clear and issued by the design professionals	113	4.49	0.733	0.538	χ^2 (3, N = 112) = 4.49, p = 0.05	0.90	5
WBS should be used in complex projects	112	3.86	0.938	0.88	χ^2 (4, N = 112) = 3.86, p = 0.05	0.77	6
BIM should be implemented in all project phases	113	3.5	1.103	1.216	χ^2 (4, N = 112) = 3.5, p = 0.05	0.70	7
Immersive VR technology should be implemented during the design phase	113	3.25	0.996	0.992	χ^2 (4, N = 112) = 3.25, p = 0.05	0.65	8

2.3.7. Ranking of the Grouped Control Measures

The ranking of the grouped control measures relied on comparing the calculated means as well as the RII of each group (collaborative review, change order procedures, and method & technologies) (Tables 8 and 9).

Table 8 Ranking of the proposed control measures groups.

Control Measures	N	Mean	SD	Variance	χ^2	RII	Rank
Contract documents should be reviewed by all parties involved in the project—gray areas should be highlighted, clarified, and agreed upon prior to construction	113	4.65	0.563	0.317	χ2 (3, N=112) = 4.65, P= .05	0.93	1
Any change order should be addressed and negotiated by knowledgeable individuals	113	4.6	0.527	0.277	χ2 (2, N=112) = 4.46, P= .05	0.92	2
Owner, design professionals, and contractor should be involved in all project phases	113	4.52	0.628	0.395	χ2 (2, N=112) = 4.52, P= .05	0.90	3
Change orders procedures should be explained in the contract documents	113	4.52	0.599	0.359	χ2 (2, N=112) = 4.52, P= .05	0.90	4
The scope of change should be made clear and issued by the design professionals	113	4.49	0.733	0.538	χ2 (3, N=112) = 4.49, P= .05	0.90	5
WBS should be used in complex projects	112	3.86	0.938	0.88	χ2 (4, N=112) = 3.86, P= .05	0.77	6
BIM should be implemented in all project phases	113	3.5	1.103	1.216	χ2 (4, N=112) = 3.5, P= .05	0.70	7
Immersive VR technology should be implemented during the design phase	113	3.25	0.996	0.992	χ2 (4, N=112) = 3.25, P= .05	0.65	8

Collaborative review   change order procedures   Methods and technologies

Table 9 Ranking of the proposed g roups of control measures.

Control measures	Mean	RII	Rank
Collaborative review	4.59	0.92	1
Change order procedures	4.5	0.90	2
Methods and technologies	3.53	0.71	3

2.3.8 *t*-Test Results between Groups with regard to BIM Familiarity

There was no significant difference between respondents who are familiar with BIM and respondents who are not in terms of BIM perceived importance (Table 10). For the familiar group (M = 3.58, SD = 1.14) and for the non-familiar group (M =3.26, SD = 0.94); $t(52) = 1.47$, $p = 0.15$.

2.3.9 *t*-Test Results between Groups with regard to VR Familiarity

The *t*-test was found to be significant between groups, indicating that there are significant differences between the respondents who are familiar with VR and respondents who are not in terms of their VR perceived importance. For the familiar group (M = 3.60, SD = 1.06) and for the non-familiar group (M = 2.89, SD = 0.77); $t(102.52) = 4.01$, $p < 0.05$.

2.3.10 Univariate Analysis of Variance Results with regard to the Respondent's Degree of Familiarity with BIM and Its Perceived Importance

The univariate analysis of variance results shows that there are no significant differences between the respondent's degree of familiarity with BIM, and its perceived importance as a control measure for change orders ($F(2, 83) = 1.36$, $p = 0.26$).

2.3.11 Univariate Analysis of Variance Results with regard to the Respondent's Degree of Familiarity with VR and Its Perceived Importance

The univariate analysis of variance results shows that there are no significant differences between the respondent's degree of familiarity with VR, and its perceived importance as a control measure for change orders ($F(2, 51) = 0.55$, $p = 0.57$).

2.3.12 Univariate Analysis of Variance Results with regard to the Respondent's BIM Frequency of Use and Its Perceived Importance

The one-way ANOVA test was found to be statistically significant, indicating that there are significant differences between respondents in terms of their frequency of using BIM on one hand and its perceived importance on the other hand ($F(2, 83) = 5.33$, p = 0.007). The ANOVA test was followed by a post hoc test in order to determine where the differences are between the groups of respondents. According to the Tukey HSD (honestly significant difference) post hoc test, respondents who use BIM very frequently have higher perceived importance for BIM as a control measure for change orders (M = 0.87, SD = 0.28).

2.3.13 Univariate Analysis of Variance Results with regard to the Respondent's VR Use in Their Projects and Its Perceived Importance

The one-way ANOVA test was found to be statistically significant, indicating that there are significant differences between respondents in terms of their usage of VR in their projects and its perceived importance ($F(1, 55) = 4.34$, $p = 0.042$). The ANOVA test was followed by a post hoc test in order to determine where the differences are between the groups of respondents. According to the Tukey HSD post hoc test, respondents who have used VR in their projects have higher perceived importance for VR as a control measure for change orders (M = 0.57, SD = 0.27). Parameter estimates for the model are presented in Table 10.

Table 10 Parameter estimates.

Dependent Variable: In order to minimize and control change orders: - Immersive VR technology should be implemented during the design phase.							
Parameter	B	Std. error	*t*	Sig.	95% confidence interval		Partial eta squared
					Lower bound	Upper bound	
Intercept	3.344	0.183	18.254	0	2.977	3.711	0.858
VR use: Yes	0.576	0.277	2.083	0.042	0.022	1.131	0.073
VR use: No	0	.	.	.	.	.	.

3. Results

This section provides a brief analysis of the respondent's demographic and background, such as, age, gender, level of education, and professional experience. It is important to provide such information when it comes to analyzing opinions and perceptions on important issues. The respondent's background will contribute to the overall reliability of collected data; hence, will increase the reliability of data analysis results. Tables 11 to 17 summarize the results of this section:

Table 11 Respondents by gender.

Gender	Percentage
Female	23.01%
Male	76.99%
Total	100.00%

Table 12 Respondents by age.

Age	Percentage
18 to 24 years	0.88%
25 to 34 years	28.32%
35 to 44 years	23.01%
45 to 54 years	24.78%
55 to 64 years	15.04%
Age 65 or older	7.96%
Total	100.00%

Table 13 Respondents by level of education.

Education level	Percentage
Completed some high school	0.88%
High school graduate	1.77%
Completed some college	4.42%
Associate degree	2.65%
Bachelor's degree	60.18%
Completed some post-graduate	7.08%
Master's degree	22.12%
Ph.D., law or medical degree	0.88%
Other advanced degree beyond a Master's degree	0.00%

Table 14 Respondents by decision-making authority on change orders.

Level of decision-making authority you have on issuing, reviewing, and approving change order	Percentage
Final decision-making authority	32.14%
Significant decision-making or influence	57.14%
Minimal decision-making or influence	8.04%
No input	2.68%

Table 15 Respondents by job title.

Job title	Percentage
Architect	15.93%
Engineer	25.66%
Project Manager	29.20%
Superintendent	3.54%
Other	25.66%

Table 16 Respondents by role.

Role	Percentage
Owner	42.48%
Design professional	29.20%
Contractor	24.78%
Other	3.54%

Table 17 Respondents by type of delivery method.

Construction delivery methods	Percentage
DBB (design-bid-build)	71.68%
DB (design-build)	72.57%
CMAR (construction management at risk)	59.29%
IPD (integrated project delivery)	20.35%
Other	9.73%

The most important finding of the research based on the pre- and post-survey results are presented according to both AEC expert and the three parties involved in construction projects. It appears that the owner change in design is the number one cause of change orders with an overall RII of 0.78. The change of the project scope by owner was ranked second with a RII of 0.70. This result is interesting because most of the owners participating in the study agree with the consultants and contractors that the most important causes for change orders are due to owner change in design or change in projects scope. These two variables, in fact, measure the same construct. The change in design might be due to the lack of visualization and presence of the project during the design phase. The change in scope might be also due to the lack of visualization and understanding of the design as well as other factors, such as responsibly assigned to each party and the risk associated with it. Table 4 summarizes the ranking of change order causes by importance. The ranking of different parties involved in a project by responsibility places the owner in the first rank, due to the change in design, change in project scope, or change in the project schedule. These results can be interpreted as follows:

- Lack of visualization and understanding of the design by owner.
- Change of the "in-charge individuals" during the design or between the design phase or between the design and construction, which might create confusion and lack of the design understanding and the overall project scope by the owner's new representative.
- The owner was not included in all design phases.
- The consultant failed in clearly communicating the design and making it understandable for the owner.
- The owner lacks the necessary knowledge to read and interpret the plans.

The ranking of change orders effects on construction projects places "increase in the overall cost of the project" in the 1st rank with a RII of 0.86, followed by "delay in schedule" with a RII of 0.81. "Delay in payments", "decrease in productivity of workers", and "decrease in quality of work" were ranked 3rd, 4th, and 5th by RII of 0.71, 0.64, and 0.56 respectively. All parties agreed that the "increase in the overall cost of the project" is by far the effect that might have the higher negative impact on the project and may lead to other problems, such as lawsuits and delay in schedule.

As indicated in the data analysis section, the RII is used not only to rank the change orders control measures but also to predict the contribution of a particular control measure to eliminating and minimizing change orders in construction projects. The results indicated that the most important measure that should be taken into consideration in order to minimize the risk of change order orders is "Contract documents should be reviewed by all parties involved in the project—gray areas should be highlighted, clarified, and agreed upon prior to construction" this result highlights the high importance of collaborative review during the design phase. This measure ranked 1st with a RII of 0.93, followed by "Any change order should be addressed and negotiated by knowledgeable individuals" with a RII of 0.92. The results show that "Owner, design professionals, and contractor should be involved in all project phases" is ranked third with a RII of 0.90. The "Change orders procedures should be explained in the contract documents" was ranked fourth with a RII of 0.90, followed by "The scope of change should be made clear and issued by the design professionals" in the fifth rank with a RII of 0.90. It was also noted that control measures 3, 4, and 5 have equal RII, so they can be placed in one rank and considered of equal importance. "WBS should be used in complex projects", "BIM should be implemented in all project phases", and "Immersive virtual reality technology should be implemented during the design phase" are ranked six, seven, and eight by importance with RIIs of 0.77, 0.70, and 0.65, respectively.

The ranking of the grouped control measures that was obtained through the PCA and validated with the AEC expert, relied on comparing the calculated means as well as the RII of each group (collaborative review, change order procedures, and method & technologies). The results are as follows: "Collaborative review" is ranked first by importance in eliminating and minimizing change orders with a RII average of 0.92, followed by "Change order procedures" in the second rank with a RII average of 0.90. "Organizational methods and collaborative technologies" was ranked a distant third with a RII average of 0.71. Tables 8 and 9 summarize these data analysis results.

The results of this section places BIM and VR at the lowest ranks, which does not line up and adhere to the findings of the first section on change order's causes, which suggests that, the owner's change in design is the most important and frequent cause for change orders, and the potential explanation for that is the lack of visualization and understanding of the design, or difficulties in reading the plans. VR would be an alternative control measure to solve the problem of lack of visualization and understanding of the design, in consequence, it should be placed among the higher ranked control measures. Therefore, it was decided to investigate if the familiarity and frequency of use of

BIM and VR have an impact on its perceived importance. The result of the *t*-test between groups with regard to VR familiarity was found to be significant, indicating that there are significant differences between the respondents who are familiar with VR and respondents who are not in terms of their VR perceived importance, as opposed to BIM, where there were no significant differences between respondents who are familiar with BIM and the respondents who are not. These results might be an indicator that the AEC experts have a better understanding of VR concept and can foresee its usability and benefits for a better understanding of the design.

It was also found that respondents who use BIM and VR very frequently have higher perceived importance for both BIM and VR as a control measure for change orders. This indicates that frequency of use and involvement in BIM and VR is a predictor for their perceived importance and it was confirmed by the regression model presented in Table 11.

4. Discussion

Change orders are almost inevitable in construction projects and have negative impacts on projects. Change orders could be minimized by identifying and eliminating their causes at an early stage in the project. The present study objective was to further investigate and rank causes, effects, and control measures of change orders in the AEC industry in the U.S.A. The most important findings of this study are:

- The main responsible party for change orders is the owner. It was found that owner's change in design and change in scope are the most important and frequent causes for change orders. These requested changes might be justified by: the lack of visualization and understanding of the design by owner; change of individual(s) in charge during the design phase or between the design and construction phases; the owner was not included in all design phases; the consultant failed to clearly communicate the design and make it understandable for the owner; and finally the owner lack of necessary knowledge to read and interpret the plans.
- The second major responsible party for change orders in construction projects was found to be the consultant due to errors and omissions in design, poor details, and conflict between contact documents.
- The third most important source of change orders is the contractor due to numerous factors, such as poor planning and inaccurate cost estimates.
- Other causes for change orders such as weather condition, equipment, and new regulations were ranked the lowest.

The most important effects were ranked according to their impact on projects as follows: increase in the overall cost of the project; delay in schedule; delay in payments; decrease in productivity of workers; and decrease in quality of work.

Control measures were organized into three major groups. The first group is collaborative review and it was ranked the highest by importance in terms of controlling and minimizing change orders. This group included important preventive measure, such as "Contract documents should be reviewed by all parties involved in the project—gray areas should be highlighted, clarified, and agreed upon prior to construction" and "Owner, design professionals, and contractor should be involved in all project phases".

The second group included procedures on how to approach change orders prior and during construction, such as "Change orders procedures should be explained in the contract documents" and "The scope of change should be made clear and issued by the design professionals".

Finally, the group named methods and technologies were ranked lowest by importance in minimizing change orders. This group included organizational methods such as WBS and collaborative-visualization technologies such as BIM and VR.

4.1 Recommendations for Owners

- Provide a well-defined scope of work and a clear description of the expected end results.

- Understand the design and ensure it reflects the expected results.
- Understand the scope of work and the risk assigned to each party during the construction.
- Hire experienced consultants and contractors to minimize the risk of errors and omission.
- Continuous communication with all parties during all phases.
- Use visualization technologies such as 3-D renderings or virtual reality to better understand the design prior to construction.

4.2 Recommendations for Consultants

- Understand the owner's scope of work and expected result, to better translate into construction documents.
- Establish regular checkpoints and deliverables to confirm alignment. For example: Feasibility Study, Owner's Project Requirements (OPR), Basis of Design (BOD), Schematic Design, Design Development, Construction Documents.
- Continuous communication and collaboration with owner and contractor during all phases of the project.
- Use collaborative and design communication technologies such as BIM to facilitate the collaboration between all parties and identify any design problem that may cause change orders during construction.
- Use visualization technologies such as 3-D renderings and VR to increase the owner's understanding of the design.

4.3 Recommendations for Contractors

- Provide professional input on constructability, cost, and schedule during early stages of the project.
- Confirm that there is no conflict between the contract documents.
- Investigate the construction site prior to the onsite construction to minimize the risk of unforeseen conditions.
- The final cost included in the project contract should be based on real estimates obtained from subcontractors or based on similar projects completed in near geographical locations and relatively recent.
- Continuous coordination with owner and consultant throughout all the project phases.
- Include contingency funds in the overall cost of the project for unforeseen conditions.
- Use organizational methods and collaborative technologies such as BIM.
- Use visualization technologies such as VR to give the onsite superintendent and project managers a better understanding of the constructability.

5. Conclusion

This research is exploratory in nature, it does not claim causation. It investigated the causes, effects, and control measures of change orders, and ranked them by the perceived importance given to each by the AEC experts. We recommend more studies to concentrate on the owner's design understanding as it was the most important and frequent reason causing change orders. New technologies should be implemented to help the owner better understand the design at an early stage of the project to avoid potential changes during construction.

References

[1] Alaryan, A., Emadelbeltagi, Elshahat, A., and Dawood, M. 2014. "Causes and Effects of Change Orders on Construction Projects in Kuwait." *Int. Journal of Engineering Research and Applications* 4 (7): 1-8.

[2] Osman, Z., Omran, A., and Foo, C. K. 2009. "The Potential Effects of Variation Orders in Construction Projects." *Journal of Engineering* 2: 141-52.

[3] Sadi A. Assaf and Sadiq Al-Hejji (2006). Causes of delay in large construction projects. International Journal of Project Management, 24(4): 349–357.

[4] Assbeihat, J. M., and Sweis, G. J. 2015. "Factors Affecting Change Orders in Public Construction Projects." *International Journal of Applied Science and Technology* 5 (6): 56-63.

[5] Hanna, A., Camlic, R., Peterson, P., and Nordheim, E. 2002. "Quantitative Definition of Projects Impacted by Change Orders" Journal of Construction Engineering and management 128 (1)

[6] Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods, 4*(3), 272–299.

[7] MacCallum, R. C., Widaman, K. F., Zhang, S., & Hong, S. (1999). Sample size in factor analysis. *Psychological Methods, 4*(1), 84–99

[8] Mulaik, S. A. (1990). Blurring the Distinctions between Component Analysis and Common Factor Analysis. Multivariate Behavioral Research, 25, 53-59.

[9] Widaman, K. F. (1993). Common factor analysis versus principal component analysis: Differential bias in representing model parameters? *Multivariate Behavioral Research, 28*(3), 263–311.

[10] Johnson, J. W., and LeBreton, J. M. 2004. "History and Use of Relative Importance Indices in Organizational Research." *Organizational Research Methods* 7: 238-57. http://dx.doi.org/10.1177/1094428104266510.