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The causation of design error in the construction industry: A multi-stakeholder perspective

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Abstract:	A seemingly minor design error can have significant repercussions in a construction project, leading to serious safety and quality consequences, cost overrun and delays. This error can have a lasting impact, potentially affecting usability and safety during the operational stage of the completed facility. Despite these consequences, there is limited research on which stakeholders contribute more significantly to design errors. Furthermore, there is a disconnection in understanding among stakeholders about the causes of design errors. In order to address the knowledge gap, this research aimed to identify the critical causes of design errors from a multi-stakeholder perspective. Empirical survey data was collected from 243 design professionals (e.g., architect, structural designer, and water supply and drainage designer) across various stakeholders (e.g., client, design company, and construction company) in the Chinese construction industry. Descriptive and structural equation modeling (SEM) analyses reveal that contrary to common understanding, clients and geological surveying companies are the major stakeholders responsible for design errors in construction projects. The major factors leading to design errors are design input information error, unreasonable intervention on design, noncompliance with standard requirements, and error in site geological survey document. In contrast, concurrent design and construction requirements and poor working conditions are the least influential factors. Design professionals, regardless of their stakeholder groups, shared similar views on the causes of design errors. This research is among the first to uncover the causes of design errors on construction projects from a multi-stakeholder perspective. The findings offer valuable insights for stakeholders to improve design quality in the Chinese construction industry and other countries with similar environments.
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Question	**Response**
The journal requires that all submissions fall within its aims and scope, explained here. Please explain how your submission fits the journal's aims and scope.	A seemingly minor design error can have significant repercussions in a construction project, leading to serious safety and quality consequences, cost overrun and delays. This error can have a lasting impact, potentially affecting usability and safety during the operational stage of the completed facility. Despite these consequences, there is

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	limited research on which stakeholders contribute more significantly to design errors. Furthermore, there is a disconnection in understanding among stakeholders about the causes of design errors. In order to address the knowledge gap, this research aimed to identify the critical causes of design errors from a multi-stakeholder perspective. Empirical survey data was collected from 243 design professionals across various stakeholders in the Chinese construction industry. Descriptive and structural equation modeling (SEM) analyses reveal that contrary to common understanding, clients and geological surveying companies are the major stakeholders responsible for design errors in construction projects. Design professionals, regardless of their stakeholder groups, shared similar views on the causes of design errors. This research is among the first to uncover the causes of design errors on construction projects from a multi-stakeholder perspective. The findings are valuable for stakeholders in the construction industry in China and other countries with similar characteristics to take more targeted measures to improve design quality, which will in turn improve overall project performance. The submission falls within the journal's aims and scope of focusing on human errors in design and methods of investigation of failures issues. In addition, there are plenty of papers on design error or design quality topic published in this journal.
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The causation of design error in the construction industry: A multi-stakeholder perspective

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Abstract: A seemingly minor design error can have significant repercussions in a construction project, leading to serious safety and quality consequences, cost overrun and delays. This error can have a lasting impact, potentially affecting usability and safety during the operational stage of the completed facility. Despite these consequences, there is limited research on which stakeholders contribute more significantly to design errors. Furthermore, there is a disconnection in understanding among stakeholders about the causes of design errors. In order to address the knowledge gap, this research aimed to identify the critical causes of design errors from a multi-stakeholder perspective. Empirical survey data was collected from

243 design professionals (e.g., architect, structural designer, and water supply and drainage designer) across various stakeholders (e.g., client, design company, and construction company) in the Chinese construction industry. Descriptive and structural equation modeling (SEM) analyses reveal that contrary to common understanding, clients and geological surveying companies are the major stakeholders responsible for design errors in construction projects. The major factors leading to design errors are design input information error, unreasonable intervention on design, noncompliance with standard requirements, and error in site geological survey document. In contrast, concurrent design and construction requirements and poor working conditions are the least influential factors. Design professionals, regardless of their stakeholder groups, shared similar views on the causes of design errors. This research is among the first to uncover the causes of design errors on construction projects from a multi-stakeholder perspective. The findings offer valuable insights for stakeholders to improve design quality in the Chinese construction industry and other countries with similar environments.

Keywords: Design error; Causes; Construction projects; Construction Industry; China

Practical Applications

The research findings have significant practical implications for various stakeholders to more effectively reduce design errors in construction projects. By identifying the critical factors leading to design errors from a multi-stakeholder perspective, this research provides a strong empirical foundation for developing novel evidence-based design quality management strategies to prevent the chronic problem of design errors in the construction industry. The results highlight that in addition to ensuring the capability of design development company and designers, design quality is heavily dependent on the accuracy of design input information provided by the clients, and compliance with standard requirements and high-quality site geological survey documents provided by geological surveying companies. Adequate time is needed in the preliminary design phase to thoroughly review the input information provided by clients and geological surveying companies. In addition, clients should avoid excessive interference in the design process and should instead empower the designers to determine design details or design solutions as these are helpful to reduce design changes and avoid potential design quality problems. Finally, stakeholders should also pay special attention to changes to design-related laws/regulations and standards/codes as these are major factors causing design error in the construction industry.

1. Introduction

Design quality has significant impacts on the construction and operation of facilities and infrastructure (Lopez and Love, 2012; Ham et al., 2018; O’Connor and Koo, 2020). Design error, including incorrect dimensions, conflicts between different design elements and documents, and non-compliance with building standards and codes (Lopez et al., 2010; O’Connor and Koo, 2021b), is one of the primary causes of delays, rework, change orders, poor quality, cost overruns, disputes, accidents, and negative environmental and social consequences (Love et al., 2009a; Sun and Meng, 2009; Lopez et al., 2010; Lopez and Love, 2012; Love et al., 2012; Ham et al., 2018; O’Connor and Koo, 2020). Defective design accounted for around 30% of total rework and cost overruns (Andi and Minato, 2003). Lopez and Love (2012) reported that design errors lead to additional direct and indirect costs which are 6.85% and 7.36% of the contract value, respectively. In another study, Love et al. (2014) found that the mean costs of design error in construction projects are 14.2% of the original contract value. Design error has been identified as a critical factor responsible for the collapse of a tunnel in the Nicoll Highway in Singapore (Lopez et al., 2010). It is also a main factor contributing to poor construction waste management in infrastructure projects (Naji et al., 2022).

Design process in construction has become more complex due to client demands, resource constraints, regulatory changes, and increased project complexity (O’Connor and Koo, 2021a; Koo and O’Connor, 2022). In a typical construction project, design can be divided into several phases, such as programming, schematic design, design development, and construction documentation (AIA, 2013). Many stakeholders, such as client, design company and geological surveying company, contribute to the design process and its corresponding outcome (Huang, 2020; Zhang et al., 2021; Zhang et al., 2023). Therefore, high-quality design relies heavily on close collaboration among these stakeholders. However, conflict of interest among them is common. For instance, clients may require designers to complete their design with the lowest possible price at the shortest possible duration. In addition, frequent changes initiated by the clients make design an iterative and time-consuming process, which further adds to the designers’ workload. As a result, design error has become a chronic problem in the construction industry (Love et al., 2014).

Due to its significance, there has been research on design quality and design error. For instance, O’Connor and Koo (2020) identified 47 high-priority design defects. Hassanain et al. (2022) developed standardized design quality indicators suitable to evaluate the design quality of campus facilities. Despite this, the industry still lacks an in-depth understanding of design errors in construction projects (O’Connor and Koo, 2020). Firstly, as design involves multiple disciplines and many stakeholders, it remains unknown which stakeholders contribute more significantly to design errors. This understanding is important as project stakeholders have different contributions and inputs in different design phases, which influence final design quality. This highlights that critical causal factors related to different stakeholders should be identified to formulate more effective and targeted measures to improve design quality. Secondly, research is limited in exploring the differing perspectives on design errors among project stakeholders.

Andi and Minato (2003) found that designers and contractors have different understandings of the quality of design documents. O’Connor and Koo (2020) also reported that significant differences exist in relation to the frequency of problematic design deliverables between two groups of professionals with different expertise areas and organizational types. In this case, different stakeholders in the design process may attach the importance of a particular cause or the impact of design error differently (Naji et al., 2022; Zhang et al., 2023). This requires gathering empirical insights from design professionals working for different types of stakeholders to obtain their comprehensive views.

As explained above, there is a lack of research on which stakeholders contribute more significantly to design errors and a comprehensive understanding on the different perspectives among stakeholders about the causes of design errors. In order to fill this knowledge gap, this paper takes a state-of-the-art multi-stakeholder perspective, primarily aiming to (1) identify the critical causes of design errors; (2) compare the perspectives on the causes of design errors among different stakeholders. This research focuses on the Chinese construction industry, a pillar industry contributing to the national economy, with its added value accounting for 6.89% of the gross domestic product in 2022 (China Construction Industry Association, 2022). The results have critical implications for practitioners to improve construction project performance in China, which can also be adapted to other countries with similar practices.

2. Literature Review on Design Error Causation

Many factors can cause design errors. Love et al.’s (2009b) investigation indicated that practice, task, and circumstance factors are major contributors to design errors. Lopez et al. (2010) and Love et al. (2012) categorized design error casual factors into three groups, comprising people, organization and project, while Ham et al. (2018) grouped design errors into simple design, rework related, and delay related. More recently, O’Connor and Koo (2021b) sorted the contributing factors of design defects into ten categories, including deficient designer knowledge and experience, incomplete statement of basis/requirements, and others. Based on an extensive literature review of relevant research, 36 casual factors relevant to the Chinese construction industry were identified and grouped into four dimensions (Table 1). Although various delivery methods are used in the Chinese construction industry, including design-build and engineering-procurement-construction, traditional method is still the most popular one where contractors and subcontractors have no or little involvement in design process. In this context, client, design company and geological surveying company are viewed as the most critical stakeholders influencing the design quality of construction projects (Huang, 2020; Zhang et al., 2021; Zhang et al., 2023).

<Place Table 1 here>

2.1. Client-related factors

Design quality is heavily dependent on whether and how well the client recognizes their project needs, define these needs accurately, and communicate their requirements to designers clearly (Kärnä and Junnonen, 2017). Inexperienced clients who are uncertain about their project requirements and scope tend to provide insufficient project information and incomplete design input documents, which increase the occurrence of errors (Lopez and Love, 2012; Shoar and Chileshe, 2021). In contrast, experienced clients are more sophisticated and may make frequent changes, resulting in design errors (Hwang and Yang, 2014; Wang et al., 2016). In China, majority of the clients pay more attention on fast delivery of design for early start of construction work (Zhang et al., 2023), which leads to tight design schedule and causes negligence during design audits, reviews, and verifications (Assaf et al., 2018). Low design fee required by client is another common factor contributing to design errors (Zhang et al., 2023), as a result, design companies sometimes reuse existing design details and specifications to reduce cost and time, resulting in inappropriate design which fails to meet the intended purpose (Shoar and Chileshe, 2021).

2.2. Design company-related factors

Design companies play a direct and critical role in ensuring the quality of design outcomes. In China, normally one design company provides an overall design service to clients. However, for some specific projects, usually large and complex infrastructure projects, design work is sub-divided into different packages, which are completed by different design companies (Huang, 2020). In addition, some specialized design companies may be hired by the leading design company to complete design development tasks. Therefore, the quality of design for this type of project not only relies on the experience of the leading design company but also the close collaboration of different design companies involved (Zhang et al., 2021).

Insufficient designers' skills, knowledge, and experience have been widely recognized as design company-related causes for design errors in construction projects (Yap et al., 2017). Jingmond and Agren (2015) highlighted that the lack of knowledge and insufficient knowledge transfer within design teams are critical factors leading to design flaws. A design team with high morale tends to have positive attitudes, which in turn is more likely to stimulate their design skill and knowledge to solve problems and avoid mistakes (Love et al., 2014c). On the other hand, designers' excessive workload due to tight design schedule can negatively affect their design quality (Love et al., 2009b; Shoar and Chileshe, 2021). Ye et al. (2015) revealed that excessive design tasks and time constraints are significant contributors of design error in the Chinese construction industry.

Designers' poor understanding of client requirements can produce errors in design documents (Assaf et al., 2017), demonstrating the need for clients to convey their requirements and expectations succinctly (O'Connor and Koo, 2020; Koo and O'Connor, 2022). The lack of communication between design and construction stakeholders can also cause inadequate consideration to constructability of design outcomes

(Ye et al., 2015).

Moreover, inadequate application of technology has been considered as another factor leading to design errors (Andi and Minato, 2004). Wang et al. (2016) highlighted that novel technologies, such as building information modelling (BIM), facilitating design clash detection, can create more integrated and optimized design (Ham et al., 2018; Craveiro et al., 2019). Interestingly, over-reliance on technologies can also cause design errors due to technical problems, such as poor software interoperability, poor practicality, and human errors (Yap et al., 2017; Assaf et al., 2018).

2.3. Geological surveying company-related factors

Geological site surveying is important to determine the selection and design of the foundation and structural systems of the facility to be built. Andi and Minato (2004) identified errors of site surveying activities as one of the direct factors causing defective design. Hwang and Yang (2014) indicated that incomplete site surveying documents can result in significant rework and delay in the design process. Similarly, Hughes and Thorpe (2014) found that incomplete site survey is a critical factor leading to incomplete drawings in the design stage. Yap and Skitmore (2018) identified site-induced factors, including unforeseen ground conditions, undetected underground utilities, and insufficient soil investigation as important contributors to design changes.

2.4. Other factors

Other factors are those which may not be attached to a particular stakeholder but have considerable influences on design quality. Changes to the design standards and codes have been widely recognized as causes for design errors (Yap et al., 2017). The stereotype of “the best bid is the lowest bid” may encourage unqualified companies to compete using improper methods, leading to poor quality of design documents (Shan et al., 2017). Also, the highly complex, ever-changing, and multidisciplinary nature of construction projects make design error prone (Assaf et al., 2018). In this case, ineffective communication and poor coordination among stakeholders can jeopardize collaboration, generating more human and organizational errors (Yap and Skitmore, 2018). Finally, poor working environments, such as unbearable noises, can also result in design errors (Assaf et al., 2018; Huang, 2020).

3. Research Methodology

3.1. Research process

This research was conducted in three stages. In the first stage, an extensive literature review was conducted to identify the causes of design errors on construction projects in China. The identified causes were categorized into four groups, which are presented in previous section. In the second stage, a questionnaire was designed and verified through a pilot survey, and was administered among design professionals working for different major stakeholders in the Chinese construction industry.

In the third stage, the collected data was analyzed by the following three steps. First, the Cronbach' s alpha coefficient, Bartlett's test of sphericity, and the Kaiser-Meyer-Olkin (KMO) were calculated to evaluate the reliability and internal consistency of the survey data and determine the suitability for further analysis. A Kolmogorov Smirnov (KS) test was also carried out to ascertain whether the data was normally distributed and choose the appropriate test to explore the differences of perspectives among major stakeholders. Second, descriptive analyses were conducted to obtain the mean values of the causal factors of design errors. Mean value results for different sub-groups and Kruskal Waillis (KW) test were used to compare the perspectives on the importance of design error causation factors among different types of design professionals working for various stakeholders. As the data for the causes of design error was not normally distributed, Spearman's correlation analysis was employed to ascertain the relationship between the four dimensions causing design error. The Spearman's rho coefficient was used to evaluate the characteristics of the relationship between the variables, including the direction and strength of the relationship. Third, structural equation modeling (SEM) was used to determine the relationships among the causal factors. SEM is considered as the most powerful technique to determine the significance and relationships among the observed and latent variables in a model (Zahoor et al., 2017), and has been frequently used in the construction management field. For instance, Naji et al. (2022) used SEM to ascertain major factors influencing construction waste management in infrastructure projects, while Gunduz et al. (2022) employed SEM to determine value engineering factors influencing design management performance of construction projects. Although four indices are adequate to determine the degree of fit for the structural equation model (Keline, 1998), six indices were employed in this study, including Chi-square χ^2, df (degrees of freedom), RMSEA (root mean square residual), GFI (goodness-of-fit index), CFI (comparative fit index), and IFI (incremental fit index), and the following thresholds are used for these indices: χ^2/df $<$ 3, RMSEA $<$ 0.08, GFI $>$ 0.8, CFI $>$ 0.8, and IFI $>$ 0.8 (Awang, 2012; Xiong et al., 2015; Tripathi and Jha, 2018; Naji et al., 2022).

3.2. Data collection

The questionnaire comprised two sections. The first section collected the demographic information of the surveyed design professionals, including their age, type of organization they are working for, discipline involved, and years of working experience. In addition, one single-choice question was used to find out the type of projects tend to have more design errors. The second section sought to identify the critical factors causing design errors, drawn from the literature review. A five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree) was used in this section.

A pilot study was conducted with eight experienced design professionals who have different backgrounds (two architects, one structural designer, one water supply and drainage designer, two heating ventilation and air-conditioning (HVAC) designers, one electrical designer and one landscape designer, with five to over 15 years of working experience) to validate and improve the questionnaire. Through this process some factors leading to design error were regrouped or added, including OF-7 and DCRF-14 in Table 1 which were further verified through literature review results. In addition, the wording for some statements was refined to improve clarity. The final questionnaire was administered online and face-to-face to design professionals (designers and professionals who primarily deal with design issues in their work) with the aim of obtaining a representative sample from different key stakeholders to get balanced views, including clients, design companies, geological surveying companies, and construction companies. The survey participants were approached using research team networks.

Data underwent a two-step screening process to ensure their validity. First, the responses were scrutinized for completeness. Second, standard deviation (SD) values for the Likert scale parts were calculated to determine whether all the answers to the questions were the same. If the SD value was zero, the response was considered as repeated answers and thus invalid (Zheng et al., 2023). In total, 268 responses were collected, in which 243 are valid. Among these, 34 are face-to-face responses and 209 are online responses (see Table 2). Existing research argues that an SEM analysis requires a minimum between 100 and 400 responses, with over 200 as the rule of thumb (Iacobucci, 2009; Tripathi and Jha, 2018). The sample size of this research is also better than or comparable to other similar research (e.g., Lopez and Love, 2012; O'Connor et al., 2020).

<Place Table 2 here>

4. Data Analysis Results

4.1. Reliability and validity

Statistical analyses were conducted using Statistical Package for Social Science (SPSS) 24.0. The

Cronbach’s alpha coefficients for the causes of design error are 0.929. The value is beyond the 0.7 threshold, meaning the questionnaire is reliable (George and Mallery, 2003). Furthermore, the KMO for the causes of design error is 0.907, higher than the acceptable threshold of 0.5. The Bartlett’s test of sphericity result (0.00) is lower than 0.05, indicating a good strength of relationship among the variables. These results suggest that the validity of the survey is acceptable and suitable for further analysis (Deng et al., 2014).

4.2. Causes of design errors

4.2.1. Differences among stakeholders

A KS test found that each data group of the 36 causes of design error was not normally distributed. Therefore, KW test was used to find the perspectives of different stakeholders on factors that lead to design errors. The results are presented in Table 3.

<Place Table 3 here>

Table 3 shows that generally the stakeholders had common understanding on the importance of 32 factors (88.90%) that can cause design errors in Chinese construction projects. However, they opined differently on four factors, including CRF-1, DCRF-12, DCRF-14, and DCRF-16. The results in the table also indicate that majority of the casual factors were perceived as important by respondents from different types of stakeholders (mean value close to or over 4).

4.2.2. Correlation among different dimensions

Spearman’s correlation analysis was employed to explore the direction and strength of relationship between the four dimensions causing design errors. The mean values of the factors in each dimension were calculated as the input for Spearman’s correlation analysis. The results are shown in Table 4.

<Place Table 4 here>

Table 4 shows that the four dimensions have strong and positive correlations with each other. This indicates that an increase in one dimension will also increase the problems in the other dimensions. Practically, it is necessary to pay attention to all the factors in these dimensions to reduce design errors.

4.2.3. SEM analysis

AMOS24.0 was first used to conduct first-order confirmatory factor analysis on the four latent variables and thirty-six observed variables. The preliminary first-order confirmatory factor analysis results indicated that factor loadings for CRF-3, CRF-4, DCRF-6, DCRF-8, DCRF-10, DCRF-15, DCRF-16, and DCRF-17 were less than 0.5, so they were excluded from further analysis (Awang, 2012; Xiong et al., 2015). Similarly, analysis on the remaining 28 factors resulted in the exclusion of OF-3. The loadings for the remaining 27 factors are all above 0.5 after another round of analysis. The final first-order confirmatory factor analysis model indicated a good fit ($\chi^2/df=2.011 < 3$, $RMSEA=0.065 < 0.08$, $GFI=0.819 > 0.8$, $CFI=0.876 > 0.8$, and $IFI=0.878 > 0.8$). The second-order confirmatory factor analysis was then followed, and the result indicated no data problem with the model ($\chi^2/df=2.014 < 3$, $RMSEA=0.065 < 0.08$, $GFI=0.817 > 0.8$, $CFI=0.877 > 0.8$, and $IFI=0.875 > 0.8$) (Awang, 2012; Xiong et al., 2015; Tripathi and Jha, 2018; Naji et al., 2022). The final result is shown in Figure 1.

Figure 1 shows that at the dimension level the path coefficients (i.e., standardized factor loadings) between the overall DE and the four constructs (CRF, DCRF, GSCRF, and OF) are 0.8834, 0.8323, 0.8737, and 0.8324, respectively. At the factor level, DCRF-14 has the strongest standardized factor loading (0.658) with DCRF, CRF-2 has the strongest path coefficient (0.667) with CRF, GSCRF-1 has the strongest path coefficient (0.864) with GSCRF, and OF-1 has the strongest standardized factor loading (0.728) with OF.

<Place Figure 1 here>

4.3 Design error occurrence in different types of projects

Respondents were also asked the type of project where design errors occur most frequently, and the results are shown in Table 5. Buildings primarily includes office buildings, residential buildings, and apartment complexes. Civil engineering projects mainly involve roadways, bridges, canals, dams and tunnels. Mechanical and electrical works are most related to the installation of HVAC systems, power systems, and fire-fighting systems. The majority of the respondents (57.61%) concluded that design errors most often occur in building projects, and this view is shared among different design stakeholders. Interestingly, clients, design companies, and geological surveying companies pointed out that after building works, design errors commonly occur in mechanical and electrical works, while construction companies argued that civil engineering projects are more problematic.

<Place Table 5 here>

5. Discussion

5.1. Causes of design errors at the dimension level

SEM analysis results indicate that client-related and geological surveying company-related factors are the leading causes of design errors in Chinese construction projects. This result is somewhat unexpected because traditionally design company is the primary stakeholder undertaking the majority of the design works, and logically design company-related factors should be the leading causes of design errors (Huang, 2020). Despite this, existing research does argue the important role played by clients in determining the design quality. For instance, the extent of client-provided design in design and build projects decreases design innovation and increases design change (Zhang et al., 2019). In addition, unrealistic design expectations and tight schedule required by clients are significant factors causing design errors (Love et al., 2014). In fact, clients have critical influences on design quality because they determine design requirements and constraints, and have considerable managerial inputs in the overall design process. The first author of this paper had the experience of being involved in an industrial construction project where the spatial arrangement of production line was incorrect, leading to design errors which affected productivity. Liu et al.'s (2023) investigation into the Chinese water conservation construction projects also indicated that clients' design management capability strongly influences design performance, including design quality. Notwithstanding the above, the importance of geological surveying company-related factors on design errors derived from this research is new and enlightening. This means that although geological surveying companies may not be a main stakeholder in the actual design process, which is a common practice in China, the quality of information and documents provided by them has major influences on the occurrence of design errors. Lv (2022) further reported that poor quality of geological surveying documents in Chinese water conservation construction projects is mainly caused by insufficient investigation into the site, poor quality management system of geological surveying companies, poor skill and knowledge of surveying professionals, low contract price because of competitive tendering, and tight schedule for surveying work.

Additionally, the correlation analysis indicated that the four dimensions causing design errors are strongly interrelated, where an increase in one dimension corresponds to an increase in the remaining three. Therefore, comprehensive measures are required to address all the dimensions to effectively reduce design errors. As claimed by Andi and Minato (2003), the problems of defective designs are complex and deep rooted, influenced by many factors operating at individual, organizational, industry and national levels. In such an interrelated work environment, close collaboration between the major stakeholders in the overall design process is needed to improve design quality, constructability, innovation and value engineering.

5.2. Causes of design errors at the factor level

First, *design input information error* and *unreasonable intervention on design* are two critical client-related factors causing design errors. In contrast, Andi and Minato (2003) revealed that client's tendency to reduce design fee is an important factor affecting the quality of design documents. The importance of design input information has been frequently mentioned in past research (Yoon et al., 2021), but the influence of unreasonable intervention on design by the client has not been brought into attention previously. Due to the rapid development of the Chinese construction industry in the past three decades or so, some clients who repetitively construct projects, such as real estate developers, have become more and more sophisticated and stronger in making design-related decisions (Zhang et al., 2023). As a result, designers have weaker influences on the design process, such as finalizing design proposals, determining materials to be used, and arranging space usability and layouts. Too much intervention can also lead to frequent design changes, which further complicate the design process, make the designers feel frustrated, and lead to more design errors.

Second, *poor design ability of design development company* and *poor design skills of designers* are two leading design company-related factors causing design errors. Design development companies usually have considerable input in detailing and optimizing design (Huang, 2020). However, these companies tend to be small in scale and are limited in their capacity to employ high-profile and experienced designers, which in turn limits their ability to provide high-quality design services. As to the skills of designers, referring to the practical application of knowledge in the design process (Ibrahim et al., 2021), similar to Assaf et al. (2018), inadequate experience and education is a major issue causing poor design quality in China. Specifically, designers in the Chinese construction industry have less experience of working on site, which limits their comprehensive understanding on the overall building or civil engineering works systems as well as construction methods and process (Huang, 2020), leading to potential design conflicts among different design disciplines.

Third, *noncompliance with standard requirements* and *error in site geological survey document* are two major geological surveying company-related factors responsible for design errors. The first author witnessed significant rework (over 10% of the foundation needed redesigning and reconstruction), delay and cost overruns occurred in designing and constructing the foundation of an industrial construction project because of incorrect soil composition investigation results. The root cause for the poor soil investigation is noncompliance with standard requirements by the geological surveying company to reduce cost, resulting in insufficient number of surveying points on site. The significant problem here is that these incorrect survey results, which are an important basis for foundation and structural design, are difficult to detect in the design review process. Notably, geological surveying errors may lead to more profound and cascading effects on the design quality and downstream design if they are related to important structural systems or components of buildings or civil engineering works.

Finally, *changes to design-related laws/regulations* or *standards/codes* are two other critical factors causing design errors. There are a large number of design laws/regulations or standards/codes in China and it is a normal practice to make adjustments to them due to the evolution of best practices in the construction industry. Specifically, the popular application of digitalization and pre-manufacturing together with the development of more large-scale infrastructures (e.g., Hong Kong-Zhuhai-Macao Bridge) and skyscrapers (e.g., Shanghai Center) make it necessary to update the design laws/regulations or standards/codes to meet the trends. For instance, recently, the Ministry of Housing and Urban-Rural Development of China issued three adjustment notices related to joint connection technical code, concrete road surface technical code, and manufacturing plant design code. The majority of these requirements are mandatory, which designers must strictly follow. When designers are not aware of these changes in the requirements, design errors may occur. Koo and O'Connor (2022) claimed that BIM can be valuable in performing detailed design tasks, especially in terms of compliance with design standards and codes.

The KW test results indicated that designers working for different organizations have common understanding on the majority of the factors causing design errors. Similarly, O'Connor and Woo (2017) also revealed similarities in responses between clients and contractors regarding sources of problems in design deliverables. This result facilitates the development of general solutions to reduce design errors in the Chinese construction industry.

5.3 Design error occurrence in different types of projects

This research found that design errors occur more frequently in building works, which are somewhat different from past research conducted in other locations. As to the occurrence of design errors on different types of construction projects, Love et al. (2014a) found no significant variations in the cost of design error in different types of projects and procurement methods. In another study, Love et al. (2014b) revealed that design error costs in civil engineering projects are higher than those in fit-out projects. Love and Li (2000) reported that the cost of design errors is lower in building projects, accounting for 14% of rework costs. Lee et al. (2012) revealed that 54.42% of design errors occur in structures, followed by 33.82% in architecture and 11.76% in mechanical, electrical and plumbing system. The construction of high-rise buildings is common in China in recent years. High-rise building works include complicated structures and sub-systems, which are also affected by environmental factors, such as wind and earthquake loads (Huang, 2020). This may be the reasons behind the frequent occurrence of design errors in this type of project.

6. Implications

An input-process-output model (Bernold and AbouRizk, 2010; Meng, 2014) was used to further interpret the results about the critical causes and find more effective measures to reduce design errors in Chinese construction projects. According to the model depicted in Figure 2, if the design process is divided into input, process and output, the findings highlight the criticality of design input to reduce design errors. In order to produce high-quality design, designers need reliable information, particularly from clients and geological surveying companies. Less intervention from the clients is also advocated as it is helpful to reduce unnecessary design changes and increase designer's motivation which is valuable to improve the design quality (Love et al., 2014c; Wang et al., 2016; Liu et al., 2023). In addition, there should be better communication to ensure that designers are aware of changes to laws/regulations and standards/codes which affect design. Incorrect input will produce latent and profound consequences on the following downstream design process. In terms of the design process control, special attention should be paid to the capability of design development companies as design subcontracting is a normal practice in China and these companies complete a considerable portion of design work. Finally, designers' skill is critical for design quality. For instance, the skill of using virtual reality and other technologies could enhance their understanding on the actual construction process which in turn reduce design errors.

<Place Figure 2 here>

Based on the input-process-output model, it implies that if design errors can be detected in an earlier stage, their negative consequences can be reduced more effectively. However, in practice, design input problems are difficult to identify in the design review process (Palaneeswaran et al., 2014), which includes the internal design review by design companies, external design review by clients or design experts invited by clients, and final design review by the authorities in China. Therefore, all major stakeholders should pay special attention to the three essentials of design quality (completeness, correctness, and timeliness) as suggested by Woo and O’Connor (2021), meaning that designers should have and be well informed of all the required and accurate information in a timely manner. Specifically, more attention should be paid to building works and mechanical and electrical works as these two types of works tend to have more design errors in Chinese construction projects.

7. Conclusion and Future Research Directions

While previous studies have examined the origins of design errors, there has been a notable absence of insights from design professionals across various Chinese organizations. Addressing this gap, this research identified the critical factors causing design errors, offering a comprehensive view from a multi-stakeholder perspective. Recognizing that different stakeholders may perceive the cause of design errors divergently is key to understanding the full spectrum of these issues.

It was found that *incorrect information* and *unreasonable intervention on design* by the client, *noncompliance with standard requirements* and *incorrect survey document* by the geological surveying company, as well as *changes to design-related laws/regulations* or *standards/codes* are critical factors causing design errors in Chinese construction projects. This implies that the input in the design process is an important factor that determines design quality. In addition, the stakeholders had common understanding on the importance of nearly 90% of the factors causing design errors in construction projects. Notably, design errors are more prevalent in building projects compared to other types of works.

These findings are critical to formulating more targeted and effective measures to reduce design errors in the Chinese construction industry. It is recommended that in the preliminary design phase, the input information provided by clients and geological surveying companies should be meticulously scrutinized by an assembly of stakeholders, including experienced construction companies who have local construction experiences. This collaborative review is vital, as flaws in design inputs are often not readily detectable during the design review process. Early detection of incorrect, insufficient or out-of-date information can be a cost-efficient approach to significantly reduce later-stage design and construction changes and reworks.

There are limitations in this research that need further exploration in future research. First, although design professionals are more directly involved in the design process and have a more comprehensive understanding of design errors, other professionals, such as construction managers, may also have hands-on experience in handling design errors. Hence, it is necessary to collect viewpoints from other types of professionals working on construction projects to get a broader understanding of this issue. Second, other data collection approaches (e.g., interviews) can be employed to obtain qualitative data to further complement the quantitative survey results in this study.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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Figure caption list

Table 1 Factors causing design error

Factors (code)	Literature source
Dimension1: Client-related factors (CRF)	
Unclear project requirements (CRF-1)	Andi and Minato (2004); Love et al. (2012); Yap et al. (2017); Woo and O’Connor (2021); Shoar and Chileshe (2021); O’Connor and Koo (2021b)
Design input information error (CRF-2)	Jingmond and Agren (2015); Yoon et al. (2021)
Tight design schedule (CRF-3)	Love et al. (2009b); Lopez et al. (2010); Love et al. (2014); El-Sayegh et al. (2020); Shoar and Chileshe (2021); O’Connor and Koo (2021b)
Low design fee (CRF-4)	Love et al. (2009b); Lopez et al. (2010); Assaf et al. (2018); Huang (2020)
Concurrent design and construction requirements (CRF-5)	Bogus et al. (2011); Dehghan and Ruwnapura (2014)
Unreasonable intervention on design (CRF-6)	Yap et al. (2017); Yap and Skirmore (2018); Shoar and Chileshe (2021); Zhang et al. (2023)
Frequent changes in requirements (CRF-7)	Zhao et al. (2016); Assaf et al. (2018); Shoar and Chileshe (2021); Zhang et al. (2023)
Dimension2: Design company-related factors (DCRF)	
Poor design knowledge of designers (DCRF-1)	Lopez et al. (2010); Love et al. (2014); Jingmond and Agren (2015); Assaf et al. (2018); O’Connor and Koo (2021b)
Poor design experience of designers (DCRF-2)	Love et al. (2009b); Lopez et al. (2010); Love et al. (2012); Love et al. (2014); Assaf et al. (2018); O’Connor and Koo (2021b)
Poor design skills of designers (DCRF-3)	Love et al. (2009b); Lopez et al. (2010); Love et al. (2012); Love et al. (2014)
Poor ethics of designers (DCRF-4)	Love et al. (2014c); Lohne et al. (2017); Huang (2020)
Poor design accountability of designers (DCRF-5)	Andi and Minato (2004); Love et al. (2009b); Love et al. (2012); O’Connor and Koo (2021b)
Excessive design workload of designers (DCRF-6)	Lopez et al. (2010); Ye et al. (2015); Assaf et al. (2018); Shoar and Chileshe (2021); O’Connor and Koo (2021b)
Inadequate review of design preliminary documents (DCRF-7)	Lopez et al. (2010); Yap et al. (2017)
Misunderstanding of client's requirements (DCRF-8)	Love et al. (2009b); Lopez et al. (2010); Wang et al. (2016); Assaf et al. (2017); O’Connor and Koo (2020); O’Connor and Koo (2021b); Koo and O’Connor (2022)
Inadequate consideration of constructability in design proposal (DCRF-9)	Ye et al. (2015); Yap and Skitmore (2018); Yoon et al. (2021); O’Connor and Koo (2021b)

Inadequate design review and quality control policy (DCRF-10)	Love et al. (2009b); Lopez et al. (2010); Love et al. (2012) Assaf et al. (2018); Shoar and Chileshe (2021); Woo and O’Connor (2021)
Nonconformance to design process management (DCRF-11)	Love et al. (2009b); Love et al. (2012); Assaf et al. (2018); Shoar and Chileshe (2021)
Design work mismatching with designer's ability and experience (DCRF-12)	Love et al. (2009b); Love et al. (2012); Hughes and Thorpe (2014); O’Connor and Koo (2021b)
Inadequate communication among different disciplinary designers (DCRF-13)	Andi and Minato (2004); Lopez et al. (2010); Ye et al. (2015); Assaf et al. (2018); O’Connor and Koo (2020); O’Connor and Koo (2021b); Koo and O’Connor (2022)
Poor design ability of design development company (DCRF-14)	Wang et al. (2016); Huang (2020)
Inadequate payment incentives to designers (DCRF-15)	Love et al. (2009b); Lopez et al. (2010); Jingmond and Agren (2015)
Over reliance on design software (DCRF-16)	Andi and Minato (2004); Love et al. (2009b); Lopez et al. (2010); Assaf et al. (2018)
Inadequate application of modern technology (DCRF-17)	Andi and Minato (2004); Love et al. (2012); O’Connor and Koo (2021b)
Dimension3: Geological surveying company-related factors (GSCRF)	
Noncompliance with standard requirements (GSCRF-1)	Andi and Minato (2004); Hughes and Thorpe (2014)
Error in site geological survey document (GSCRF-2)	Andi and Minato (2004); Hughes and Thorpe (2014)
Error in geological survey results (GSCRF-3)	Andi and Minato (2004); Lopez et al. (2010)
Incomplete geological survey documents (GSCRF-4)	Hughes and Thorpe (2014); Hwang and Yang (2014)
Dimension4: Other factors (OF)	
Changes to design-related laws/regulations (OF-1)	Ye et al. (2015); Yap et al. (2017); Shoar and Chileshe (2021)
Changes to design-related standards/codes (OF-2)	Andi and Minato (2004); Lopez et al. (2010); O’Connor and Koo (2020); Koo and O’Connor (2022)
Fierce competition leading to low design fee (OF-3)	Lopez et al (2010); Love et al. (2012); Love et al. (2014c); Huang (2020)
Unqualified design company trying to win the bid using improper methods (OF-4)	Liu et al. (2011); Shan et al. (2017)
Project nature (complexity, large scale, many disciplines involved) (OF-5)	Lopez et al. (2010); Assaf et al. (2018); O’Connor and Koo (2021b)
Poor communication among the stakeholders involved (OF-6)	Lopez et al. (2010); Jingmond and Agren (2015); Shoar and Chileshe (2021); O’Connor and Koo (2021b); Koo and O’Connor (2022)
Changes to design team or designers (OF-7)	Love et al. (2009b); Assaf et al. (2018)
Poor working conditions (OF-8)	Lopez et al. (2010); Assaf et al. (2018)

Table 2 Profile of the respondents

Category	Profile	Percentage
Age	Less than 20 years old	0.00%
	21-25 years old	12.76%
	26-30 years old	21.81%
	31-35 years old	27.57%
	36-40 years old	17.70%
	41-45 years old	7.40%
	46-50 years old	4.12%
	51-55 years old	8.23%
	56-60 years old	0.41%
	Over 60 years old	0.00%
Type of organization	Client	31.28%
	Design company	53.91%
	Geological surveying company	3.29%
	Construction company	8.64%
	Other (e.g., Consultant)	2.88%

Category	Profile	Percentage
Type of discipline	Architect	31.69%
	Structural designer	28.39%
	Water supply and drainage designer	10.70%
	Heating ventilation and air-conditioning (HVAC) designer	2.06%
	Electrical designer	2.06%
	Landscape designer	8.23%
	Interior designer	4.94%
	Other (e.g., Exterior facade designer, Building Information Modeling)	11.93%
Years of working experience	Less than 1 year	11.93%
	1-5 years	23.05%
	6-10 years	18.93%
	11-15 years	18.93%
	16-20 years	13.99%
	21-25 years	7.00%
	26-30 years	5.35%
	Over 30 years	0.82%

Table 3 Mean score and KW test results

Factor	Mean value					*p*
	Client	Design company	Geological surveying company	Construction company	Other	
CRF-1	3.93	4.04	4.19	3.75	4.86	0.009*
CRF-2	4.05	4.01	4.29	3.75	4.57	0.111
CRF-3	3.91	3.89	4.00	3.38	4.43	0.085
CRF-4	3.61	3.78	3.86	3.75	4.00	0.701
CRF-5	3.97	3.96	4.19	4.00	4.57	0.304
CRF-6	3.87	3.90	4.19	3.63	3.57	0.271
CRF-7	3.96	3.99	4.33	3.88	4.57	0.100
DCRF-1	3.87	3.75	4.00	3.88	3.86	0.801
DCRF-2	4.01	3.88	4.05	3.63	4.14	0.464
DCRF-3	3.86	3.94	4.00	3.75	3.86	0.876
DCRF-4	3.83	3.84	3.81	3.63	4.14	0.934
DCRF-5	4.04	3.91	4.00	3.88	4.29	0.564

DCRF-6	4.11	4.07	4.29	3.50	4.14	0.082
DCRF-7	3.70	3.79	3.86	3.38	3.86	0.651
DCRF-8	3.82	3.89	3.95	3.75	4.00	0.938
DCRF-9	3.53	3.50	3.86	4.25	3.71	0.073
DCRF-10	3.46	3.66	3.62	3.50	3.14	0.576
DCRF-11	3.79	3.76	3.57	3.75	3.57	0.691
DCRF-12	3.78	4.11	3.86	3.38	4.00	0.008*
DCRF-13	4.16	4.24	3.86	4.13	4.00	0.298
DCRF-14	3.87	3.98	3.38	4.00	3.57	0.023*
DCRF-15	3.83	3.93	3.95	4.00	4.00	0.926
DCRF-16	3.76	4.15	4.10	3.63	4.43	0.009*
DCRF-17	3.86	3.84	3.95	3.75	3.71	0.927
GSCRF-1	3.62	3.86	3.90	3.25	4.00	0.285
GSCRF-2	3.67	3.89	3.95	3.13	4.14	0.109
GSCRF-3	3.82	3.89	4.14	3.25	4.14	0.210
GSCRF-4	3.82	3.87	3.86	3.00	4.14	0.124
OF-1	3.63	3.74	3.52	4.13	3.71	0.352
OF-2	3.88	3.79	3.81	3.63	4.00	0.819
OF-3	3.86	3.88	3.76	4.13	3.86	0.877
OF-4	3.84	4.02	3.71	4.00	4.00	0.535
OF-5	3.97	3.77	3.95	3.88	4.00	0.413
OF-6	3.91	4.05	4.00	3.88	4.29	0.522
OF-7	3.99	3.78	3.76	4.25	4.00	0.152
OF-8	3.58	3.42	3.00	3.75	3.71	0.152

Note: When the *p*-value is less than 0.05 (two-tailed), highlighted with *, perceptions are significantly different among the stakeholders.

Table 4 Spearman's correlation analysis results

Dimension	CRF	DCRF	GSCRF	OF
CRF	1			
DCRF	.606**	1		
GSCRF	.533**	.684**	1	
OF	.636**	.627**	.548**	1

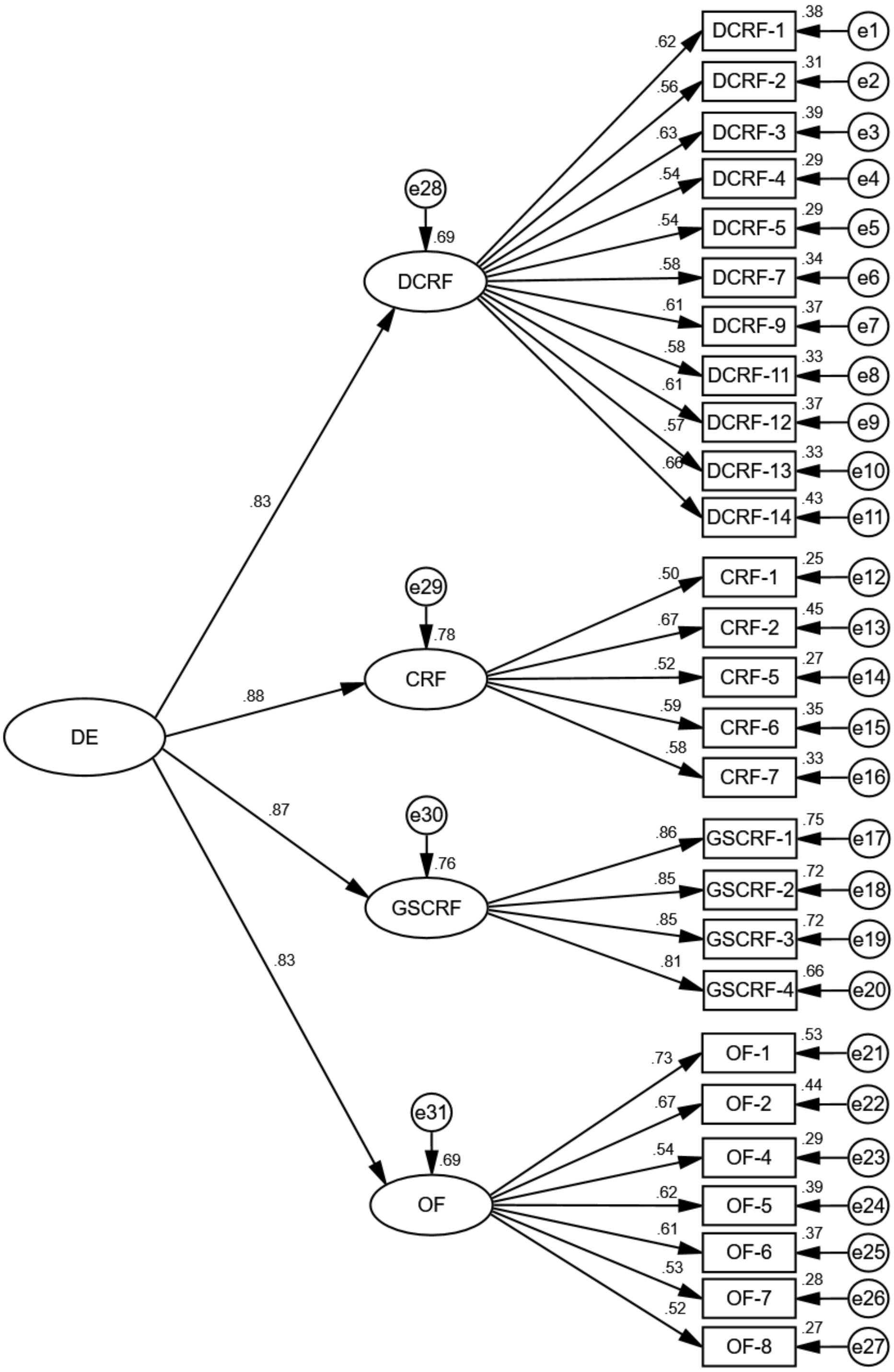
Note: **Correlation is significant at 0.01 level (two-tailed).

Table 5 Frequency of design error occurrence in different types of project

Frequency	Client	Design company	Geological surveying company	Construction company	Other	Total
Building	55.26%	59.54%	62.50%	47.62%	71.43%	57.61%
Civil engineering	13.16%	14.50%	0.00%	33.33%	14.29%	15.23%
Mechanical and electrical	31.58%	25.95%	37.50%	19.05%	14.29%	27.16%

Figure 1

Click here to access/download;Figure;Figure 1 Model for the causes of design errors.pdf



Note: DE=Design error.

Figure 1 Model for the causes of design errors

Figure 2

Click here to access/download;Figure;Figure 2 Reducing design errors.pdf

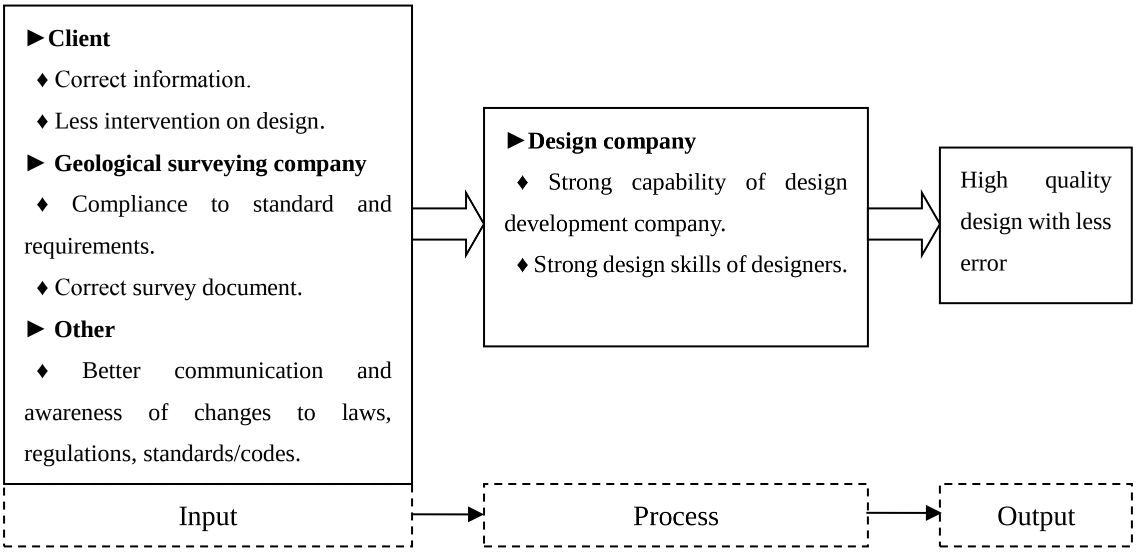


Figure 2 Reducing design errors in Chinese construction projects

Click here to access/download;Response to Reviewers Comments;Response to Reviewers Comments.doc

Response to Reviewers Comments

Journal: Journal of Performance of Constructed Facilities

Manuscript title: The causation of design error in the construction industry: A multi-stakeholder perspective

Manuscript ID: CFENG-4862

Dear Editor

Many thanks for the feedback on paper Ref.: Ms. No. CFENG-4862 (The causation of design error in the construction industry: A multi-stakeholder perspective).

We found the reviewers' comments constructive and helpful in improving the paper further, and have addressed the suggested changes and responded to each point below. We have also taken the opportunity to check and edit the paper again and have track changed the paper to show the changes.

Editorial Coordinator

Comments: 1. When submitting a new and revised manuscript, authors are asked to include a standardized Data Availability Statement, with specific items listed as appropriate. Please include the selected statements in a separate "Data Availability Statement" section in your manuscript, directly before the acknowledgements or references. The statement(s) listed in your manuscript must match those selected in response to the submission question. See ASCE's Data Sharing policy for more information. **Response:** Thank you. We added the following statement in a separate "Data Availability Statement" section in our revised manuscript, as the following: "*Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.*" (Lines 452-453)
2. Double-spaced list of figure captions: Please provide a double-spaced list of figure captions with your submission. This can be at the end of your manuscript text or uploaded as a separate Word file. If you have figures labeled as Figure 1a, 1b, etc., please make sure that the captions for these parts of the figure are included in your Figure Caption List.

Response: Thank you. A double-spaced list of figure captions was added at the end of the revised manuscript text.
3. Remove the figures from your manuscript text and upload them separately (one figure per file) in TIFF, EPS, BMP, or PDF format. Please reference the figure number in each file name. **Response:** Thank you. We removed the figures from the revised manuscript text and uploaded them separately in PDF format. We referenced the figure number in each file name.
4. ASCE is now encouraging authors to add a Practical Applications section to their paper. The Practical Applications section is a concise plain-language summary (150-200 words) of the paper written for non-academic or practitioner audiences to identify the results, relevance, or potential applications the research describes. You can read more about requirements for the Practical Applications section in the Peer Review Process section of the ASCE Author Guide. **Response:** Thank you. A Practical Applications section was added in the revised paper, as the following: "*The research findings have significant practical implications for various stakeholders to more effectively reduce design errors in construction projects. By identifying the critical factors leading to design errors from a multi-stakeholder perspective, this research provides a strong empirical foundation for developing novel evidence-based design quality management strategies to prevent the chronic problem of design errors in the construction industry. The results highlight that in addition to ensuring the capability of design development company and designers, design quality is heavily dependent on the accuracy of design input information provided by the clients, and compliance with standard requirements and high-quality site geological survey documents provided by geological surveying companies. Adequate time is needed in the preliminary design phase to thoroughly review the input information provided by clients and geological surveying companies. In addition, clients should avoid excessive interference in the design process and should instead empower the designers to determine design details or design solutions as these are helpful to reduce design changes and avoid potential design quality problems. Finally, stakeholders should also pay special attention to changes to design-related laws/regulations and standards/codes as these are major factors causing design error in the construction industry.*" (Lines 37-51)

Reviewer #2

Comments:

1. In the submitted research, the critical causes of design errors in Chinese construction have been investigated. The study aimed to identify the critical causes of design errors from a multi-stakeholder perspective. However, the differences between different construction works and the reasons for design errors have not been studied.

Response: Thank you for your comment. In fact, we have investigated the differences of design error occurrence in different types of projects and elaborate the reasons for differences of design error occurrence. However, in order to meet the paper length requirements of the journal, we have deleted these results in our previous submission. Following this comment, we added this part in the revised manuscript as the following:

"……*In addition, one single-choice question was used to find out the type of projects tend to have more design errors*……" (Lines 216-217)

"*4.3 Design error occurrence in different types of projects*

Respondents were also asked the type of project where design errors occur most frequently, and the results are shown in Table 5. Buildings primarily includes office buildings, residential buildings, and apartment complexes. Civil engineering projects mainly involve roadways, bridges, canals, dams and tunnels. Mechanical and electrical works are most related to the installation of HVAC systems, power systems, and fire-fighting systems. The majority of the respondents (57.61%) concluded that design errors most often occur in building projects, and this view is shared among different design stakeholders. Interestingly, clients, design companies, and geological surveying companies pointed out that after building works, design errors commonly occur in mechanical and electrical works, while construction companies argued that civil engineering projects are more problematic.

<Place Table 5 here>" (Lines 288-298)

"*5.3 Design error occurrence in different types of projects*

This research found that design errors occur more frequently in building works, which are somewhat different from past research conducted in other locations. As to the occurrence of design errors on different types of construction projects, Love et al. (2014a) found no significant variations in the cost of design error in different types of projects and procurement methods. In another study, Love et al. (2014b) revealed that design error costs in civil engineering projects are higher than those in fit-out projects. Love and Li (2000) reported that the cost of design errors is lower in building projects, accounting for 14% of rework costs. Lee et al. (2012) revealed that

54.42% of design errors occur in structures, followed by 33.82% in architecture and 11.76% in mechanical, electrical and plumbing system. The construction of high-rise buildings is common in China in recent years. High-rise building works include complicated structures and sub-systems, which are also affected by environmental factors, such as wind and earthquake loads (Huang, 2020). This may be the reasons behind the frequent occurrence of design errors in this type of project." (Lines 384-395)

"……*Notably, design errors are more prevalent in building projects compared to other types of works.*" (Lines 435)

2. Abstract:

In the abstract, it is necessary to present the characteristics of the statistical population, including the number, expertise, and occupation. At least two or three highlighted results should be mentioned at the end of the abstract, including the most and least effective causation of design error.

Response: Thank you for the suggestion. The characteristics of the statistical population, including the number, expertise, and occupation were added in the revised abstract. The most and least effective causation factors of design error were also included in the revised manuscript. Please refer to the following revised elaborations.

"*……Empirical survey data was collected from 243 design professionals (e.g., architect, structural designer, and water supply and drainage designer) across various stakeholders (e.g., client, design company, and construction company) in the Chinese construction industry……The major factors leading to design errors are design input information error, unreasonable intervention on design, noncompliance with standard requirements, and error in site geological survey document. In contrast, concurrent design, construction requirements and poor working conditions are the least influential factors……*" (Lines 22-30)

3. Introduction:

This section is well organized, but it is necessary to describe and discuss the research gap as the conclusion of the introduction section.

Response: Thank you for the comment. The research gap has been identified and discussed in the Introduction section as the following in our previous submission.

"*Firstly, as design involves multiple disciplines and many stakeholders, it remains unknown*

which stakeholders contribute more significantly to design errors……Secondly, research is limited in exploring the differing perspectives on design errors among project stakeholders." (Lines 83-95) Following this suggestion, the research gap was further described and discussed as the conclusion of the introduction section, as the following. "*As explained above, there is a lack of research on which stakeholders contribute more significantly to design errors and a comprehensive understanding on the different perspectives among stakeholders about the causes of design errors……*" (Lines 96-98)
4. Research methodology: The second step needs more explanation. **Response:** Thank you for the comment. More explanation was added in the second step as the following: "*……Second, descriptive analyses were conducted to obtain the mean values of the causal factors of design errors. Mean value results for different sub-groups and Kruskal Waillis (KW) test were used to compare the perspectives on the importance of design error causation factors among different types of design professionals working for various stakeholders. Since the data for the causes of design error was not normally distributed, Spearman's correlation analysis was employed to ascertain the relationship between the four dimensions causing design error. The Spearman's rho coefficient was used to evaluate the characteristics of the relationship between the variables, including the direction and strength of the relationship……*" (Lines 194-201)
5. Results and discussion: From lines 264 to 274, it appears that the effect of the customer on design errors is more than other types of stakeholders, but in lines 368 to 370, it is stated that in China, there are many design errors in building works and mechanical-electrical works. In this research, how do you explain the difference between the reasons for design errors in different construction works? It seems that some causes of design errors are general, while others are a function of the type of construction work. It is better to pay more attention to this part. **Response:** Thank you for the comment. As responded in comment 1, in the revised manuscript, we added the investigation results related to the differences of design error occurrence in different types of project and elaborate the reasons for differences of design error occurrence. This can

avoid the confusion for the result. The added revisions are as follows:

"……*In addition, one single-choice question was used to find out the type of projects tend to have more design errors*……" (Lines 216-217)

"*4.3 Design error occurrence in different types of projects*

Respondents were also asked the type of project where design errors occur most frequently, and the results are shown in Table 5. Buildings primarily includes office buildings, residential buildings, and apartment complexes. Civil engineering projects mainly involve roadways, bridges, canals, dams and tunnels. Mechanical and electrical works are most related to the installation of HVAC systems, power systems, and fire-fighting systems. The majority of the respondents (57.61%) concluded that design errors most often occur in building projects, and this view is shared among different design stakeholders. Interestingly, clients, design companies, and geological surveying companies pointed out that after building works, design errors commonly occur in mechanical and electrical works, while construction companies argued that civil engineering projects are more problematic.

<Place Table 5 here>" (Lines 288-298)

"*5.3 Design error occurrence in different types of projects*

This research found that design errors occur more frequently in building works, which are somewhat different from past research conducted in other locations. As to the occurrence of design errors on different types of construction projects, Love et al. (2014a) found no significant variations in the cost of design error in different types of projects and procurement methods. In another study, Love et al. (2014b) revealed that design error costs in civil engineering projects are higher than those in fit-out projects. Love and Li (2000) reported that the cost of design errors is lower in building projects, accounting for 14% of rework costs. Lee et al. (2012) revealed that 54.42% of design errors occur in structures, followed by 33.82% in architecture and 11.76% in mechanical, electrical and plumbing system. The construction of high-rise buildings is common in China in recent years. High-rise building works include complicated structures and sub-systems, which are also affected by environmental factors, such as wind and earthquake loads (Huang, 2020). This may be the reasons behind the frequent occurrence of design errors in this type of project." (Lines 384-395)

"……*Notably, design errors are more prevalent in building projects compared to other types of works.*" (Lines 435)

Reviewer #3

Comments:

Yes. The author is using the correct article type.

Response: Thank you.

A marked copy of the manuscript including the detailed revision track record is attached for your kind reference.

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