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Causes of Design Change Depending on Power Project-Types in Ghana

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Abstract: Design change is a common but significant problem in construction projects. Issues of delay, cost overruns, claims, and disputes in projects occur as a result. However, design change studies in the power-project area are less often discussed. As a result, the primary objective of this study was to identify important cause factors of design changes according to different power-project types in Ghana. Following a thorough assessment of the literature, 36 potential causes were identified, which were narrowed down by expert reviews to 30. In this study, power projects were classified into three categories: power plant, renewable, and distribution and transmission. The results indicate owner-related financial problems as the most important cause of design change for all three project types, followed by the second and third most significant in each of the categories, respectively: errors and omission in design and problems or unforeseen site conditions in power plant projects; deficient quality and quantity of resources and inflation and changes in interest and exchange rates in renewable projects; and problems or unforeseen site conditions and changes of plans in distribution and transmission projects. Based on the findings, power-project stakeholders are able to comprehend the dynamics of design change and develop effective design management strategies to reduce impact.

Keywords: design change; power plant project; renewable project; distribution and transmission project; owner-related; contractor-related; design-related; controllable factors; uncontrollable factors

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1. Introduction

The construction industry is a critical component of any country's growth and an important metric for evaluating its economic output [1]. According to Akinradewo et al. [2], construction accounts for a significant portion of a country's economy, contributing up to 10% of the GDP and employing roughly 10% of the working population. Additionally, construction industry investments are just as important as investments in any other sector. Unfortunately, the industry experiences delays and cost overruns as a result of issues that arise throughout the project design and construction phases. Yana et al. [3] discovered that design and construction have the greatest impact on overall construction costs. Challenges confronted in the construction phase of projects result from the high occurrence of uncertainties, according to Suleiman and Luvara [4]. Uncertainties cannot be eliminated from the project execution phase, adding further complexity, which makes it difficult to complete any project without changing plans before and during the construction period [5]. One of the many problems causing delays and overruns is design changes. Change in design is often unavoidable, but it is important that its triggers be minimized in order to manage the consequences. Design changes occur in every type of project, including power projects. Design change is the most influential change-causing factor in the construction phase [3], invariably having a negative impact on project performance. In support of this, Khanh [6] concluded that time–cost overruns of 5% to 20% are due to design change in residential construction projects. Similarly, the cost of projects increased at an average of 11% to 15% due to change orders [7]. Design change is likely to occur at the design or construction phase of a project life cycle. Changes made during the design phase pose no significant risks to the project and can be resolved with minimal cost and schedule impact. Changes in the construction phase, however, are more troublesome because the project has already progressed, and adjusting the scope of work results in delays and having to redo much of the work, according to [6].

Previous studies have covered much ground when it comes to design change. Researchers have focused on important topics on design change such as its causes [8,9], its impacts [5,10,11], its effects on cost [12,13], its impact on schedules [14], the parties responsible for design change, its root causes, its management and other impact aspects that contribute significantly to the body of knowledge on the subject. However, the majority of previous studies on design change have focused on residential and commercial building projects and civil areas. For example, [4–6,15–17] describe design changes related to residential buildings, and [9,18] describe design changes in road construction projects and also in general construction phases [2,5,6,8,15,18]. Despite the fact that most disciplines have similar causes and effects of design change, each discipline has its own key approach to the construction process and scope of work, resulting in a variety of underlying causes and concerns, as well as changes in management strategies. For the purposes of this study, power projects were divided into three project-types: power plant projects, renewable projects, and distribution and transmission projects. To fully control issues of design changes in power projects, design change must be understood from the various project-types. Due to the nature of the project types, a strategy used to manage design change issues in one project type may not be the best strategy for managing design changes in another, requiring a unique approach to managing design changes.

First, previous academic research has dealt less about design change in power projects, and there has been no research to verify the design change gap among the power-project-types, to the best of the authors' knowledge. The prime objective of this study identifies design change causes that are important in power-project-types and verifies the significant differences that exist between the project-types. Second, from the industry perspective, design change is a very serious issue that leads to delays and cost overruns in most projects, especially the Ghanaian and African power construction industry. The findings from this study will be helpful for project managers or leaders to understand the issues surrounding design changes in their respective fields, allowing them to apply appropriate design change management strategies to reduce its occurrence and impacts. Overall, the focus of this study is to identify, for each subdivision, important cause factors affecting design changes and to understand the relationships that exist among them.

To achieve this goal, the study follows the research procedures indicated in Figure 1. First, this study reviews and discusses previous research that focuses on the causes of design changes in construction projects, as well as some of their consequences. Following reviews, this study identifies 30 design change causes that are common among power projects and divides them into two categories: controllable and uncontrollable. The authors then created a questionnaire based on these factors. In addition, the study surveyed and collected valid responses from 129 experts, including 45 power plant project experts, 42 renewable experts, and 42 distribution experts. Finally, the study analyzed the rank of design change causes for power-project-types and identified the relationships that exist between the power-project-types and discussed the significance on their relationships.

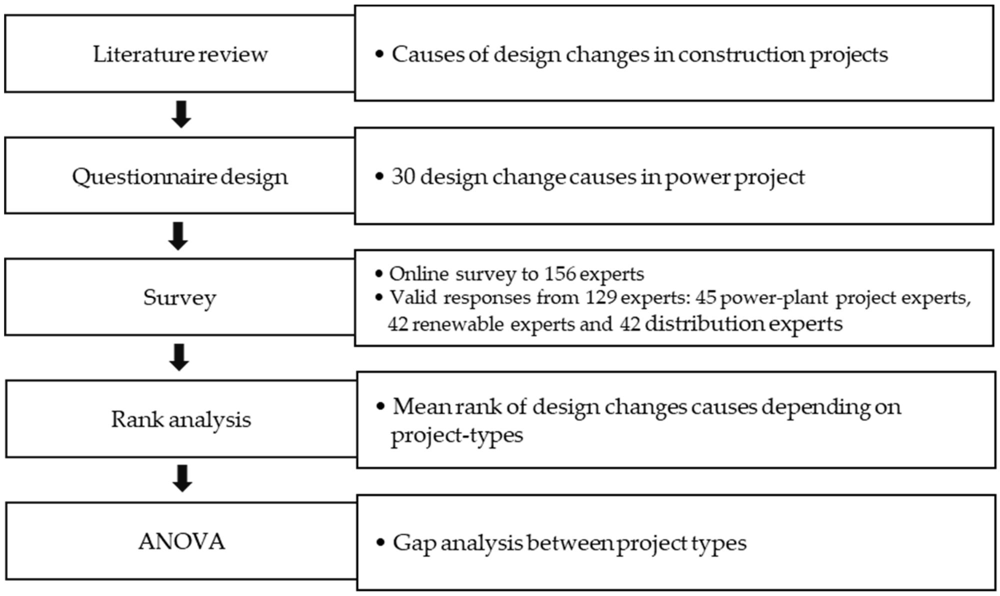

Figure 1. Research procedure.

2. Literature Review

As the foundation for this research, a related literature evaluation of results and findings was undertaken to establish the current understanding of the definition of major reasons for design change in the construction sector, power construction projects in particular. Previous research has looked into design changes as a major cause of delays and cost overruns, as well as studying the causes of design changes and those responsible for them in a given construction project. Additionally, in the area of power projects, design change issues have rarely been discussed by past researchers. As such, the focus of the literature has substantively been on the area of civil and other disciplines. There is no single definition for what design change means, because previous scholars have each interpreted it differently. Bassa [5] defines design change as any modification to a project's design or construction after the contract has been awarded. Design change is any change to the scope of work as highlighted by the contract document following the creation of legal relations between the principal and the contractor [4]. Modifications to the design, quality, and quantity of work, as well as changes to standards and materials utilized in the job, comprise design change according to [19]. Many studies point out that any additions, omissions, or modifications made to the original scope of work after a contract is awarded are considered design changes [6]. Several causes of design change have been established in previous reports from different perspectives, with the key drivers being the owner, contractor, consultant, design engineer, and natural occurrences, as described in most previous research. Some authors observed change in the scope of work, less knowledge about the construction field, poor supervision, design errors, poor work quality, change in government policies and laws, lack of design experience as causes of design change [3,5,10,15,17]. Many design change causes will be thoroughly discussed in the literature review subsection below and in the methodology of the main research.

2.1. Causes of Design Change

Design changes have been an inevitable part of construction projects and cannot be avoided [10]. This is due to the clarity of project plans, as well as the confidence of assumptions and design variables established early in the planning stage, which becomes increasingly apparent to the design team during construction [20]. Construction design changes have a huge effect on project performance; they are complex to tackle when the exact cause is unknown, although they can be managed, if not entirely reversed [21]. Alaryan et al. [10] investigated the causes and effects of design change in construction projects in Kuwait and identified 20 unique items. The author used a questionnaire and statistical approach to identify changes in plans by the owner, changes of project scope by the owner, problems on-site, design errors and omissions, and poor design working details as the five main causes of design change. Similarly, Lature and Hinge [22], through an extensive questionnaire and two case studies, identified 16 causes of design change, and concluded that of the variables that induce changes in construction projects, changes in scope or plan by the owner are the most common. In the private Jordanian construction sector, design change causes that are responsible for cost overrun are broken down into three main categories: engineering causes, causes related to clients, and circumstances of the project, with four, four, and two causes, respectively [8]. Additionally, a correlation was established to understand the relationship between the causes of change for each category. Aslam et al. [13] identified the impact of design change on cost while also pinpointing actions that are responsible for these changes. They indicated that 45.85% and 27.1% of the causes of design changes are related to the designer and contractor, respectively. However, these design improvements have a much smaller effect than clients and external variables, which contributed 10.45% and 16.7%, respectively, in their analysis. In the main causes of design change in construction projects in West Bank projects, results from the study identified the owner as the main cause of design change [7]. Yana et al. [3] classified influential factors of design change into internal and external factors: internal factors consist of owners, design consultants, construction management consultants, and contractors, whereas external factors involve politics and economics, the natural environment, advancements in technology, and third parties. These findings illustrated that the owner has the highest influence on the causes of design change with a loading factor of 0.884, a value higher than the other factors. Additionally, 41% of projects had 10% or more changes and the researchers concluded that this is not a rare phenomenon [11]. Owner and consultant engineers are the most responsible parties causing design changes in Erbil construction projects. They further identified changes in the bill of quantities, changes in plans by the owner, and inadequate contractor experience as the three important causes of variation in orders in the Erbil governorate [23]. Design changes mainly originate from the owner side and are important causative factors to time and cost overruns [24]. In another study, poor working drawings and a lack of coordination among design documents were the leading causes of variation, also describing errors in design calculations and erroneous specification descriptions as two examples of design errors that resulted in variance [25]. Owner design changes during construction were identified as the most important cause generating delays in building projects in Egypt by the questioned owners, consultants, managers, engineers, and contractors, with a relative importance index value of 76.769%. This top-ranked component is also placed twenty-sixth in terms of its effect among all factors studied, indicating that it has a considerable impact on the causes of delays in construction projects in Egypt [26]. The most prevalent causes pertaining to the consultant were a lack of awareness of the client's demands and modification for improvement, whereas the most common causes mentioned by interview participants for contractor-related, site-related, and external-related factors were improving buildability/ease of construction, unforeseen ground conditions/geotechnical challenges, and changes in government regulations, laws, and policies, respectively [27]. Additionally, a study in the South–South zone, Nigeria, revealed that changes in plans or the scope of work, client financial issues, insufficient working drawings, insufficient project objectives, faults and omissions in design are the most common reasons of variation orders in public construction projects [20]. Design change cause studies in Gaza highlight that the most common factors causing variations were Israeli restrictions in terminals and siege, discrepancies between contract documents, internal political problems, changes in specification by the client and budget-allocated constraints. In addition, the most influential factors impacting the VOs were completion schedule delay, increases in the duration of individual activities, delays in payment, suspended work in other activities, a dispute among professionals, and increases in project costs [28].

2.2. Effects of Design Change

Several delay and cost overrun problems occur in projects mainly because of design changes which, according to the reviewed literature, account for the sizeable number of factors leading to delay and cost increase problems. Previous studies have elaborated on the effects of design changes on delay; in construction projects in Ukraine, the main cause of reworks is design change [25]. In a preliminary study on the causes of schedule delays and cost overruns of power projects in Nigeria, Ismaila et al. [29] identified design change as an important cause for delays among three industry groupings, which included building construction, general power projects, and NPP projects. Additionally, five factors common to all three groupings identified design change/error issues as common causes for delays. Changes in design ranked as the fifth leading cause for delays in building projects in Ghana out of the nine main factors identified for delays [30]. In another study, delay in completion schedule was the most visible effect of variation orders from all the viewpoints [18]. In Malaysia, this study identified that design changes contributed to project delays by 10% to 20% and cost increases by 10% to 20% of the planned schedule and construction budget, respectively [27].

Similarly, for cost effects, design changes are the most predominant factor influencing time overruns or delays for projects and project stakeholders [31]. According to the findings of a study on the effects of design changes, design modifications increased the cost by 0.16% of the entire estimated amount [22]. The second evident result of design change, after delay, is an increase in project cost [18]. Using Interpretive Structural Modeling (ISM) to investigate the mutual relationships between the sources of design modifications, unfamiliarity with new construction methods, design errors, value engineering, scope uncertainty, change orders, and constructability were ignored in the design phase, which is highly influenced by other factors, although emerged at the highest level of the ISM diagram, and clients' attitudes and experience as the main root cause of design changes emerged at the bottom of the diagram, according to the authors' findings. The findings of this study provide project managers with a greater understanding of how different causes of design changes are linked to one another, which can help them adopt effective measures to limit design changes in building construction projects [32]. Experience in designing and detailing work and complexity in design were ranked seventh and twelfth, respectively, among the most influencing factor causing time delay in construction projects in Chennai [33]. Additionally, regardless of the cause of modifications, the redesign part of the project has a "cost impact" on each stakeholder involved in the project [34].

On the other hand, some researchers think differently from this phenomenon and cite evidence that design changes have minimal effects on cost overrun. For example, changes in the scope of the project and frequent design changes are the least affecting factors on construction costs [31]. As a result, it may be concluded that design change management, in some form or other, plays a vital role in minimizing cost and time overruns.

2.3. Research Objectives

This study's findings will assist clients, consultants, and contractors in identifying the important causes of design changes in the three types of power projects. This will enable key construction players to adopt methods that will support them in reducing the negative consequences of design changes and increasing project performance. Hence, the objectives of this paper are:

1. To investigate the most important cause of design change for all power-project-types;
2. To analyze the gaps between different power-project-types.

3. Methodologies

The study derived the cause factors of design changes through a literature review and expert interviews. Then, the questionnaires were sent to industrial experts in power plants, transmission and distribution facilities, and renewable projects. Data were analyzed using SPSS.

3.1. Causes Factors of Design Changes

3.1.1. Literature Review

This study includes a thorough literature review to determine the causes of design changes in power projects. Due to the dearth of literature specifically linking design changes in power projects, a general qualitative literature research was conducted for design changes in all construction disciplines, mainly for mega and complex projects. A total of 47 causes of design change were identified, which were then narrowed to 36 causes after considering further reviews, as well as mutual exclusivity and collectively exhaustive factors. The literature review includes papers from academic journals for construction management, engineering management, and project management.

3.1.2. Expert Input and Respondent Profiles

Initially, 36 factors were derived through literature reviews by authors. After consulting with seven experts, 9 factors were eliminated, and 3 were added as expert opinions, bringing the total number of causes to 30. Seven experts, who were project managers, field engineers, and technicians from the power industry with ample knowledge and experience in power projects were consulted via phone and video conversations. Three expert opinions were deficient in quality and quantity: contractors' desire to improve the financial situation, and inflation and interest and exchange rates. These three added factors in power projects have been discussed much less in past studies. Experts who were consulted prior to the survey for their opinions were also asked to participate in the survey. Additionally, survey respondents were chosen from the power industry with extensive experience in one or more of the three project types. Table 1 summarizes the respondent profiles, including respondents' experience.

Table 1. Respondent profile.

Respondent Profiles	Number of Respondents	Proportion
	Years of Experience	
1–5	32	25%
6–10	33	26%
11–15	47	36%
Above 15	17	13%
Total	129	100%
	Role company played	
Project Owner (Client)	52	40%
Project Contractor	41	32%
Project Subcontractor	24	19%
Project Consultant	12	9%
Total	129	100%

3.1.3. Causes of Design Change in Power Projects

The 30 identified causes were divided into controllable and uncontrollable factors. Controllable factors were subdivided into owner-related, contractor-related, and design-related factors, as shown in Figure 2. Overall, 25 of the identified causes were controllable factors, with 5 causes representing uncontrollable factors. Among the 25 controllable factors, 11 causes were owner-related factors, 8 were contractor-related factors, and 6 were design-related factors, as summarized in Table 2.

3.2. Questionnaire and Survey

Questionnaires were designed constructively to identify important cause factors among the 30 design change causes. The causes were scaled using a five-point Likert scale for each subdivision, as per the study's objective. Constructive interviews were conducted to streamline results and test for objective understanding and expectations, whereas questionnaires were produced in accordance with the research objectives. The questionnaire structure was in two forms, labeled section A and section B. Section A sought information about the respondents and project information offered by the respondents. Section B focused on seeking the opinions of respondents on identifying important cause factors. Further descriptions of the three subdivisions are presented in Section 3.2. Additionally, the items in the questionnaire were pre-tested with experts for clarity and usability. These few select respondents were instructed to complete the questionnaire and note any complexity, contradictions, or inconsistencies they encountered when answering the questions. The questionnaire was modified based on their feedback.

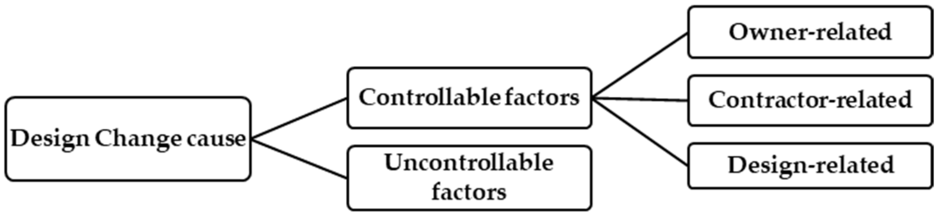

Figure 2. Flowchart showing cause and factors.

Table 2. Cause factors of design changes in power projects with descriptions.

ID		Description	References
	Controllable Factors		
		Owner-Related	
O1	Change of Plans	Frequent revisions made by the owner, either at the initial stages or later in the project’s life cycle, which have an impact on the project’s scope.	[1–3]
O2	Technology changes	Problems that occur as a result of the introduction of new technology.	[3–5]
O3	Conflict between contract documents	Discrepancy or inconsistency between initial terms of agreement, mostly at the progressive phase of the project.	[1,4,5,8,9]
O4	Lack of technical knowledge to comprehend and visualize project	When the owner (owner’s consultant), in most cases, lacks the expertise and experience in understanding the project.	[10]
O5	Financial problems	Lack of funds or bankruptcy by the owner to continue the project.	[1,3,5,8]
O6	Poor project objective definition	Owner fails to vividly define the scope of the project to the designer or contractor.	[3,4,8]
O7	Long decision-making time	Taking a long time to define and make decisions has an impact on the design and construction process.	[1,3,10]
O8	Additional work	Owner adds more work to the initial scope.	[1,2,5]
O9	Change of designers	Designer is replaced with a different designer.	[3,8]
O10	Estimation errors	Poorly or incorrectly estimating the number of resources and materials needed for project.	[3–5]
O11	Ineffective supervision	Owner fails to keep a close eye on the design and construction process.	[2,8,11]
		Contractor-Related	
C1	Equipment and material failure	Machine and equipment breakdown due to poor operation.	[1,17]
C2	Health and safety considerations	Contractor believes their safety is being jeopardized; safety design elements are subject to additional consideration.	[1,3,4]
C3	Lack of coordination and communication	Poor communication and coordination among project stakeholders, as well as late information dissemination.	[1,2,4,5,8,11]

Table 2. *Cont.*

ID		Description	References
C4	Resources deficient in quality and quantity	No available resource (human and material). Additionally, low-quality materials and inexperienced human resources.	Expert opinion
C5	Inadequate construction experience	Contractors lack the necessary experience to manage and build such projects.	
C6	Lack of awareness about governmental regulations, statutes and their modification	Lack of awareness of current and evolving legislation and government laws affecting such projects.	[1,9]
C7	Inadequate pre-construction study and review of design documents	Contractor fails to thoroughly evaluate design documentation before starting work.	[1,10]
C8	Contractor's desire to improve their financial situation	Contractor attempts to make a lot of money to compensate for their poor financial status.	Expert opinion
		Design-Related	
D1	Design complexity	Projects involving power plants often need a large number of labor and design activities. This complicates design work by adding complexities and information.	[1,2,11]
D2	Errors and omissions in design	Making mistakes during the design process or failing to include important data and information.	[1–5,9,11]
D3	Noninvolvement of other parties during design phase	Misinterpretations in construction due to the designer's failure to involve the owner and contractor throughout the design phase.	[1,4,5]
D4	Modification of original design	Improving the design, which in some cases differs significantly from the initial concept.	[5,13]
D5	Lack of design experience	Design consultant's inexperience, especially in designing mega projects.	[5,9,11]
D6	Application of inappropriate standards	Designing using incorrect specifications and standards.	[5,10]
	Uncontrollable Factors		
U1	Problems or unforeseen site conditions	Issues related to the site that are not initially identified or noticed. Sometimes, this is due to poor study conduction.	[3–5,8,9]
U2	Political instabilities	Change in government and threats that result during election periods.	[8,9]
U3	Very poor weather conditions	Adverse, unstable, and unpredictable weather conditions.	[2,4,9]
U4	Changes in governmental policies	The changes in laws and regulations that directly or indirectly affect a project	[1,3–5,8,9,11]
U5	Inflation and interest and exchange rates	The effects these changes in monitory value have on projects' design change	Expert opinion

A five-point Likert scale method was adopted for the survey to determine and prioritize important cause factors. The scale prioritizing index was (5 = extremely important, 4 = very important, 3 = important, 2 = slightly important, and 1 = not important). This type of scale has the advantage of not eliciting a straightforward yes/no response from the respondent, but instead allows for varying degrees of input or even no opinion at all [35]. Moreover, quantitative data were obtained, implying that the data can be evaluated relatively quickly.

The internal validity of quantitative techniques is attained by structuring a questionnaire to quantify what it is intended to quantify [8], a technique which was employed in this study. For all three subdivisions, the external validity was determined by using a sufficient number of participants who represented various industry players. A total of

156 questionnaires were distributed to respondents in various sectors of Ghanaian power industry. Of those completed, 129 responses were valid for analysis: 45 were power plant project experts, 42 were renewable experts and 42 were distribution experts. The surveys were sent and conducted electronically using Google Forms and lasted two months, from May to June 2021.

3.3. Power Projects

From an industry perspective, there are three kinds of subindustries. Due to the differences in project characteristics, specifications, and requirements, comparisons across the three subdivisions are crucial. Individual findings for each subdivision, as well as comparisons, can be used to draw valuable lessons. The questionnaire was given to respondents from areas of each subdivision.

3.3.1. Power Plant Projects

Power plants in this study were categorized into thermal power plants, hydropower plants, nuclear power plants, and any other combined-cycle power plant. However, under this category, hydroelectric power and thermal power are the most common in Ghana. Therefore, the scope of this study's results for power plants will cover these two key areas, but other sources in this category can be included in this research to enhance future studies.

3.3.2. Renewable Power Projects

Renewable power projects are designed to aid in the reduction in global warming while also promoting economic sustainability. Despite their entrepreneurial nature, such projects are prone to significant project deviations [36]. The scope of this subdivision is solar and wind power projects. Other renewable power plants were not considered in this study, because solar and wind are the most widely adopted renewable energy technologies in Ghana. A lot of renewable power projects experience changes leading to cost and time overruns. Even though design changes in renewable projects are important, few studies have been conducted on this facet of power construction.

3.3.3. Distribution and Transmission Projects

Distribution and transmission subdivision projects under study describe the construction of transmission and distribution lines for the dissemination of electrical energy from generation sites to the consumer. Pall et al. [37] mentions that transmission and distribution projects typically comprise the construction of station(s)/substation(s) and transmission line/transmission lines, which involve the construction of various types of buildings, equipment and structure foundations, roads, open and closed drains, underground and overhead water tanks, and site surfacing. During such projects, several issues of design change also occur, with numerous effects.

3.4. Data Analysis

3.4.1. Reliability Test

To ensure the reliability of data, the Cronbach's alpha value, $C\alpha$ for data, was tested. The Cronbach's alpha test is conducted on a scale of 0 to 1, and greater reliability is consistent with higher values approaching 1 [6]. The minimum acceptable value for data reliability is 0.7, i.e., $C\alpha > 0.7$ [38]. To ensure maximum reliability in this study, the Cronbach's alpha test was conducted for all three subdivisions and conducted separately for each subdivision in SPPS. Overall, the Cronbach's alpha value was 0.941, whereas for the separate tests conducted, power plant was 0.953, renewable was 0.947, and distribution and transmission was 0.918. The results indicated a high Cronbach's alpha value; thus, data were reliable.

3.4.2. Analysis of Variance (ANOVA)

This study aimed to determine whether there were significant differences in the 30 causes of design changes depending on the power project. Data were analyzed using IBM SPSS software to determine the mean of each cause factor for each project type. To determine the mean value for each cause factor, a one-way between-group analysis of variance (ANOVA) was chosen. Analysis of variance (ANOVA) is a statistical test for detecting differences in group means when there is one parametric dependent variable and one or more independent variable [39]. Prior to conducting the ANOVA, the assumption of normality and homogeneity of variables were tested. Results from the Shapiro–Wilk test ($p = 0.810$) showed that data were normally distributed, because $p > 0.05$. Following the ANOVA results, a post hoc test was also conducted to further understand the difference between groups.

4. Results

This section summarizes the results of the statistical data analysis. Significant observations and findings are discussed in the subsections below.

4.1. Analysis of Important Cause Factor

The mean score was calculated from the ratings of respondents and ranked as presented in Table 3. Respective mean values show the weight attributed to the cause factors, with the standard deviation indicating the degree of distribution variation. Overall, financial problems (O5) attributed to owner-related factors were the most important cause of design change in all subdivisions. Among power plant projects, financial problems (O5), errors and omissions in design (D2), problems or unforeseen site conditions (U1), modifications of original design (D4), conflict between contract documents (O3), noninvolvement of other parties during the design phase (D3), poor project objective definition (O6), application of inappropriate standards (D6), lack of coordination and communication (C3), and lack of design experience (D5) were the top ten ranked causes of design change, listed in descending order. Nine of these top causes are controllable factors.

For the renewable projects, financial problems (O5), resources deficient in quality and quantity (C4), inflation and changes in interest and exchange rates (U5), errors and omissions in design (D2), problems or unforeseen site conditions (U1), inadequate preconstruction study and review of design documents (C7), long decision-making time (O7), equipment and material failure (C1), poor project objective definition (O6), and health and safety considerations (C2) ranked as the top ten most important causes. Among these top ten causes, eight are controllable factors, whereas two are uncontrollable factors.

In distribution and transmission projects, financial problems (O5), problems or unforeseen site conditions (U1), change of plans (O1), long decision-making time (O7), poor project objective definition (O6), additional work (O8), inflation and changes in interest and exchange rates (U5), resources deficient in quality and quantity (C4), errors and omissions in design (D2), and health and safety considerations (C2) were the top ten critical causes which account for design change. Under this subdivision, eight of the ten most important causes were controllable factors, whereas two were uncontrollable factors. Among the controllable factors, five causes were owner-related, two were contractor-related, and one was design-related. Figure 3 shows a representation of the top five most important project-type causes based on mean-based rankings. As a result of the findings, certain causes had equal means and thus ranked in the top five. For example, in power plants, six items were ranked in the top five, whereas in distribution and transmission, seven items were ranked in the top five.

Additionally, common among the top ten ranked causes for all three project-types are financial problems (O5), errors and omissions in design (D2), problems or unforeseen site conditions (U1), and poor project objective definition (O6), clearly indicating how significant and predominant these causes are in power projects.

Table 3. Descriptive statistics and ANOVA results for causes of design change by subdivisions.

	Power Plant			Renewable			Distribution and Transmission			ANOVA	
	Mean	**S.D.**	**Rank**	**Mean**	**S.D.**	**Rank**	**Mean**	**S.D.**	**Rank**	**F**	**Sig.**
O1	2.82	1.051	18	3.02	1.259	20	3.33	1.162	3	2.139	0.122
O2	2.62	0.984	28	2.93	1.113	24	2.36	0.983	30	3.254	0.042
O3	3.07	1.092	5	3.12	1.173	16	2.93	1.156	13	0.499	0.609
O4	2.8	0.786	20	3.14	1.260	13	2.67	0.979	18	2.432	0.92
O5	3.67	1.187	1	3.93	0.973	1	3.71	0.995	1	0.743	0.478
O6	3.04	1.043	7	3.29	1.111	9	3.14	0.977	5	0.583	0.560
O7	2.93	1.095	11	3.33	1.223	7	3.21	1.116	4	1.409	0.248
O8	2.73	1.009	22	3.07	1.257	18	3.14	1.026	5	1.733	0.181
O9	2.71	1.121	23	2.64	0.958	30	3	1.148	12	1.302	0.276
O10	2.64	1.049	26	2.86	1.144	26	2.67	0.916	18	5.934	0.003
O11	2.64	1.111	26	2.83	1.181	27	2.55	0.874	26	0.515	0.599
C1	2.87	1.004	17	3.31	1.124	8	2.74	0.942	16	0.844	0.432
C2	2.93	1.179	11	3.21	1.239	10	3.1	1.083	10	2.772	0.066
C3	3.02	1.136	9	2.88	1.138	25	2.64	0.958	21	0.741	0.479
C4	2.89	0.905	14	3.64	1.194	2	3.12	0.906	8	0.716	0.490
C5	2.89	0.832	14	2.98	1.199	23	2.67	1.004	18	1.034	0.359
C6	2.93	1.136	11	3.14	0.977	13	2.52	0.917	27	4.029	0.020
C7	2.89	1.053	14	3.38	1.209	6	2.64	1.165	21	4.419	0.014
C8	2.29	1.058	30	3	1.307	22	2.57	1.129	25	4.073	0.019
D1	2.82	1.093	18	3.07	1.276	18	2.71	0.970	17	1.127	0.327
D2	3.47	1.272	2	3.4	1.149	4	3.12	1.064	8	1.080	0.343
D3	3.07	1.195	5	3.19	1.087	11	2.9	1.206	14	0.636	0.531
D4	3.16	1.147	4	3.1	1.055	17	3.05	1.125	11	0.103	0.902
D5	2.96	0.999	10	3.14	1.221	13	2.6	0.939	24	2.908	0.058
D6	3.04	1.127	7	3.17	1.188	12	2.9	1.226	14	0.518	0.597
U1	3.29	1.199	3	3.4	0.964	4	3.43	0.941	2	0.224	0.799
U2	2.78	1.106	21	2.81	1.401	28	2.45	0.942	29	1.222	0.298
U3	2.67	1.000	24	2.71	1.235	29	2.48	1.065	28	0.552	0.577
U4	2.6	1.074	29	3.02	1.137	20	2.62	0.909	23	2.232	0.112
U5	2.67	1.158	24	3.57	1.063	3	3.14	0.952	5	3.160	0.046

However, the contractor's desire to improve their financial situation (C8) recorded the lowest mean score for the power plant subdivisions, ranking as the least important for this type of project. This cause is considered to be of little importance in this project type because most power plant contractors usually are big companies, whereas the others are usually small and medium-sized companies. Moreover, a contractor's desire to improve their financial situation in the renewable and distribution and transmission projects had higher mean scores compared to the power plant project type, highlighting the fact that its probability to occur due to the nature of project type is low in the power plant project-type. Change of designers (O9) had the lowest mean in the renewable subdivision, which can be attributed to the less complex nature of this subdivision compared to the power plant and distribution and transmission projects. Mostly, it is rare for designers to change in renewable projects, unlike in the other project types. Lastly, in distribution and transmission, technology changes reported the lowest mean score, ranking as the least important cause for this subdivision.

4.2. Differences of Design-Change Causes Depending on Power-Project-Types

A one-way between-groups ANOVA test was conducted with power-project-types as independent variables and causes of design changes as the dependent variable. The null hypothesis of this study's test was that important causes of design change are the same for all three project-types in the power industry. The independent project-type between-group ANOVA testing revealed a statistically significant effect, rejecting the null hypothesis.

To further evaluate the difference between groups, the ANOVA test was followed by a pairwise Tukey HSD post hoc comparison test (results summarized in Table 4).

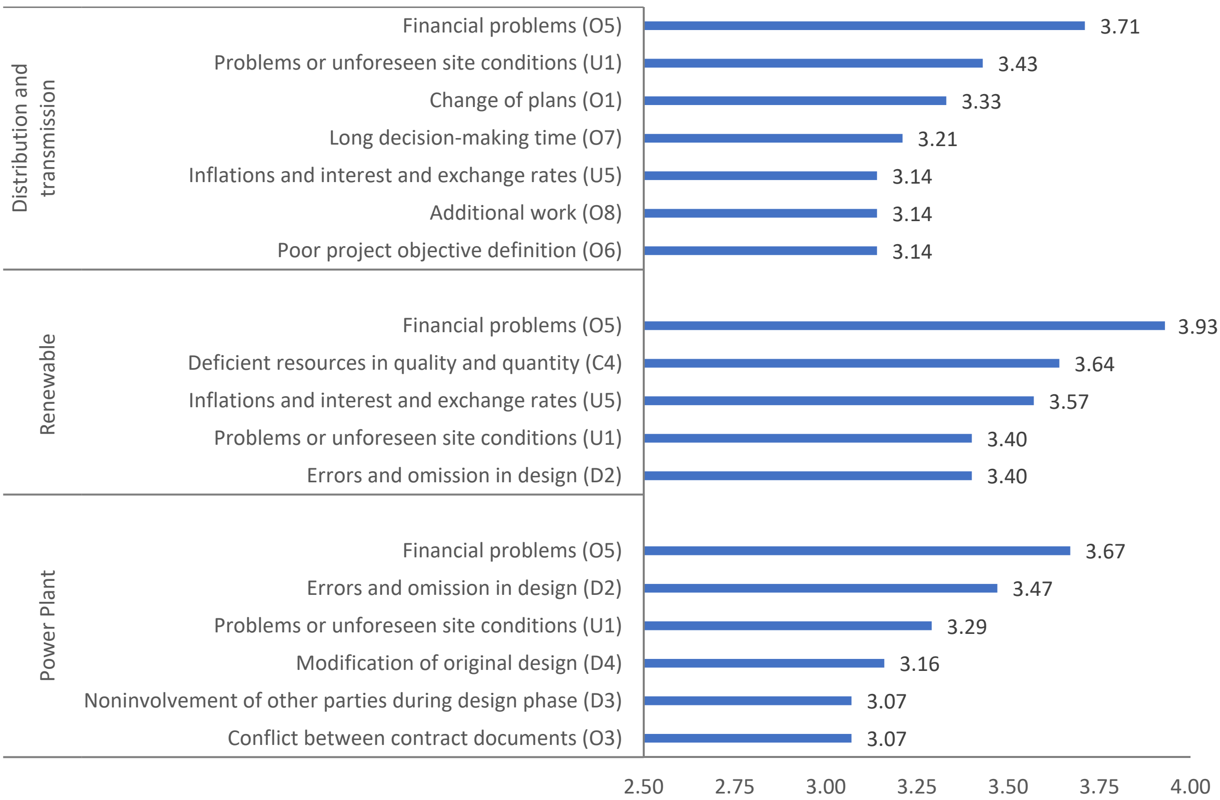

Figure 3. Top five ranked causes depending on project types.

The ANOVA results (Table 4) showed a significant difference between groups in technology changes (O2), ($F(2, 126) = [3.254]$, $p = 0.042$). The post hoc test results revealed a higher mean score and significant difference in renewable projects (M = 2.93, SD = 1.113) than in the distribution and transmission projects (M = 2.36, SD = 0.983) for technology changes (O2). In estimation errors (O10), significant differences ($F(2, 126) = [5.934]$, $p = 0.003$) were found between the renewable and power plant project-types. The mean score of the renewable project-type (M = 2.86, SD = 1.144) was higher and significantly different from the power plant project-type (M = 2.64, SD = 1.049) following a post hoc analysis. Lack of awareness about governmental regulations, statutes, and their modification (C6), ($F(2, 126) = [4.029]$, $p = 0.020$) revealed significant difference between the renewable and distribution and transmission project-types. Post hoc results revealed that the renewable project-type (M = 3.14, SD = 0.977) was significantly different and yielded a higher mean score compared to the distribution and transmission project-type (M = 2.52, SD = 0.917). Inadequate pre-construction study and review of design documents (C7), ($F(2, 126) = [4.419]$, $p = 0.014$) revealed a significant difference between the renewable and distribution and transmission project-types; the mean score of the distribution and transmission project-type (M = 2.64, SD = 1.165) was lower and significantly different from the renewable project-type (M = 3.38, SD = 1.209) after post hoc analysis. Additionally, the mean score in the renewable project-type (M = 3.000, SD = 1.307) was higher and significantly different than in the power plant project-type (M = 2.29, SD = 1.058) for the contractor's desire to improve the financial situation (C8), after the ANOVA results demonstrated a significant difference between project types ($F(2, 126) = [4.073]$, $p = 0.019$). Lastly, post hoc analysis results indicated that the mean score for renewables (M = 3.57, SD = 1.063) in inflation and changes in interest and exchange rates (U5) was higher and significantly different from the distribution and transmission project-type (M = 3.14, SD = 0.952) after the ANOVA results reported a significant difference ($F(2, 126) = [3.160]$, $p = 0.046$). Overall, results revealed that the power plant and distribution and transmission subdivision project-types are not significantly different from each other, as the post hoc results show $p < 0.05$ in Table 4.

Table 4. Tukey HSD post hoc test results of significantly different causes.

					95% Confidence Interval	
			Std. Error	**Sig.**	**Lower Bound**	**Upper Bound**
O2	Power plant	Renewable	0.220435	0.349	−0.8292	0.2165
		Distribution	0.220435	0.454	−0.2577	0.7879
	Renewable	Power plant	0.220435	0.349	−0.2165	0.8292
		Distribution	0.224203	0.032	0.0397	1.1032
	Distribution	Power plant	0.220435	0.454	−0.7879	0.2577
		Renewable	0.224203	0.032	−1.1032	−0.0397
O10	Power plant	Renewable	0.223304	0.003	−1.2836	−0.2244
		Distribution	0.223304	0.559	−0.7598	0.2995
	Renewable	Power plant	0.223304	0.003	0.2244	1.2836
		Distribution	0.227122	0.059	−0.0149	1.0625
	Distribution	Power plant	0.223304	0.559	−0.2995	0.7598
		Renewable	0.227122	0.059	−1.0625	0.0149
C6	Power plant	Renewable	0.21828	0.604	−0.7272	0.3082
		Distribution	0.21828	0.150	−0.1082	0.9272
	Renewable	Power plant	0.21828	0.604	−0.3082	0.7272
		Distribution	0.222012	0.017	0.0925	1.1456
	Distribution	Power plant	0.21828	0.150	−0.9272	0.1082
		Renewable	0.222012	0.017	−1.1456	−0.0925
C7	Power plant	Renewable	0.245033	0.408	−0.8954	0.2669
		Distribution	0.245033	0.198	−0.1573	1.0050
	Renewable	Power plant	0.245033	0.408	−0.2669	0.8954
		Distribution	0.249222	0.010	0.1470	1.3292
	Distribution	Power plant	0.245033	0.198	−1.0050	0.1573
		Renewable	0.249222	0.010	−1.3292	−0.1470
C8	Power plant	Renewable	0.25033	0.014	−1.3048	−0.1174
		Distribution	0.25033	0.498	−0.8763	0.3112
	Renewable	Power plant	0.25033	0.014	0.1174	1.3048
		Distribution	0.25461	0.216	−0.1753	1.0324
	Distribution	Power plant	0.25033	0.498	−0.3112	0.8763
		Renewable	0.25461	0.216	−1.0324	0.1753
U5	Power plant	Renewable	0.228091	0.046	−1.0902	−0.0082
		Distribution	0.228091	0.857	−0.6616	0.4203
	Renewable	Power plant	0.228091	0.046	0.0082	1.0902
		Distribution	0.23199	0.159	−0.1216	0.9788
	Distribution	Power plant	0.228091	0.857	−0.4203	0.6616
		Renewable	0.23199	0.159	−0.9788	0.1216

5. Discussion

The causes and effects of design change on power plant projects are complicated and are influenced by a variety of interconnected factors. In terms of cost and scope, all three subdivisions have various levels of commitment. By determining important cause factors, a more holistic insight and broader approach is determined to easily identify causes of design changes that occur in projects, as well as offering adaptable design management strategies for power-project stakeholders to manage design changes. This research will also provide valuable information from an academic standpoint on this topic. The main results reflect the fact that each project type shows a different perspective on the important causes of design change based on their mean ranks. Variations in findings are a result of the scope and nature of work, project complexity, the type of contractual agreement, and the involved stakeholders for each subdivision project. In this particular instance, Table 4 presents the post hoc results, which revealed significant differences between project types. Estimation errors (O10) and the contractor's desire to improve their financial situation (C8), show significant differences between renewable project-type and power plant project-type. This is due to the vast difference in project scope between the aforementioned project types, as well as the complexity of scope. In a more technical sense, power plant project types have a longer construction period than renewable project types, and several occurrences during this period affect the project's forecasted estimation. This type of issue is less common in renewable project types. Furthermore, most contractors in renewable projects are comparatively smaller. Therefore, they cannot afford to lose money and thus have a strong desire for profits. This finding aligns with an author's findings who conducted a study of 401 power plant and transmission projects in 57 countries, where costs were overestimated in 3 out of every 4 projects, with only 39 projects experiencing no cost overrun or underrun across the whole sample. Each of these types of power infrastructure comes with its own set of construction concerns [40].

Nonetheless, results from the analysis pointed out the owner-related financial problems factor (O5) as the most important cause of design change for all project-types, ranking first. This means that the most significant cause of changes in design that occur in power projects in Ghana is financial problems (O5). Furthermore, the experts' remarks suggest that this is a major problem in Ghana's construction industry as a whole, not just in the power sector. Quite different from past research, owner-related financial concerns are seen as a significant driver of design change, but they are not the major cause [25]. This may be attributed to differences in the discipline and region of research. In the case of Ghana, lack of funds for projects and mishandling of funds during such projects are key drivers to owner's financial problems. Additionally, an owner's inability to satisfy a contractor's demand financially due to increasing business and market demands, as well as estimation errors, places serious pressure on contractors. This type of problem causes the owner to adjust the scope of the project in order to meet the project's budgetary requirements.

Additionally, apart from financial problems (O5), the results highlight errors and omissions in design (D2), problems or unforeseen site conditions (U1), and poor project objective definition (O6) as common among the top ten most important causes for the three project types. Problems or unforeseen site conditions (U1) is an important common cause, and experts ranked this cause in the top five for all subdivisions. Sometimes, there are fewer surveys and studies conducted by owners but, more importantly, such problems are difficult to detect even though geological and seismic features are described in reports, causing serious determent to project progress and allowing for design adjustments and modifications. This situation creates conflicts between owners and contractors about who should bear the risk. Design-related errors and omissions in design (D2) also ranks among the top ten causes for all categories. This is in line with one finding that the most common factors in design change are design errors and inconsistencies (material, detail, manufacturing errors) [41], depicting how consistent they are during the design phase. This situation is even more critical in the power plant subdivision because the design process in this project type is extremely complex. The owner assigns responsibility to the designer for various designs of the project. Good-quality design documentation is necessary for project efficiency (accurate or accurate, thorough, and unambiguous), although it is unfortunate that these documents frequently contain erroneous or conflicting information and are frequently incomplete [42]. Inexperienced designers make numerous errors, which are typical, especially in sophisticated and complicated power projects. Additionally, owner's poor project objective definition (O6) becomes a major hindrance to accurate designs because the designer is not able to fully comprehend the owner's requirements. In Ghana, the owner's inexperience accounts for the majority of such issues. Due to a lack of funds, most developing countries choose to hire contractors and enter into contractual arrangements that relieve them of financial obligations. As a result, contractors and designers with little expertise are hired. Errors and omissions in design (D2), the conflict between contract documents (O3), lack of coordination and communication (C3), modification of original design (C4), and problem or unforeseen site conditions (U1) have all been identified as major contributing causes in previous studies [4,17]. This is consistent with findings from the power plant subdivision, where characteristics evaluated by previous researchers can be found in the top ten most important causes of the power plant subdivision in this study. However, renewable and distribution projects present a different case according to experts because the contractual and scope approaches differ from those used in power plant projects. For example, power plant subdivisions require a lot more civil work than renewable and distribution and transmission project-types, as well as hundreds of design diagrams and considerable contract paperwork.

Similarly, a long decision-making time (O7), inflation and changes in interest and exchange rates (U5), and health and safety considerations (C2) commonly rank in the top ten most important causes for renewables and distribution and transmission project-types but are less relevant in power plant projects according to the findings. Generally, each cause is characterized by factors that make a lot of difference in the same industry. Thus, the different approach is key to ensuring effective change management for project types. Renewable projects in Ghana are constructed through utility-scales in small capacities compared to other countries; as such, they are less complex in nature and have fewer design-change issues than those of power plant projects. Nonetheless, their ramifications continue to have a negative impact on projects. In distribution and transmission projects, the majority are constructed by local contractors; such projects in Ghana are also dominated by the government (owner), hence accounting for the third to the sixth rank of change of plans (O1), long decision-making time (O7), poor project objective definition (O6), and additional work (O8), respectively, in this subdivision. This study weighed the causes of design change by ranking means; in practice, the risk register is utilized to determine design change priorities. By identifying design change priorities, appropriate measures can be used to effectively manage their impacts. Additionally, probabilistic risk analysis using Monte Carlo simulation is often advised for large projects such as developing power plants to minimize the negative impacts of design change because they can be used for delay and cost overrun predictions. Design changes in construction projects are not unavoidable; as a result, industry stakeholders should be aware of and develop a template for evaluating variation orders, particularly during the planning and execution stages of construction projects [20].

This study purposely investigated the important causes of design change in the Ghanaian power industry. The approach categorized power projects into three project types and identified important cause factors for each, comparing these cause factors among the subdivisions. In the future, more studies can be conducted on design change for power projects from the perspective contractors and clients, and their impacts, because in Ghana and perhaps the rest of western Africa, the concept of design changes, especially in power projects, is a less-discussed topic but contributes hugely to the challenges a project faces.

6. Conclusions

Several studies have been conducted on causes of design changes, with few identifying important causes and factors. This study mainly aligns to power projects, which is a topic rarely discussed in past studies. This research was carried out on Ghanaian power projects. As is well known, design-change problems are inevitable in power projects, as in any other industry. Design changes occur during the design phase and the construction phase; however, the impact of design changes on the construction phase is more significant. The final result identified owner-related financial problems as the most important cause of design changes in power projects in Ghana among all subdivisions. Among the power plant project-types, financial problems, errors and omissions in design, problems or unforeseen site conditions, modification of the original design, a conflict between contract documents, and noninvolvement of other parties during the design phase ranked as the top five most important causes. For the renewable project-type, financial problems, resources deficient in quality and quantity, inflation and changes in interest and exchange rates, errors and omissions in design, and problems or unforeseen site conditions were the five most important causes. In distribution and transmission project-types, financial problems, problems or unforeseen site conditions, change of plans; long decision-making time, poor project objective definition, and additional work ranked as the five most important causes. Owners, contractors, and designers are the most important participants in construction projects, and design changes are most often caused by the intentional or negligent actions of one or more of these parties. In Ghana's power-project industry, managing and enhancing design changes is critical, and project success is viable. This is because, as shown in Table 2, the majority of the important causes are due to controllable circumstances, implying that efficient design change management procedures can effectively minimize the number of major causes. According to the findings in this article, project stakeholders from various sectors of the power industry can better understand design change elements and causes that impede power-project performance and offer effective design change management solutions to reduce the negative effects of design change on projects.

Despite the fact that this study contributes to identifying design change causes, it has several limitations. First, the study's investigation was carried out among Ghana's power-project-types. As a result, practitioners in other industries and countries who use this study must pay close attention to specific conditions. Furthermore, the study did not reflect specific projects, project sizes, or contract types. As such, future studies could focus on identifying design change causes for various project conditions under various power project types as well as finding the impact of design changes.

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