Summary

Since 1978, the real estate industry has formed and developed rapidly in China. A large number of residential buildings were built to meet people's needs, especially in the 1980s and 1990s in China, but the quality and performance of these buildings were ignored due to the lack of laws, regulations, and standards. More than 70% of buildings in China are those with high energy consumption, especially in the Hot Summer and Cold Winter (HSCW) zone, where more than half of urban residential buildings were built without any thermal insulation measures (Fu, 2002). However, compared with the huge stock of the buildings with high energy consumption, the renovations for energy-saving that have been completed are far from enough, especially in the HSCW zone (MOHURD, 2017). To achieve the climate target, it is necessary to accelerate the implementation of residential energy retrofitting in the HSCW zone of China. Nevertheless, homeowners are generally unwilling to make major changes to their homes (e.g. the renovation of the building envelope) in China (Baldwin et al., 2018), even if they can benefit from energy retrofitting, like the improvement of building quality and living comfort. This unwillingness can be attributed to the existence of risks and their negative impacts on project performance in quality, time, costs, etc. Indeed, the retrofitting projects are vulnerable to the problems of cost overruns, poor quality, project delay, etc. (Hwang et al., 2015; Liu et al., 2020), which would damage homeowners' interests. Thus, the risk is an important factor hindering these project objectives and project success (Zou et al., 2007). Residential energy retrofitting in the Chinese context is featured by uncertainties, posing various risks about homeowner attitudes and behaviours, stakeholder coordination, the quality of design and construction, etc. This thesis aims to deepen the understanding of risks in the whole process of residential energy retrofitting to smoothen its implementation and develop risk mitigation strategies for the HSCW climate zone of China. It answers the following main research question: What are the risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China, and what strategies can mitigate these risks?

This research study adopts the risk management process as a conceptual framework for exploring the strategies of risk mitigation in energy retrofitting of residential buildings in the

HSCW zone of China. This process includes risk identification, risk assessment, and risk mitigation. Transaction Costs Theory (TCT) is incorporated into this framework, contributing to risk identification and mitigation. Project stages and stakeholders are taken into consideration to identify the risks in the whole process of energy retrofitting projects systematically. This study assesses the importance of these identified risks in both objective and subjective aspects. The objective assessment considers two parameters of risk probability and impact, while subjective assessment measures the risk perception of different stakeholders. Mitigation strategies are explored from the perspective of stakeholder behaviours to reduce the occurrence of key risks identified from both objective and subjective assessments. Given the importance of homeowners-related risks and the key role of the government in retrofitting projects, homeowners and the government are considered as the main viewpoints for developing mitigation strategies. Anhui province is a representative province of residential energy retrofitting in the HSCW zone, and thus was selected as the case area for data collection in the thesis.

This thesis first explored the key risks hindering the implementation of residential energy retrofitting projects from the perspective of objective risk assessment. A list of energy retrofitting risks with TCs considerations was identified through literature review and semi-structured interviews with key stakeholders in case projects. The questionnaire surveys with professional practitioners were conducted to measure the probability and severity of each identified risk. All risks were ranked in order of importance by combing two methods of risk matrix and Borda voting. The results reveal that ten top risks representing key risks are mostly associated with homeowners and contractors as well as occurring during the stage of on-site construction. Three of the four top risks impeding project implementation are associated with homeowners, starting from their low awareness at the early stage and poor cooperation and opportunistic behaviours during the on-site construction. In terms of risks, and except for the homeowners, the contractors are the most critical stakeholders in on-site construction. Their professional expertise, construction management, and safety management are the essential sources of project risks. In particular, the importance of the risk related to contractors' competence comes from its severe impacts instead of the occurrence probability. The results

also show that information, negotiation, and monitoring costs are the main sources of TCs related to ten key risks. Information costs are the most common costs, and government and homeowners are the main bearers. These costs are incurred not only by the government's activities of selecting retrofit projects, technical standards, and technical staff but also by homeowners' behaviours of collecting information on retrofit merits, the reliability of the construction company, and maintenance. Negotiation costs are associated with homeowner-related risks and arise from persuading homeowners at the early stage and renegotiating for homeowners' requirements beyond the plan during the on-site construction. Monitoring costs are related to the maintenance risk and incurred by monitoring energy-efficient technologies and building maintenance after retrofitting.

To explore the risks in-depth, this thesis analyses the risk perception of different stakeholders, which is also a subjective assessment of risks. Based on the risk list identified through literature review and interviews as mentioned above, this study conducted questionnaire surveys to explore the risk perception of four stakeholder groups, namely the government, homeowners, designers, and contractors, by measuring the level of their concern about each risk. Interviews with key stakeholders in case projects were also used to probe stakeholders' proactive behaviours for mitigating all risks. This study reveals that risk perception is diverse among different stakeholders due to their tendency towards responsibility and interests. As the organizer and decision-maker, the government has more concern about the risks affecting the overall enforceability of retrofit projects. Risk perception of designers and contractors is also consistent with their roles as service providers, focusing on the risks hindering the fulfilment of their duties, such as insufficient objective information and uncooperative partners. By contrast, homeowners pay more attention to the risks regarding their own interests, such as the quality of materials, the competence of contractors, contractors' work performance, and the safety of the construction site. In particular, in terms of some construction-related risks (e.g., contractors' abilities, material quality, and the legalization of contractors' actions), homeowners have significantly higher levels of perception than other stakeholder groups. The government selects contractors through bidding, and tends to believe that contractors take the government-investment projects more seriously. The current energy-efficient technologies

adopted in most residential energy retrofitting projects in China are relatively traditional and basic for contractors, convincing them that their professional expertise is enough to cope with the construction work. A high level of perception about these risks makes homeowners more inclined to safeguard their own interests by making more requests for retrofitting. A high level of risk perception can be viewed as a motivator of proactive measures for risk mitigation, but the effectiveness of some proactive measures, especially taken by non-risk-source-related stakeholder groups, cannot be ensured due to the limitation of individuals' knowledge and external environment factors.

Given the importance of the homeowners-related risks and the possible relationships between the occurrence of these risks and homeowners' high levels of perception of other risks, the thesis investigates how to improve homeowners' cooperation in residential energy retrofitting via information provision. Three hypotheses were developed through literature review to show the conceptual relationship between information and homeowners' cooperation, as well as the mediation role of risk perception and the moderation role of information source credibility in this relationship. Questionnaire surveys, structural equation modelling (SEM), and multiple linear regressions were adopted to test hypotheses. The results reveal the varied roles of different kinds of information in homeowners' cooperation and support the mediation effects of risk perception and the moderation effects of source credibility. They are retrofitting benefits and positive information about retrofitting services have directly positive influences on homeowners' cooperation. The indirect effect of service information via risk perception is also significant. Meanwhile, the high credibility of information sources is a prerequisite to these significant effects. Furthermore, the effects of building information and retrofitting technology information on homeowners' cooperation are diverse in different cases. There is no significant direct connection between building information and homeowners' cooperation, but increased building information amplifies homeowners' risk perception due to the poor quality of old residential buildings and which further hinders their cooperative behaviours. This significantly indirect effect also requires the high credibility of information sources. Similarly, increased technology information does not contribute significantly to homeowners' cooperation. Still, influenced by the high credibility of social contacts with laypeople, the roles of retrofitting

technology information are changed to be ‘significant’ from ‘insignificant’, which can be attributed to the difficulties of laypeople in understanding building technology information.

The thesis finally develops broader strategies from the perspective of the government to mitigate the key risks identified based on the assessment of probability and severity and the risks perceived highly by homeowners. Given the important roles of the government in residential energy retrofitting in China, a theoretical framework was established based on TCT to understand the barriers (e.g., asset specificity, uncertainty, and frequency) to government performing risk-related project activities and mitigating risks. Based on questionnaire surveys with the government officials, both exploratory factor analysis (EFA) and artificial neural network (ANN) were adopted to examine the influence of these factors on the government’s behavioural intentions towards project activities related to each risk. The results reveal the importance of asset specificity and uncertainty to project running and risk mitigation. Immaturity in the operation of project activities is the most important obstacle to the government running projects. Environmental uncertainty regarding costs and time restrictions and the immature retrofitting market also needs to be better recognized and valued. Retrofitting complexity and quality is a special uncertain factor because it can motivate to a large extent the government to perform the risk-related project activities well. Through survey respondents' views on risk allocation, the results consider the government to be responsible for the mitigation of risks about homeowners’ awareness and cooperation, the expertise of technical staff, technical standards, and building quality. Accordingly, this study develops mitigation strategies for these risks in two aspects of immaturity in the operation of project activities and costs and time restrictions. It recommends the government to disseminate information, build energy service databases, exchange technology experience, enhance building diagnosis, develop financing diversification, and promote project post-evaluation. The results also reveal the role of the government as the supervisor and guide in the mitigation of other important risks regarding on-site construction and post-retrofitting usage. It further provides the corresponding recommendations from the perspective of the maturity of the retrofitting market and suggests the government to encourage certification of both material and personnel standards.

The findings of this thesis are conducive to the understanding and mitigation of risks in the whole process of residential energy retrofitting projects in the HSCW zone of China, providing both scholarly and practical value. Prior studies focus on the investment risks in energy retrofitting in terms of the energy efficiency gap, and few of them explored the risks in the whole process of retrofitting projects from the perspective of project management. Particularly in the Chinese context, risks in energy retrofitting projects have been barely considered. This study fills in the research gap. It identifies systematically important risks existing in the current retrofitting projects and develops a set of strategies to mitigate these risks. This research methodology can be applied to the risk research of residential energy retrofitting in other climatic regions and even the renovation of buildings for other uses. This thesis contributes to the body of knowledge by conducting a systematic exploration of risks in retrofitting projects. In terms of the practical contributions, it does not only enable project managers to recognize the priority of the risks and further prioritize resources to cope with the key issues in future retrofitting projects, but also provides a set of strategies for the government to understand risk causes and guide them to tackle these issues at its source for promotion of residential energy retrofitting. Homeowners can also benefit from these strategies by maximizing homeowners' living quality and housing value in future retrofitting projects.

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