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DOI

[10.3390/en13102442](https://doi.org/10.3390/en13102442)

Publication date

2020

Document Version

Final published version

Published in

Energies

Citation (APA)

Qi, Y., Qian, Q., Meijer, F., & Visscher, H. (2020). Causes of Quality Failures in Building Energy Renovation Projects of Northern China: A Review and Empirical Study. *Energies*, 13(10), Article 2442. <https://doi.org/10.3390/en13102442>

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Article

Causes of Quality Failures in Building Energy Renovation Projects of Northern China: A Review and Empirical Study

Yuting Qi * , Queena Qian, Frits Meijer and Henk Visscher

Faculty of Architecture and the Built Environment, Delft University of Technology, Julianalaan 134, 2628BL Delft, The Netherlands; k.qian@tudelft.nl (Q.Q.); F.M.Meijer@tudelft.nl (F.M.); H.J.Visscher@tudelft.nl (H.V.)

* Correspondence: Y.Qi@tudelft.nl; Tel.: +31-6-39-89-84-58

Received: 7 April 2020; Accepted: 9 May 2020; Published: 13 May 2020



Abstract: Building energy renovations can effectively improve the environmental performance and energy sustainability of existing buildings. From 2007 onwards, the Chinese government has promoted energy-saving renovations of existing urban residential buildings. Nevertheless, various quality failures happen during the construction period in energy-saving renovation projects of residential buildings. Yet, the causes and their characters remain largely unknown. Through a literature review, this paper investigates the causes of quality failures. Validated through experts' interviews, a total of 18 causes were identified in building energy renovation projects. These causes were analyzed from two main aspects: the importance of a cause (related to impact and frequency), and the level of effort required to address a cause (related to origin and scale), using both a questionnaire survey and a focus group. The results indicate that the critical causes of quality failures are working under high-cost and high-time pressure, adverse natural conditions, fraud of construction companies, incomplete construction site survey, poor checking procedures of supervisors, poor operational skilled workers, inadequate equipment performance, lack of experienced project managers, and incomplete building information in projects. The causes were classified as external and internal causes of building energy renovation projects. The outcome of this paper should aid policy makers and project coordinators to focus on critical causes of quality failures, and to develop effective actions and policy interventions to achieve successful renovation projects with high-quality performance.

Keywords: causes; quality failures; building energy renovation projects; Northern China

1. Introduction

Energy problems and carbon emissions have become global issues, so there has been growing consciousness regarding energy consumption and carbon emission reductions. Based on past statistics, a global increase in energy demand of about 28% may occur by 2024 [1]. More specifically, in terms of the building sector, energy consumption has remarkably increased in the last several decades [2]. In China, the energy consumption of existing buildings is far larger than that of the total energy consumption [3]. Specifically, the poor energy efficiency of existing residential buildings wastes a large amount of energy [4]. To improve energy performance, the Chinese government focuses on the energy efficiency renovations of existing residential buildings in Northern China [5]. For example, doors, windows, roofs, and external walls are renovated. However, various quality failures have happened and resulted in construction repair and even rework [6,7]. Additionally, some quality failures were repeated in building energy renovation projects [8,9], which caused losses for stakeholders [10,11].

These quality failures hinder energy efficiency during the construction and even usage processes of building energy renovation projects [12]. Moreover, due to quality failures, a tremendous amount

of energy is wasted annually in construction and usage processes, and hereby the high-quality performance of the constructions can reduce energy wastage [7]. According to Forcada et al.'s studies, due to quality failures, a majority of the existing buildings that have been energy renovated do not save as much energy as the designs have predicted [13]. Johnston et al. found that the heat-transfer coefficient is 1.6 times greater than predicted, caused by quality failures [14]. Similarly, based on Bell et al.'s research, quality failures result in overall heat loss being 54% higher than predicted in residential buildings [15]. Furthermore, occurrences of quality failures can lower the health and safety levels of residents [16]. Thus, overcoming these quality failures is necessary to promote and boost the successful accomplishment of building energy renovation projects.

Building energy renovation projects lie at the heart of the implementation of energy-saving and low-carbon policies [17]. Quality control and management in building energy renovation projects are challenging because of the presence of different technologies and government roles, which makes building energy renovation projects significantly different in scope from other construction projects [18]. More precisely, building energy renovation projects have their own unique causes of quality failures [19]. The mere identification of the causes alone is insufficient for understanding reasons for the quality failures during renovation construction. Therefore, it is important not only to identify but also to study the root causes to avoid quality failures happening in energy-saving renovations of residential buildings in the future.

In spite of building energy renovation projects' significance, there are limited detailed studies that investigate the causes of quality failures [20]. Therefore, this study took empirical cases and made field visits in Hohhot, the provincial capital of Inner Mongolia, in Northern China. The city was selected as the case site for research based on three selection criteria. First, Hohhot is located in the 'heating areas' in Northern China, and is well known as a building energy renovation city. Second, this city is supported by central and local governments to be an exemplar for building energy renovations. Third, as part of the energy renovation program in Hohhot, there is a requirement to record the occurrence of quality failures, and construction quality is strictly controlled and managed. These selection criteria ensure the renovation projects in Hohhot cover a broad diversity of the characteristics of the causes of quality failures, allowing an understanding of the quality failures that have occurred and their causes.

Fortunately, it was possible to locate cooperative respondents for the building energy renovation projects in Hohhot. The authors visited there twice, in 2018 and 2019, to organize expert interviews and a focus group. The respondents were representative of the stakeholders involved in the building energy renovation projects, including government officials, project managers, supervisors, and designers. The questionnaire survey was conducted in Northern China, and 113 valid questionnaires were received with a representative sample of the stakeholders playing different roles in energy building renovation projects.

Our research departs from previous studies. Some of these studies have identified and analyzed according to the impact or severity of the causes of quality failures (e.g., [21–24]). Others have paid attention to ranking the causes of the quality failures from the frequency angle (e.g., [24–27]). However, these previous studies have predominantly evaluated only one particular area, particularly the impact of the factors affecting the construction quality. Hence, they only offer limited information about the causes of the quality failures in practice, combining both their importance and levels of effort required to tackle a cause [28]. Tackling a cause means to address the consequences of the causes after it occurs.

In the Chinese energy renovation context, the specific causes have not yet been treated in the academic literature in a systematic way. The importance and the level of effort required to tackle a cause are proposed as key indicators. As a result, there is a need for systematic identification and analysis of the causes: the importance of a cause (related to impact and frequency), and the level of effort required to tackle a cause (related to origin and scale). In this paper, the evaluation indicators adopted are the combination of the importance, origin, and scale for building energy renovation projects. The "importance of a cause" in this context refers to the impact and frequency of the causes before the causes occur. "The origin and scale" refer to the level of the consequences of the causes after

they occur. The combination of four evaluation indicators provides a comprehensive comparison of different causes throughout the whole process of the causes occurring. Furthermore, this combination would be novel and meaningful for the main stakeholders, whose main priorities might tend to avoid and address the causes of quality failures in building energy renovation projects. This paper is the first to make sense of the evaluation of the causes of these four perspectives jointly.

The objectives of this paper are: (1) to identify the causes associated with quality failures in building energy renovation; (2) to determine their importance (related to impact and frequency); (3) to classify the causes based on their levels of effort required to tackle a cause (related to origin and scale).

The paper is organized as follows. A review of related studies on quality failures and the framework of their causes from global experiences are contained in Section 2. Section 3 presents the research methods to collect data. Section 4 presents the interrelationships of the quality failures and their causes, the cause analysis of the importance (impacts and frequency), and efforts required to address a cause (origins and scales). Section 5 discusses the critical causes and gives implications for policy makers and project coordinators. Finally, the main findings and recommendations for future research are concluded in Section 6.

In more detail, first, the causes were identified based on a literature review, validated through experts' interviews. The experts were interviewed to confirm if the causes were valid in empirical cases, and the relationships between quality failures and causes were obtained. Second, a questionnaire survey was carried out to collect data for analyzing the importance of the causes (impact and frequency) using a five-point Likert scale. Finally, the levels of effort required to tackle causes (origin and scale) were evaluated based on a focus group (see Figure 1).

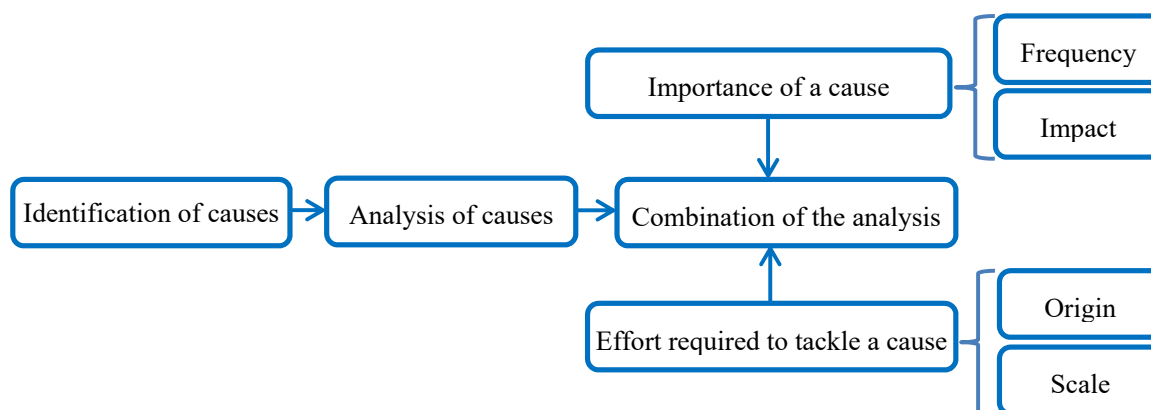


Figure 1. The research process and indicators.

2. Literature Review

2.1. Quality and Quality Failures

Over the last few decades, there have been various expressions adopted to define construction quality [29]. The International Standards Organization (ISO) defined quality in the construction industry as the sum of elements and features of a product or service that satisfy given needs. According to the American Society of Civil Engineers (ASCE), quality is the consistency to meet predetermined requirements. In addition, the Construction Industry Institute (CII) published the definition of quality as the conformance with established requirements. Jha and Iyer [30] defined quality as “compliance with customer’s specifications and customer’s expectations”. As defined by Qi et al. [7], the definition of quality in construction projects is to meet the technical requirements of regulatory agencies.

In the building construction industry, various interchangeable terms are used to refer to “quality failures” to describe imperfections, including “error”, “non-conformance”, “defect”, “fault”, and “quality deviation” [25,31]. In addition, Shanmugapriya and Subramanian [26] identified quality failure as one of the main shortcomings in the output of technical requirements and specifications.

As defined by ISO 9000: 2005, quality failure is such that quality cannot fulfill a requirement. According to Mills et al.'s studies [24], quality failure is a “shortcoming in the building performance.” Watt [32] and Alencastro [33] defined quality failure as “inadequacy or user requirements of a building”. Sim and Putuhen [34] considered that construction quality fails because quality standards and requirements are not earnestly implemented. In this paper, the authors define a quality failure as “the nonfulfillment or the implementation gap of the technical requirements as laid down (stated) by regulatory agencies.”

2.2. Causes of Quality Failures

There have been studies to identify the causes of quality failures; for example, Chong and Low [35] investigated and considered that poor craftsmanship is the fundamental cause. Hughes and Thorpe [36] identified that causes are poor supervisor competency and incomplete drawings. Love et al. [37] advocated causes of quality failures, including inefficient use of information technologies, excessive client involvement in the project, lack of clearly defined working procedures, insufficient changes. Aiyetan [38] investigated the causes of quality failures and suggestions for quality improvements. Meanwhile, inadequate communication, incomplete construction planning, ineffective management, inexperience of personnel, and weak quality concrete were identified as the causes of quality failures. Kakitahi et al. [39] ranked inadequate communication, embezzlement, and dishonesty as the three significant causality factors leading to quality failures. Enshassi et al. [40] studied the five leading causes of quality failures, namely, fraud, competitive pressure, poor management, time pressure, and the absence of work security. As shown in Table 1, a provisional set of causes was identified based on a thorough review of previous studies.

Table 1. List of identified causes from a literature review.

Causes	Descriptions	References
Incomplete construction site survey	Designers or construction companies ignore or make a deficient site survey.	[38]
Inaccurate design work	There are mistakes and discrepancies in design documentations	[36,38,41]
Unsettled plan or lack of construction plan	Construction companies ignore or make deficient construction planning	[38,42]
Unauthorized changes in design documentations	Construction companies change design documentation without the agreement of designers	[37]
Incomplete building information in projects	Technical information or original documentation are missing	[36–39,41,43,44]
Poor operational skilled workers	Operational skilled labor in construction processes lacks	[23,25,27,35,38,41,45,46]
Use of poor materials	Quality of construction materials is non-specified	[38,43,45]
Inadequate equipment performance	Mechanical equipment is non-specified	[36,41]
Poor on-site coordination	The speed of communication on-site between main stakeholders is low.	[23,38,42]
Poor site management	Workers, material, and equipment on site are not strictly managed and controlled	[38,42]
Complex on-site environment	Site conditions are limited such as narrow construction spaces	[36,43]
Poor checking procedures of supervisors	Supervision and feedback processes make failures	[36–38,43,45]
Fraud of construction companies	Construction companies cut corners by cheating in work.	[23,40]
Working under high-cost pressure	Budget and funding for renovation projects is insufficient	[23,38–40]
Working under high-time pressure	Design time and construction time is urgent	[23,38,40]
Adverse natural conditions	The natural environment is an interference such as low temperature, inadequate solar energy, rain interference	[43]

2.3. Previous Studies on the Analysis of the Causes

In order to avoid quality failures, the analysis of the causes is crucial. In previous studies, two main aspects (four sub-aspects) have been considered: the importance of a cause (related to frequency and impact), and efforts required to tackle a cause (related to scale and origin), as explained below.

Some studies were carried out to rank causes from the frequency angle. For studying the current situation of the construction markets and existing causes of quality failures, Forcada et al. [25,46] carried out a series of research projects. They concluded that poor craft is more likely to cause quality failures than non-specified materials or equipment used. Aljassmi and Han [27] identified the majority of quality failures related to a violation of operations or poor workers' skills.

Various causes were analyzed according to their impact on construction quality. Schultz et al. [23] identified the most significant influences on quality failures in Denmark. These causes include "budgetary conditions", "schedule pressure", and "discontinuous quality control". Dixit et al. [42] studied and ranked the causes based on the responses affecting construction productivity in India. The causes are improper planning, poor site coordination, lack of commitment, lack of organization competency, and inefficient site. Oyedele et al. [45] proposed the five most substantial causes, namely, non-specified materials, lack of skill and labor experience, inadequate inspection, poor site installation process, and incomplete quality assurance. In the context of China, Ye et al. [43] investigated a total of 39 causes of quality failures through an in-depth literature review and an interview of practice and experience. In addition, they conducted a questionnaire survey to rank these causes, in which poor project process management, non-specified construction technology, and inferior construction materials were the highest.

In terms of the scale of causes, Reddy [47] classified the causes into three categories—micro, meso, and macro—to analyse the circumstances under which different causes arise. Iqbal et al. [48] explained the causes took place in micro, meso, and macro environments. Following this approach to categorize causes, this paper evaluates causes based on the micro and macro scales.

The studies of the origin of the causes can be used to prevent these causes occurring before the start of a project. According to Page's study [49], a framework of the causes was presented according to whether they were internal or external to the projects. In addition, Chaplin and O'Rourke [50] analyzed causes and concluded that it was necessary to study some internal causes of projects and focus on the communications and messages in external projects. This paper also groups the causes as external and internal to the renovation projects.

Taking into account the previous research globally, a systematic cause analysis from these four aspects (including impacts, frequency, scales, and origins) has not yet been investigated.

2.4. Main Characteristics of Energy-Saving Renovations of Existing Residential Buildings in Northern China

2.4.1. Background of Building Energy Renovations in Northern China

In China, the energy consumption of buildings is influenced by a variety of regional climates. China covers a land area of about 96 million km² with different climate zones [51]. According to the Standard of Thermal Design Code for Civil Building (GB50176-93) [52], five climate zones are classified, including Severe Cold Zone (SCZ), Cold Zone (CZ), Hot Summer and Cold Winter Zone (HSCWZ), Hot Summer and Warm Winter Zone (HSWWZ), and Mild Zone (MZ). Of these, urban residential buildings in the Severe Cold Zone and Cold Zone receive district heating in winter, and are called heating zones.

Chinese governments have carried out energy-saving renovation to improve building energy efficiency of heating zones since 2007 [53]. According to the technical guidelines for the energy-saving renovation of existing residential buildings in Northern China, energy-saving renovations usually include external envelope structure (including the external walls, roof, doors, and windows), outdoor pipe network and heat source balance, indoor heating system and heating meter [54]. Additionally, the current situation is that a large number of existing buildings were renovated in the large-scale

implementation stage [5]. Meanwhile, the energy-saving renovations undertaken have shown that renovation can achieve the 50% energy efficiency target from central governments and produce a good thermal performance and indoor environment [55].

Empirical cases in this paper were selected in Hohhot, which is a northern city of the center in the Inner Mongolia Autonomous Region. It is a typical city of the heating areas in a building energy renovation context. Based on technical guidelines for building energy-saving renovation in Northern heating areas [56] at the national level, the provincial government has the potential autonomy to issue their own technical requirements with consideration of different regional circumstances. Thus, the provincial government in Inner Mongolia (where Hohhot is located) issued technical guidelines for the energy-saving renovation of existing residential buildings in the Inner Mongolia Autonomous Region. In these technical specifications, the main three construction technology categories are described, including doors and windows, roof, and external walls. Meanwhile, the compulsory use of expanded polystyrene insulation (EPS) is required by technical guidelines at the local level [57]. EPS is a type of insulation material with a significant effect on long-term thermal performance.

2.4.2. Responsibilities of Main Stakeholders in Building Renovation Projects

As a standard mode, the government leads building energy renovation projects. That is, the governments planned and guided the renovation of the existing residential buildings. In 2000, in order to ensure the construction participant's compliance with their responsibilities, the national government published Regulations on quality control of construction projects [58]. The provincial governments transfer the policies to local government (the municipal government and district government), and then the local governments implement the policies accordingly [53]. In addition to the local governments, other stakeholders, including construction companies, supervision companies, and design companies, share in carrying out the building energy renovation projects. Since the local government and supervision construction and design companies are fully involved in renovation projects, they are naturally the main stakeholders.

In most building energy renovation projects, local governments (the municipal government and district government) guide and lead the whole renovation processes. Correspondingly, they organize the activities in renovation projects and contract the tasks with the other stakeholders.

As the delegates of local governments, supervision companies are required to manage the construction quality and conduct on-site inspections, evidential tests, and final checks.

Construction companies are the main body to complete the renovation construction processes. They affect quality by organizing workers, materials, and other necessities for construction. Construction companies are responsible for organizing, arranging, and checking the construction scheme in construction preparation.

A site survey and design documents are provided by design companies. Design documents include renovation specifications, technical drawings, and other relevant documents, which guide construction methods and materials.

3. Research Method

This research is intended to identify the causes of quality failures and study the importance of the causes (impact and frequency), origin, and scale. First, a comprehensive literature review was conducted to establish a foundation (see Section 2.2). Second, experts' interviews supported and validated the findings from the literature review. Third, the final causes based on the experts' interviews were prioritized to be further analyzed by a questionnaire survey. Finally, a focus group was carried out to evaluate the efforts required to address these causes (Figure 2).

Method	Literature review (see Section 2.2)	Interviews with practitioner experts	Questionnaires	Focus group
Number of participants		22 experts	113 respondents	10 participants
Aim	Identify causes of quality failures based on the previous studies.	Confirm the causes if the causes were possible to appear during construction processes. Explore the relationships between quality failures and these causes.	Evaluate the causes of quality failures with respect to the level of impact and frequency.	Discuss the origin and scale of the causes and obtain the causes classification.
Result	An initial list of causes of quality failures	A final list of causes of quality failures; The relationships between quality failures and their causes	The ranking of causes: impact and frequency	The categories of causes: origin and scale

Figure 2. The research method, objective, and results.

3.1. Interviews with Practitioner Experts

A literature review was first conducted to identify an initial list of causes of quality failures. This was conducted to understand the likely causes of quality failures from a global perspective and to prepare for data collection relating to the causes of quality failures of construction projects.

A series of interviews with practitioner experts was undertaken to formulate the final list of causes, which were based on a literature review and construction documents. The causes of quality failures were provided for reference in order to elicit the opinions of experts. The following criteria formed the basis for the interviewer selection. First, the experts were from different key backgrounds/roles to provide a comprehensive understanding of the causes of quality failures. Second, the experts had sufficient working experience from engaging in the renovation field for over eight years. Separate interviews were conducted as the on-site fieldwork in January and March 2018 in the case study city with 22 experts, consisting of five quality supervisors from the supervision company, ten project managers, two designers, and five government officers (the details are provided in Table 2). They were requested to take into consideration the characteristics of building renovation projects in the Chinese context. Additionally, in order to make the data on causes more complete, they were asked to identify the relationships between quality failures and their causes.

Table 2. The position and number of experts in the interview.

Position of Stakeholders	Profiles	Number of Experts
Supervisors	Supervision company	5
Project managers	Construction company	10
Designers	Design company	2
Officers	Government	5
Total		22

All experts in the interviews were asked to inspect the list of causes and to remove those causes they had not experienced under the conditions of building energy renovations in Northern China. Likewise, they were requested to add some “new” causes, which had not been referred to in other studies. The final list of identified causes from the aggregation of expert views is provided (see in Section 4.1). From the literature, 16 causes were taken, and after discussion with industrial experts, two causes were included. These were “lack of experienced project managers” and “wrong construction flow”, both of which were added to the preliminary list. Consequently, 18 causes were considered, and they formed the main content of the questionnaire design and the focus group.

In addition, in order to ensure the data on causes was reliable, all experts in the interviews were requested to relate these causes to quality failures (see in Section 4.1).

3.2. Questionnaire

The purpose of the questionnaire survey was to have a deeper understanding of the causes of the quality failures in energy-saving renovation projects in Northern China. The data for analyzing the importance (impact and frequency) of the causes were obtained via a questionnaire survey. The questionnaire was designed based on the inputs of the 18 causal factors identified in the literature review and confirmed by the interviews with experts. It comprised two parts: (1) questions relating to the respondents' background; and (2) their rating of the impact and frequency of each listed cause of the quality failures in energy-saving renovation projects. The questionnaire scoring system was sufficient to collect respondent's perceptions while ensuring a sufficiently large size sample for subsequent analysis. The target groups for this questionnaire were design companies, supervision companies, government, and construction companies to capture their current energy-saving renovation practices. The impact of a cause was defined as the extra cost to repair the quality failures associated with this cause divided by the budget. A five-point Likert scale was used, delimited from 1 (0 < impact < 5%) to 5 (impact \geq 20%) [24,43]. Meanwhile, the frequency was defined as the number of projects in which the cause of quality failures occurred divided by the number of all renovation projects participated in by respondents, based on a five-point Likert scale ranging from 1 (0 < frequency < 20%) to 5 (80% < frequency < 100%).

In this way, a total of 280 questionnaires were dispatched to respondents. All respondents were familiar with building energy renovations with sufficient management knowledge. Finally, 113 fully completed questionnaires were received, giving a response rate of 40.4%. Of these, 22 (19%) were officers from governments, 49 (43.4%) were from construction companies, 27 (23.9%) were supervisors from supervision companies and 15 (13.3%) from design companies (Table 3).

Table 3. The summary of responses in the questionnaire survey.

Type of Group	Number of Respondents	Percentage (%)
Government	22	19.5
Construction companies	49	43.4
Supervision companies	27	23.9
Design companies	15	13.3
Total	113	100

3.3. Focus Group

A focus group was used as the collection method of data regarding the effort required to tackle a cause (related to origin and scale) to classify and analyze the causes of quality failures. The focus group was chosen rather than other qualitative research methods, because it can generate information on the collective views from the participants in the group. Thus, data from focus groups are useful to provide a rich understanding of participants' experiences and knowledge regarding causes and their origin and scale.

In this study, a focus group was conducted in Hohhot, where the energy-saving renovation of existing buildings has been carried out since 2008. The 10 participants involved in the focus group are shown in Table 4. The criteria to select focus group participants were: (1) must be at management level (i.e., project managers, construction supervisors, officers in government, designers); (2) must have worked on energy-saving renovations for more than eight years; and (3) must have rich experiences in project management and quality control. According to the relevant studies conducted by Yu et al. [59], these criteria can guarantee that the selected participants are qualified to discuss the topics pertaining to the building energy renovation projects.

The focus group meeting started with a presentation to introduce the objectives and definitions of the causes. This was followed by a session, including interactive thematic discussions. During the discussion session, each participant was requested to give their expert opinion about the origin and scale of each cause of the quality failures in energy-saving renovation projects from their perspective.

Table 4. Position and number of focus group participants.

Position Description	Type of Group	Number of Focus Group Participants
Project manager	Construction company	2
Technical engineer	Construction company	2
Supervisor	Supervision company	2
Officer	Government	3
Designer	Design company	1

4. Results

4.1. Causes of Quality Failures

Table 5 presents various quality failures recorded in documents and identified from the experts' interviews. The nature of the quality failures, needing rework or repair with extra cost and time, are shown. The results show that 25 quality failures are identified as falling into three technical categories: door and window (d), roof (r), and external wall (e).

Table 5. The quality failures that occurred in renovation projects.

Technology Measurements	No.	Quality Failures
Door and window (d)	d1	Incorrect installation of the steel nails
	d2	Incorrect size of the new window frame and door frame
	d3	Misalignment between the new doors and windows and the wall
	d4	The untreated wall around the new windows
Roof (r)	r1	Missing vapour barriers
	r2	Non-specified fire resistance of EPS boards
	r3	Non-specified volume-weight and thickness of EPS boards
	r4	Adhesive area problems
	r5	The detachment between the different EPS boards
	r6	Cracks of the roof leveling blanket
	r7	The detachment of waterproof roof layer
	r8	Misalignment of the waterproof roof layer
	r9	Cracks of roof concrete
External wall (e)	e1	Uncleaned wall
	e2	Missing interface treating mortar
	e3	Unacceptable levelness of the control wire
	e4	Non-specified fire resistance of EPS boards
	e5	Non-specified volume-weight and thickness of EPS boards
	e6	Adhesive area problems
	e7	The detachment between the different EPS boards
	e8	Missing rivets
	e9	Non-specified rivets
	e10	Incorrect drilling
	e11	Non-specified anti-crack mortar
	e12	Non-specified nylon net

Table 6 presents the distribution of quality failures contributed by 18 causes. The results show the relationships between 25 quality failures that occurred during the construction processes and their causes in energy-saving renovation projects.

Table 6. The quality failures contributed by the causes.

Causes (18)	Quality Failures (25)																								
	d1	d2	d3	d4	r1	r2	r3	r4	r5	r6	r7	r8	r9	e1	e2	e3	e4	e5	e6	e7	e8	e9	e10	e11	e12
1.Poor operational skilled workers	√	√	√				√		√	√	√	√	√	√	√	√		√				√			
2.Fraud of construction companies						√	√							√	√		√	√			√	√		√	√
3.Incomplete building information in projects					√						√	√			√										
4.Lack of experienced project managers	√						√				√	√		√	√				√	√					
5.Working under high-time pressure			√	√					√					√	√									√	
6.Working under high-cost pressure						√	√								√		√	√			√				√
7.Use of poor materials								√		√			√						√				√	√	√
8.Inadequate equipment performance																								√	
9.Complex on-site environment, such as limited construction spaces	√																√								
10.Adverse natural conditions, such as low temperature, inadequate solar energy, rain interference											√	√	√		√			√						√	
11.Inaccurate design work					√																				
12.Unauthorized changes in design documents																						√			
13.Incomplete construction site survey		√			√																				
14.Wrong construction flow										√			√												√
15.Poor checking procedures of supervisors						√	√						√				√	√			√	√		√	√
16.Unsettled plan or lack of construction plan		√	√	√										√						√					
17.Poor site management					√							√									√				
18.Poor on-site coordination		√																							

4.2. The Importance of the Causes (Impact and Frequency)

The data from the questionnaire survey were analyzed using SPSS. The Likert five-point scale was used in the survey, and its reliability was determined using Cronbach’s coefficient alpha, which measures the internal consistency among the elements. Values elements vs. values of Cronbach’s alpha of 0.7 or above normally indicate a reliable set of items [60]. The value of this test was 0.871, which was greater than 0.7, indicating that the five-point scale was reliable at the 5% significance level. Thus, the collected sample can be treated as a whole and is suitable for further ranking analysis in this section.

The mean score method was adopted in previous quality management studies to prioritize the relative importance among the factors [61]. In this study, the mean score is used to determine the relative ranking, as perceived by the respondents, in descending order of their impacts and frequency. If two or more causes had the same score, the one with a lower standard deviation (SD) was assigned a higher rank.

Table 7 presents the ranking of the mean score of the respondents’ evaluation of the causes concerning their impacts on construction quality (the column impacts). The findings show that 11 of the initial 18 causes of quality failures have mean scores greater than the average total value (3.49). The cause of the greatest impacts on construction quality is the “Incomplete construction site survey” (mean = 3.65). Both “Inadequate equipment performance” and “Lack of experienced project managers” have the same mean scores. Yet, the standard deviation of “Inadequate equipment performance” is 1.167, which is lower than that of “Lack of experienced project managers” (std. deviation = 1.276).

Table 7. Impact rankings, frequency rankings, origin, and scale of causes.

Origin	Code	Causes	Impacts (n = 113)			Frequency (n = 113)			Scale	
			Mean	Std. Deviation	Rank	Mean	Std. Deviation	Rank	Micro	Macro
External	E1	Working under high-cost pressure	3.55	1.323	5	3.51	1.344	4		√
	E2	Working under high-time pressure	3.52	1.247	6	3.49	1.196	5		√
	E3	Adverse natural conditions	3.56	1.488	4	3.38	1.358	9		√
	E4	Complex on-site environment	3.46	1.316	13	3.33	1.442	12	√	
	E5	Fraud of construction companies	3.44	1.224	14	3.53	1.261	2		√
Internal	I1	Incomplete construction site survey	3.65	1.274	1	3.27	1.459	15		√
	I2	Poor checking procedures of supervisors	3.62	1.325	2	3.42	1.334	7		√
	I3	Poor operational skilled workers	3.58	1.287	3	3.45	1.356	6		√
	I4	Inadequate equipment performance	3.50	1.166	7	3.41	1.431	8		√
	I5	Lack of experienced project managers	3.50	1.276	8	3.51	1.247	3		√
	I6	Incomplete building information in projects	3.49	1.204	9	3.58	1.321	1		√
	I7	Unauthorized changes in design documents	3.49	1.240	10	3.32	1.441	13		√
	I8	Wrong construction flow	3.49	1.337	11	3.36	1.303	10		√
	I9	Inaccurate design work	3.48	1.268	12	3.20	1.428	16		√
	I10	Use of poor materials	3.43	1.322	15	3.33	1.372	11		√
	I11	Unsettled plan or lack of construction plan	3.43	1.274	16	3.18	1.297	17		√
	I12	Poor on-site coordination	3.37	1.364	17	3.18	1.397	18		√
	I13	Poor site management	3.31	1.211	18	3.30	1.295	14		√

Similarly, because a total of 10 causes have mean scores higher than the average total value (3.38), they were identified as the common causes resulting from the quality failures. Table 7 presents the ranking of the respondents’ evaluation of the causes concerning their frequency in energy-saving renovation projects (the column frequency). The first in rank is “Incomplete building information in projects” (mean = 3.58), which is thus the most frequent in Chinese energy-saving renovation projects.

4.3. The Origin and Scale of the Causes

As for the level of effort to solve a cause, two possible approaches are combined [62]: avoiding the emergence of the cause, and reducing the influences of an already emerged cause of quality failures. The former is strongly related to the origin of the causes, which can be internal or external to the project [63]. External causes are those that originated outside the project. The origin of the causes was adopted from [28,63]. The latter is related to the cause scale, for which this research applied the micro-meso-macro scale model [47]. Micro causes can be addressed at the project management level. Macro causes are difficult to be dealt with by the project. The scale of the causes was adopted from Mosannenzadeh, Di Nucci and Vettorato [28].

The origin and scale of the causes are illustrated in Table 7. The results show that the external causes include: “Working under high-cost pressure” (E1), “Working under high-time pressure” (E2), “Adverse natural conditions” (E3), “Complex on-site environment” (E4), and “Fraud of construction companies” (E5). Of these, “Working under high-cost pressure” (E1), “Working under high-time pressure” (E2), “Adverse natural conditions” (E3), and “Fraud of construction companies” (E5) are macro causes with a high level of required action for tackling. In addition, the “Complex on-site environment” (E4) is a micro-scale cause. Regarding the internal origins of the causes, these include: “Incomplete construction site survey” (I1), “Poor checking procedures of supervisors” (I2), “Poor operational skilled workers” (I3), “Inadequate equipment performance” (I4), “Lack of experienced project managers” (I5), “Incomplete building information in projects” (I6), “Unauthorized changes in design documents” (I7), “Wrong construction flow” (I8), “Inaccurate design work” (I9), “Use of poor materials” (I10), “Unsettled plan or lack of construction plan” (I11), “Poor on-site coordination” (I12), and “Poor site management” (I13); all are micro-scale causes.

5. Discussion of Critical Causes

Although the awareness of the construction quality has increased during recent years, there are various causes to contribute the quality failures during construction stages. According to Table 7, 10 causes extracted from a total of 18 selected causes were based on the responses from experts’ views

and the literature review. All the 10 causes (E1, E2, E3, E5, I1, I2, I3, I4, I5, I6) obtained mean scores of impacts or/and frequency above the average total value.

The applications of renovation technologies play a fundamental role in the achievement of successful program goals. Various causes are closely related to the technical aspects. According to the technical guidelines in Inner Mongolia Autonomous Region, the distributions of the quality failures and their causes in technical procedures are “installation of new doors and windows”, “installation of thermal insulation materials”, “waterproofing the roof”, and “painting the protection layer”. In short, the inadequate equipment, use of poor materials, and similar technical causes occur in these procedures. The advice for technical procedures is to strengthen the standardizations and technical design standards, both of which fall behind the actual work practices. Furthermore, from technical perspectives, thermal insulation materials have significant influences on the energy consumption of existing buildings, so more attention needs to be paid when selecting new thermal insulation materials coming to the market. In addition, various technical solutions are significant to reduce the causes of quality failures, like developing and applying online tools to share information efficiently in the building energy renovation projects. Meijer and Visscher [64] also advised applying online systems further through the construction process. In contrast, Jingmond and Ågren [41] considered that organizational solutions rather than technical advice need further attention to solving the causes of quality failures. Their solution is proposed to focus on training the workers with appropriate technical knowledge and hands-on skills.

To clearly understand the causes, it is essential to precisely separate all the causes. Based on the origin in the empirical investigation, this paper classifies the causes into those external and internal to the renovation projects, in line with Mosannenzadeh [28] and Balasubramanian [65].

The origin of the critical cause of quality failures is external if the cause originated outside the project, including policy implementation gap (E1, E2), adverse natural environment (E3), and fraud of construction companies (E5).

Although particular organizations are established for quality supervision to achieve the performance of high quality in the renovation projects of this nature [53], there are still various causes that are internal to projects. These causes possibly lead to quality failures during the construction processes, which even affect the overall quality and energy performance. In this study, the results reveal that 13 causes have an internal origin to the project, and they all are at a micro-scale. In terms of impacts and frequency (see Table 7), there are six top internal causes (I1, I2, I3, I4, I5, I6) to contribute to the quality failures during construction stages, all of which are greater than the average total value. It means that these causes can be avoided or reduced through better project organization, and so these causes need action from project stakeholders and policy makers. In line with previous findings [23,42], overcoming these internal causes can remarkably reduce quality failures and improve countries' performance through improvements in construction behavior and management procedures.

In light of the analysis above, these findings help policy-makers and project coordinators to understand the allocations of their responsibilities better and to develop their proper actions in the future building energy renovation context in Northern China.

5.1. External Causes

5.1.1. Policy Implementation Gap (E1, E2)

The Chinese national government has published various policies and targets on energy-saving renovation [66]. Ran [67] illustrated that there is a gap between the national government's energy-saving renovation policy and the outcomes of its implementation at empirical levels. Actually, high-time and high-cost pressure factors are related to the energy policy implementation gap [68]. Moreover, these two causes are regarded as the dominant causes regarding the aspects of impacts and frequency (see Table 7).

The government-led model is established in building energy renovation projects in the Chinese context. Indeed, the top-down mandatory targets for renovating magnitude are set according to national energy policies from the national government. National policy targets can then be translated to lower levels of governments through the allocation of the renovation targets. Accordingly, the municipal government releases its implementation plan, which establishes the objective of renovating building areas. However, local governments are under intense pressure to complete the targets from upper levels of governments. The priorities of local governments in achieving energy conservation and climate change targets are different, and in practice they focus on construction time more. Thus, the local governments reduced attention to the goal of energy conservation and climate change [68]. From the viewpoint of the local government, their task is significantly more difficult to achieve than those of the national government. Hence, construction time pressure (E2) in building energy renovations is higher than that in other construction projects.

On the other hand, building energy renovation belongs to government investment projects. In order to complete targets, governments have to provide a renovation fee, so they minimize renovation costs as much as possible. However, the renovation cost is limited and fixed. The high-cost pressure (E1) exists in building renovation projects resulting in other levels of causes of quality failures.

5.1.2. Adverse Natural Environment (E3)

In Northern China, in the Severe Cold Zone and Cold Zone, the natural environment is an interference element of energy-saving renovation projects, such as inadequate solar energy, low temperature, high humidity wind, rain interference, etc. It is apparent that these natural environment elements would affect energy-saving renovation construction adversely and cause quality failures in Northern China.

5.1.3. Fraud of Construction Companies (E5)

Construction companies always aim to maximize income and minimize their cost to achieve their company profits because of the nature of the private companies. Thus, construction companies may tend to procure construction material at a lower price in order to reduce material costs. Thus, quality failures may appear, including non-specified fire resistance of EPS boards, non-specified volume, weight, and thickness of EPS boards, non-specified nylon net, missing rivets, non-specified rivets, non-specified anti-crack mortar, and other similar types of quality failures (see Table 6). Wu et al. [69] also stated that the fraud of construction companies is the primary cause of quality failures in construction projects. In the results of this study, the fraud of construction companies (E5) was ranked as the second cause for the impact on construction quality (Table 7) and regarded as a macro cause, which is likely the most difficult to be dealt with and requires action mainly from policy-makers. In the Chinese context, the provision of monetary incentives is insufficient for triggering substantial behavioral changes of construction companies leading toward more sincerity in building energy renovation projects [60]. Several solutions for policy makers are proposed to issue the incentives to drive the construction companies' awareness of construction quality and the connection between construction quality and project value.

5.2. Internal Causes

5.2.1. Incomplete Construction Site Survey (I1)

The errors in the on-site survey are ranked first in consideration of the level of the impact. Indeed, an incomplete or even incorrect construction site survey will lead to errors such as "incorrect size of the new window frame and door frame". In building energy renovation projects, a construction site survey could impact on the implementation steps of the projects directly, but it is always paid too little attention by the main stakeholders. Clearly, it would seem that a practical task would be to supervise the on-site survey allocated by the local government in the Chinese situation.

5.2.2. Poor Checking Procedures of Supervisors (I2)

Supervisors in energy-saving renovation projects co-supervise with local government. Inadequate supervision of materials and equipment are the main reasons for quality failures, for example, “non-specified fire resistance of expanded polystyrene (EPS) boards”, “non-specified anti-crack mortar”, and “non-specified nylon net”. The obligations of on-site supervisors are material and equipment supervision. However, some on-site supervisors do not strictly check the quality of raw materials, semi-finished products, or mix components. They fail to apply enforced inspection [43]. Moreover, administrative supervisors responsible for checking construction documents ignore checking the construction plans. On the other hand, there has been a tendency for the causes to be induced at the construction design stage [70]. Supervisors only focus on the construction stage, whereas the inspection and management of construction preparation are ignored [69]. Therefore, the supervision during the construction preparation period needs to pay more attention to material and equipment preparation stage.

5.2.3. Poor Operational Skilled Workers (I3)

Due to the novelty of the energy-saving renovation projects, the specific technologies and operations are challenges to meet construction quality requirements for workers lacking operation skills. In most projects, construction work is the preferred occupation of migrant workers with low labor costs [71]. Therefore, workers who have little knowledge and experience are more likely to make errors in operational processes. As a result, many quality failures arise, such as “incorrect installation of the steel nails” and “cracks of concrete”.

In an actual situation, “poor operational skilled workers” have a closer relationship with “inaccurate design work”. Because of incomplete design documents, workers probably make errors during their operational processes. In building energy renovation projects, it is difficult to remedy workers’ mistakes. Therefore, workers and other project participants need to be trained to identify incorrect design documents. According to the renovation policies in the context of China, it is not a mandatory requirement to train construction workers and other participants with design information and technical knowledge. Meanwhile, construction companies fail to train and manage on-site workers. Thus, to establish an internal training system is currently a necessary and urgent issue. Furthermore, mandatory requirements regarding training and educating workers and other construction participants could be needed in the renovation policy framework.

5.2.4. Inadequate Equipment Performance (I4)

Incorrect selection and usage of equipment are hindrances to the high-quality performance of energy-saving projects [72]. According to Ashokkumar’s study [73], some construction activities might use the wrong equipment, which is more likely to cause quality failures. In this empirical investigation during the processes of installing mechanical fixings, “incorrect drilling” occurs when the power of the electric drill is too low, or the drill bit is selected incorrectly. The selection and usage of equipment need to be checked and recorded strictly by construction management authorities. If the equipment performance does not meet the technical requirements, it is impossible to achieve the high-quality performance of renovation projects.

5.2.5. Lack of Experienced Project Managers (I5)

It is well known that various activities in construction work are heavily dependent on the organization of the project managers. In the current situation, the project managers’ lack of experience in energy-saving renovation results in quality failures. For the empirical investigation, some project managers ignore emphasizing to workers the knowledge of waterproofing techniques and other technical requirements. Often, project managers cannot clarify the scope of personnel responsibility due to a lack of experience in renovation construction. The “Lack of experienced project managers (I5)”

in renovation projects is considered one of the most frequent causes in the Chinese context (shown in Table 7).

Additionally, the chances for professional experience and training are very limited. It is meaningful that the local governments establish the education and training system for project managers in energy-saving renovation, and introduce a scheme mandating the employment certification of renovation projects for project managers.

5.2.6. Incomplete Building Information in Projects (I6)

Incomplete building information appears most frequently (see Table 7). This is because all renovated buildings were built before 2007, and thus it is hard to find details of old building documents. Furthermore, the delay in information updates is a reason for “Incomplete building information in projects (I6)”. For example, the size of enclosure components (including windows and doors) reinstalled by the homeowners and other information different from the original design drawings are missing in renovation projects. Therefore, the building information suitable for site operations needs to be updated and then shared among the participants during the stages of survey, design, and construction.

6. Concluding Remarks

The energy renovation of existing residential buildings is increasingly influential in reducing energy consumption in the building sector. Undoubtedly, building energy renovations are failing the challenge to meet their goals of high-quality performance due to quality failures. Despite various statutory requirements to ensure high-quality performance in energy-saving renovation projects, quality failures frequently occur during the construction processes in energy-saving renovation projects. The impact of these quality failures has resulted in unsatisfactory energy performance throughout the usage phase of the existing buildings. Until this research study, the reasons why quality failures in building energy renovation projects occur in the Chinese context were unknown.

The causes of quality failures in energy renovation projects have, however, been identified and analyzed incompletely. This results in a limited understanding of why quality failures occur and how these quality failures could be avoided. The novelty of this paper lies in the fact that it has explored and analyzed the causes systematically from two main aspects: the importance of a cause and the level of effort required to address a cause in the context of China.

The analysis and understanding of the causes are a vital prerequisite in order to prevent and eliminate quality failures. Therefore, this research study first identified the 18 causes of quality failures based on a literature review and expert opinions. Then, the detailed analysis of these causes in Northern China concluded that the “Incomplete construction site survey” (I1) was ranked as the highest level of the impacts on quality, and the most common cause was “Incomplete building information in projects” (I6). The level of action required for tackling a cause of quality failures combined their origin and scale. The “Working under high-cost pressure” (E1), “Working under high-time pressure” (E2), “Adverse natural conditions” (E3), and “Fraud of construction companies” (E5) are external to projects at macro scale, with a high level of required action for tackling the challenge. Based on the evidence in this paper, they are more likely to be influenced at the policy level from the focus group. The Chinese framework of the causes of quality failures could provide a reference for improving the construction quality of energy-saving renovations globally.

Strategies of reducing the causes of quality failures were provided at the policy level and project level, which are different from previous studies in building energy renovations. At the policy level, there is a need for a common political interest in the implementation of renovation projects among different levels of governments. In terms of the project level, the government should establish an inspection system to track and inspect the project’s implementation. An effective inspection mechanism is necessary to avoid quality failures occurring.

This paper specified how the quality failures happened, and the causes of quality failures were identified and analyzed. Meanwhile, this study also confirmed that the appraisal method was applied as a means of assessing the causes in the building energy renovation projects. On the one hand, in this paper, the applicability of the recommendations for policy makers at a policy level refers to improvement of the top-down mandatory implementations of the energy renovation policies. On the other hand, the suggestions at a project level are applied to the quality management processes of the energy renovation construction.

The outcomes of this research may help both project participants and policy makers to better understand the causes of quality failures. Thus, the findings would be valuable for policy makers and project coordinators both for predicting and avoiding the quality failures, and for developing proper action and policy interventions to ensure successful building energy renovations with high-quality performance in the future.

A few limitations should be acknowledged for future studies. The case city was only chosen in the Chinese context, and thus its situation may be different from those in other countries. Moreover, this research did not address relationships of the causes for energy-saving renovations. Future research should be wider and include the interactions of these causes, as well as the international experience, indicating that placing more stringent requirements on details in the project documentation, including work sentencing, may reduce some sources of quality failures in the construction and allow shorter construction time.

Author Contributions: Y.Q. investigated and analysed the data; Y.Q. wrote the original draft, and Q.Q. reviewed with feedback. Q.Q. and F.M. supervised the research activity planning and execution and improved the content; H.V. administrated the projects with managing and coordinating the research activity planning and execution; All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by Delft University of Technology.

Acknowledgments: This work is supported by the China Scholarship Council and Faculty of Architecture and the Built Environment, Delft University of Technology. The second author is grateful for the Delft Technology Fellowship (2014–2020) and its generous funding support. The authors wish to thank Paul Fox for proofreading.

Conflicts of Interest: The authors declare no conflict of interest.

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