

Supply chain quality management: An investigation in the Chinese construction industry

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Abstract

Recently, in China, the issue of poor quality construction has drawn much public attention. This problem is related not only to poor quality control on the part of the construction firm, but also to the use of inadequate materials and inexperienced subcontractors, that is, to poor quality assurance in the construction supply chain. The purpose of this article is to examine supply chain quality management (SCQM) in the construction industry. Using a case-study approach, this research focuses on a Chinese medium-sized private enterprise in order to determine the most efficient way to conduct a high-quality project when collaborating with material suppliers and subcontractors. To this end, we replicate and extend the SCQM practices to help develop a more refined SCQM conceptual model relevant to the construction industry. Based on the different perspectives of managers and engineers, two frameworks are presented to illustrate (1) the correlation between SCQM and purchasing function (PF), and (2) how to work with material suppliers and subcontractors; the proposed models also show how these aspects will influence and control the quality of projects. Although constrained by the limitations inherent in case-study methodology, this article consolidates the work in one particular area of supply chain management. It also succeeds in meeting two core challenges, namely to explicate the interaction between SCQM and PF, and to provide guidance to construction firms on how to deal with SCQM issues with material suppliers and subcontractors.

Keywords

Construction supply chain, supply chain quality management, supply chain management, purchasing function, case study

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Introduction

In recent years, the construction industry in China has undergone rapid development and continuous expansion. According to data from the China Statistical Yearbook, in 2016, construction amounted to 6.7% of the country's GDP, and there were 83,017 construction enterprises, compared to 12,585 30 years previously. Within the same 30-year period, the gross output value of construction had increased by approximately 200 times, to reach 19,356.68 billion yuan. The continuous growth of output indicates that the Chinese construction industry will remain robust in the long run. However, the prosperity of the construction industry has also led to complacency with regard to commodity production and made it more difficult to control the quality of construction projects. Chen and Luo¹ point out

that some construction firms succumb to the temptation of increased profit by ignoring crucial aspects of quality management (QM), for example, by hiring unqualified workers, and by tolerating an imperfect organization structure and inappropriate management. Consequently, accidents have become ubiquitous in the Chinese construction industry, arousing widespread public concern. For example, on 16 November 2016, a working platform collapsed during

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construction of a cooling tower in the city of Fengcheng in Jiangxi Province, killing 74 people and leaving 2 more injured. Such accidents reveal that the personal safety of residents is under threat in China due to the poor quality of construction projects, and should ring alarm bells for construction firms, driving them to take effective measures to improve project quality.² This raises the question as to which factors should be addressed to improve the quality of projects and decrease the number and likelihood of construction accidents, with particular reference to the practice of supply chain quality management (SCQM).

Poor QM is not just reflected in the internal organization, but is even more evident in supplier and subcontractor management. Most accidents in construction are caused by inadequate materials or inexperienced subcontractors. Indeed, material suppliers and subcontractors play vital roles in the construction supply chain (SC), and their selection and management are fundamental to ensuring project quality. According to Khamisi et al (2018)³, a trusted QM in the construction SC is crucial because it is able to improve the work efficiency and employees' safety for construction company, so integrating QM and SC will contribute greatly to fostering balanced growth in the Chinese construction industry.

There is a certain amount of existing literature focused on the internal management in the construction industry, with regard to aspects such as performance management,⁴ knowledge management⁵ and project management.⁶ Moreover, many scholars have conducted research and emphasized the importance of SCQM.^{7–9} However, the literature studying the SCQM in the construction industry is limited, and particularly so when it comes to Chinese construction. To address this issue, this article aims to provide some insights for Chinese construction firms, such that they might improve their SCQM. In addition, given that over 50% of expenditures in manufacturing firms are processed by the purchasing function (PF),¹⁰ purchasing is not just important, but is strategically essential to the overall performance of the company. As construction is a special case under the background of the intensive development of manufacture, and QM always happens in construction purchasing activities, research into QM in PF has greater significance to improve the performance of the construction SC, thereby ensuring enhanced project quality through better quality control. Therefore, the specific focus of this article is the QM in PF in the Chinese construction industry.

Based on the research gap identified in the existing literature, this research proposes:

1. to investigate the SCQM practices in the construction industry;
2. to develop a conceptual model in the Chinese SCQM, especially in PF; and
3. to validate the proposed conceptual model by conducting an in-depth case study with a Chinese construction company.

The article is structured in four parts. First, the concepts of supply chain management (SCM) and SCQM in the construction industry are illustrated from previous literature, and the relevant constructs and terminology are defined. Next, a case study-based research is used to generate ideas about the relation between SCQM and PF. Thirdly, a general conceptual framework of SCQM-PF and two extensional frameworks are developed to explain how different constituent factors of QM in PF interact with main elements of SCQM. Finally, the contribution of the frameworks is highlighted and constructive suggestions are made to direct future researchers and practitioners.

Through the case study of one privately-owned Chinese construction firm, this article obtains an in-depth knowledge of the Chinese construction environment and its management conditions. By illustrating the current complex SCQM in the Chinese construction industry, this study aims to improve understanding of how QM in the PF can affect the performance of the construction SC.

Literature review

The SC is a system that moves products or services from suppliers to customers, and the associated transformation activities are the motive power that allows the company to keep running. Nowadays, in a context of increasing customer demand, business expansion and fierce competition, more and more companies are realizing the importance of managing their SC. QM is widely accepted as an effective means to support SC activities, ensuring continuous improvement to performance throughout the SC, and thus leading to higher levels of customer satisfaction. Recently, efforts have been paid to integrate QM with SC, thus creating a process termed SCQM. According to Ramos et al.,¹¹ SCQM can be defined as 'the coordination and integration of SC business processes to measure, analyze and continually improve products, services and processes with the purposes of creating value and achieving satisfaction of intermediate and ultimate customers in the business and market'.

SCM in the construction industry

SCM is described as an 'evolutionary and cumulative innovation',¹² as it drives the holistic innovation from all internal programmes. The concept of SCM originated in the field of manufacturing, and in recent decades has become prominent as a significant influence on distribution, marketing, customer management and transportation, all of which usually involve two or more legally separated organizations, which are connected by material, financial and information flow.^{13,14} Here, the SC can be seen as a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.¹⁵ Generally

speaking, SCM influences simultaneously a firm's processes with its suppliers and those with its customers in order to match materials, services and information with customer demand.¹⁶

Since the mid-1990s, SCM has emerged as a popular and important concept, both in the construction industry and in the research community. Construction supply chain management (CSCM) refers to the management of information, flow of materials and money in the development of a construction project.¹⁷ Due to the reason that construction process includes a certain standard procedures from planning, designing, procuring, constructing, maintaining to demolishing (Charehzehi et al., 2017)¹⁸, so CSCM can also be interpreted as a system in which suppliers, contractors, clients and their agents work together in coordination to install and utilize information in order to produce and deliver materials, plant, temporary works, equipment and labour and/or other resources for construction projects.¹⁹ CSCM can be divided into two levels: the individual company level, where the focus is on the operations involved in the production process, and the production level, which encompasses the processes involved in the delivery of the client's requirements.²⁰ Previous studies have indicated that CSCM is not only a research trend and a channel to provide substantial opportunity for clients and stakeholders to look at profitability,²¹ but is also unique to each project, and should be approached on a case-by-case basis.²²

In the main, the SC of a construction project will comprise architects and engineers, main constructors, speciality subcontractors and material suppliers who come together on an ad hoc basis to build a specific project for a specific owner.¹⁹ SCM in construction plays four main roles, depending on whether the focus is on the SC, the construction site or both.²³ First, with regard to on-site activities, the main concern is to ensure reliable flows of material and labour to the site to avoid disruption to the workflow. Secondly, the SC focus may be to cut costs, especially the spending on logistics, lead time and inventory. Thirdly, suppliers or contractors may focus on transferring activities from the site to earlier stages of the SC, in order to avoid unfavourable on-site conditions, or to improve concurrency between activities. Fourthly, SCM helps to integrate management and improvement of the SC and the site production, whereby site production is subsumed under SCM. Such SCQM is vital in the construction industry, not only to enhance the SC efficiently with less resource consumption, but also to ensure safety by controlling the flow of labour and materials on the construction site.

Supply chain quality management

QM is a 'philosophy or an approach to management' made up of a 'set of mutually reinforcing principles, each of which is supported by a set of practices and techniques'.²⁴ It has been regarded as an integrated approach to achieving and sustaining high-quality output, focusing on the

maintenance and continuous improvement of processes and the prevention of defects at all levels and in all functions of the organization, in order to meet or exceed customer expectations.²⁵ With the increasing emphasis on the concept of QM, this approach has been integrated into many different disciplines to seek better organizational performance.

The research on the synergy of QM and SCM has grown significantly over recent years. From a theoretical perspective, SCQM has been defined as a systems-based approach to performance improvement that leverages opportunities created by upstream and downstream linkages with suppliers and customers.²⁶ It requires all members of a supply channel network to improve processes, services, products and work cultures, with a focus on generating sources of productivity and competitive differentiation to achieve total customer value and satisfaction.¹³ Research has identified a positive relationship between SCQM practice and overall organizational performance,^{9,27,28} where the process of SCQM creates value and achieves satisfaction of intermediate and final customers in the marketplace.²⁹

Robinson and Malhotra²⁹ identify five themes within SCQM, namely (1) communication and partnership activities, (2) process integration and management, (3) management and leadership, (4) strategy and (5) best practices. Each of these themes should be connected with traditional firm-centric and product-based mindsets to an inter-organization SC orientation involving customers, suppliers and other partners to optimize performance.

In addition to the literature that focuses on defining SCQM, many studies have been conducted to investigate the practices and characterize the nature of SCQM. Soares et al.²⁸ proposed nine SCQM constructs: top management leadership, training, product/service design, supplier QM, process management, quality data reporting, employee relations, customer relations and benchmarking learning. Kuei et al.⁸ suggested four topics significant to SCQM, namely SC competences, critical success factors of supply chain quality (SCQ), strategic components of SCQ, and SCQ practices, a division that helps to identify the variables that influence the quality performance in SC. In a similar vein, Lin et al.³⁰ identified the components of SCQM as supplier relationship, information technology, process management, top management support, human resource management, QM, strategic planning and knowledge management. In recent years, the extensive research on SCQM has led to developments in practice whereby improvements in one area can then be used to inform other areas, thus improving efficiency and enhancing results throughout the relevant industry.

SCQM in the construction industry

Although there is abundant literature on SCM in construction, only a few studies have addressed the SCQM being conducted in the construction industry, especially in the

context of China. Given that the SCQM of construction is currently attracting a great deal of attention in China, being regarded as an important strategy to benefit industry practitioners in terms of quality integration and process improvement, it is now essential to understand SCQM of construction with specific reference to the Chinese situation and to provide solid suggestions in response to current issues.

A survey of the limited literature reveals that among the main topics discussed by scholars, collaborative relationship features highly. Wong (1999)³¹ proposed some concrete suggestions with regard to the SCM issues in total quality management (TQM) for construction projects from a relationship aspect. His study indicated that (1) the design and implementation of TQM in a construction firm must incorporate an assessment of its relationship with SC members; (2) in managing the SC as an integral part of a TQM system, the general contractor maintains a portfolio of contractual relationships with suppliers or subcontractors; and (3) structured relationships with key subcontractors and suppliers will facilitate the achievement of the total quality requirements of the customer, especially in a turbulent and competitive market environment. The relationships among all participants are pointed out as a core concern for the execution of the construction projects. In addition, a study by Matthews et al.³² focused particularly on how a partnering approach enabled the QM process through the modification of the conventional main contractors–subcontractors’ relationship. The study noted that: (1) partnering can bring about improvements in the design process, communication and build ability. It has the potential to improve the levels of productivity and quality attained on site; (2) partnering is not a technique that establishes rules, regulations, documentation and procedures, but is a proactive approach to the management of business relationship; and (3) it is easier to control time and cost performance levels and achieve higher quality levels given the close cooperation and openness that facilitate earlier anticipation and minimization of potential problems. For these reasons, the understanding of partners’ behaviours has significant implications for SCQM, and therefore more communication is advocated in order to better understand participants’ ideas, thereby improving the efficiency of business cooperation.

As outlined above, the literature on SCQM in the construction industry indicates that good relationships between main contractors and their suppliers, including subcontractors, have a positive influence on the QM in the construction SC. However, the literature to date is limited and contains many gaps. First of all, previous research studies have focused on Hong Kong and UK construction firms, but have not explored the Chinese context. Secondly, as purchasing activity is a vital part in the construction SC, it has great influence on the quality of the final projects. Yet while investigation of SCQM practices in construction PF would have profound significance for controlling quality in the construction industry, research in this aspect is almost non-existent. Moreover, a distinctive feature of the

construction SC is that it includes not only the suppliers that provide materials, but also the subcontractors that provide the service. Consequently, those charged with managing the SC face two different situations, and must know how to deal effectively with and control both subcontractors and material suppliers in order to assure the project quality. Finally, QM outcomes vary with the effectiveness of SCM, which in turn is affected by changes in the supplier environment, and which should also be measured. Therefore, there remains a need for further research, and in particular for a theoretical framework of fundamental understanding of SCQM that also incorporates the specific characteristics of the construction industry.

Research methodology

Qualitative research method

While quantitative methods have prevailed in many disciplines, particularly business disciplines such as purchasing and logistics, operations management, marketing and general management, qualitative methods appear to be gaining both recognition and acceptance as viable and valuable alternatives. Qualitative research methods help us to understand the nature, strengths and interactions of variables. Moreover, rather than adopting a simplified view of the subject in order to measure and count the occurrence of states or events, qualitative methods take a holistic perspective that preserves the complexities of human behaviour. This article attempts to research the QM of suppliers and subcontractors in the construction industry. Although there has been much research on SCM and QM, as well as QM in the SC, there is little empirical knowledge regarding SCQM in construction, especially the QM in PF in construction. In this situation, the qualitative research method is particularly appropriate, as it is able to describe the complex and often chaotic systems at work.

In qualitative research, probably the most widely employed method is the interview. There are two major types of interview in qualitative research, namely unstructured and semi-structured interviews. According to Bryman and Bell (2011)³³, where a research has a clear focus, the semi-structured interview offers a flexible option to elicit specific answers, rather than more general notions. Therefore, this dissertation prefers to adopt the semi-structured interview, because its focus is to investigate the QM of suppliers and subcontractors in PF in the construction industry.

Case-study method

The case-study method is tailor-made for exploring new processes or behaviours, or ones that are little understood. It is an ideal methodology when what is needed is a holistic, in-depth investigation. Usually applied to investigate a contemporary phenomenon within its real-life context when

Table 1. Summary of interviewee profiles.

Interviewee	Interview method	Interview duration	Interview content
Managing director	Internet interview through Skype	1 h	<ul style="list-style-type: none"> – General investigation of the SC in the firm – The current situation of QM in the firm's supply chain
Purchasing manager A	Internet interview through Skype and email	1 h	<ul style="list-style-type: none"> – The materials in which it is most difficult to distinguish quality – The quality standards to select material suppliers – The quality specifications in material purchasing – The quality terms in the construction contract and compensation or penalty for non-compliance
Purchasing manager B	Internet interview through Skype	1 h	<ul style="list-style-type: none"> – The inspection and acceptance standards to ensure the materials' quality – Warehousing of the materials – The evaluation of the suppliers
Chief engineer A	Internet interview through Skype and email	1.5 h	<ul style="list-style-type: none"> – The subcontractors that are most difficult to control – The quality standards in the subcontractor selection – The construction details: discussion and communication between main contractor and subcontractor about quality issues in construction projects – Quality terms in contract
Chief engineer B	Internet interview through Skype	1 h	<ul style="list-style-type: none"> – The ways and stages of monitoring the subcontractors during the construction to control the quality – The acceptance standards and policies of the finished projects – The evaluation of the subcontractors

SC: supply chain; QM: quality management.

the boundaries between phenomenon and context are not clearly evident, it excels at bringing us to an understanding of a complex issue or object, and can extend experience or add strength to what is already known through previous research. It is worth noting that a number of studies point out the different applicability of a single case and multiple cases. A single case, like one experiment, is suitable when that case is critical to testing a well-formulated theory, is extreme or unique or reveals a previously inaccessible phenomenon.

This research is based on a single in-depth case study, conducted using semi-structured interview methodology, in order to test whether SCQM in construction is similar to the general principles of SCQM. The case study was conducted within a medium-sized, China-based, privately-owned construction firm. This firm was not selected at random: According to data from the China Statistical Yearbook,³⁴ there were 83,017 construction enterprises in China in 2016, of which 75,722, around 90%, were privately-owned, small or medium-sized firms. Consequently, the selected medium-sized private construction firm can be considered as to some extent representative of the construction industry in China. Another reason for the selection of this firm is that although the company's focus is civil engineering, it also undertakes some small building works, such as building demolition. Hence its working scope is relatively wide and varied. Moreover, as quality is the backbone of construction, and directly related to personal safety, quality issues are always a priority in that industry, regardless of firm ownership. However, although firms and

government attach great importance to quality, QM is still not performing effectively, and the selected firm has experienced many of the safety hazards common to construction projects. Therefore, in-depth case study of this company will help to investigate the current situation of supplier QM and to discover the existing quality problems in the construction SC, thereby offering some insights for the whole construction industry in China.

Data were collected through semi-structured interviews with the managing director, purchasing manager and chief engineer. While interviewing in qualitative research is usually face-to-face, owing to restrictions of time and distance the interviews for this research were done over the telephone or Internet with the assistance of modern communication tools such as Skype and email. Available archives and relevant documents were also used, to provide further information for investigation. The interview guideline and questions were designed to focus mainly on the quality measures in each activity used to ensure the quality of the completed project. The interviewee, interview method, duration and content are showed in Table 1.

Outline of case report and research evolution

The information and data collected from interviews indicate that QM in the PF plays an important role in construction SCQM. Consequently, this will be discussed as the main concern to improve the performance of SCQM. Drawing upon existing literature and the data obtained from our interview results, a fundamental model of QM

in PF in the construction industry will be formulated. This will contain the basic six dimensions of PF and the key concern(s) of each dimension, showing the interactions among different constructs. Then the article will examine the application of this fundamental model with regard to material suppliers and subcontractors, using a plastic pipe supplier and cast-in-situ bored pile subcontractor, respectively, as representatives. Through in-depth analysis of each object, we propose two models based on their specific situations to present concrete suggestions.

Case analysis

The fundamental model of QM in PF in the construction industry

QM in the PF is one branch of SCQM; it is not only a prerequisite to ensure the quality of the finished product, but also a critical measure of the performance of the whole SC. Therefore, effective implementation of QM practices in purchasing can maximize the contributions of SCQM to the organization. According to Sanchez-Rodriguez and Martinez-Lorente,³⁵ QM practices in PF can be divided into six constituent factors: cross-functional coordination, personnel management, supplier management, quality information, benchmarking and SCQ office. Among these six factors, supplier management is always the focus and the most critical practice in PF; it runs throughout the construction SC activities, from supplier participation to supplier relationship development. In addition, employee relations, quality data and reporting and supplier QM are three important elements that affect the practice of SCQM. This article attempts to evaluate the performance of each practice and reveal the relationships among them in the construction industry.

In terms of the participants in the construction SC, subcontractors, material suppliers, and main contractors are the main research objects in this model. Approximately 90% of projects need to be undertaken by subcontractors, which indicates the importance of subcontractor selection. Meanwhile, the choice of material supplier directly influences the quality of projects. For these reasons, subcontractors and material suppliers are selected as the important objects that impact the PF in SCQM. The investigation for this study has revealed the following common activities in construction projects: First, as part of the selection process the main contractor collects information about different suppliers' market prestige, previous performance, quotation and quality assurance policy. Secondly, the purchasing firm gathers information through supplier participation, where suppliers provide relevant documents to prove their previous performance and ensure their product quality or service quality. Thirdly, benchmarking involves the collection of information about the purchasing process and performance from other organizations. Investigating and analysing the supplier performance in other organizations and their influence on

the whole organization's performance in the purchasing process will assist the main contractor in their supplier selection.

In addition to the supplier selection, material inspection and project monitoring are also key QM activities; indeed, sampling inspection, and reinspection by professional institutes are routine in product QM. Once the construction project is completed or the provided materials are accepted, buyers will collect quality information from supplier management activities such as the usage of materials and equipment, and supply and delivery ability; as well as information on the subcontractors' construction schedule and their ability to handle contingencies or emergencies. Based on these quality data, the main contractor evaluates the suppliers to determine whether or not they are qualified. Thus, quality information plays a critical role in supplier evaluation, which further verifies its relationship with supplier management.

Another component in SCM activities in the construction industry is the contract. Before signing the contract, the contracting parties will discuss quality terms, including aspects such as compensation and penalties for non-compliance, in order to achieve maximum quality assurance. Moreover, the main contractor will set certain benchmarking measurements, to facilitate better supplier management. Hence, it can easily be seen that there exists a link between supplier management and benchmarking.

From the above analysis, therefore, it can be concluded that supplier management is closely related to quality information, and benchmarking connects with quality information through quality data and reporting.

Cross-functional coordination is inevitable in the construction industry. Many SCM activities require good communication and cooperation among individuals; so internally, employee relations play an important role in efficient task execution. In construction activities, the material equipment department coordinates with the purchasing department to carry out relevant procurements according to the requirements of the construction group; the project manager communicates with top managers and purchasing staff to select the material suppliers, and with the technical engineering department for subcontractor selection; top managers liaise with individual department directors to discuss the details of the contract; the security sector interacts with those responsible for quality inspection in order to deal with emergency events and to inspect materials or project quality. All these activities are conducted based on information sharing among different departments, and as pointed out by Lambert and Cooper,³⁶ such information has a strong influence on supplier relationships. Therefore, cross-functional coordination is a critical factor for effective supplier management.

With regard to personnel management, each person and department is empowered with different rights in order to do their job. Meanwhile, staff are provided with the professional skills training relevant to them; for example, purchasing staff will receive training in the standards and

specifications of different materials and equipment, while safety department staff will be trained in safety procedures and emergency treatments in the case of accidents. All such training is quality-oriented. In addition, following the completion of each project the construction firm will present the project quality evaluation report to the entire staff, in order to promote quality recognition and instil knowledge of QM, encourage everyone to participate in supplier management and improve communication and interaction among employees about quality issues, thereby establishing good employee relations in the organization. Consequently, both cross-functional coordination and personnel management interact with supplier management. In addition, cross-functional coordination not only connects to quality information, but also links to personnel management through employee relations.

Another important principle during QM is that suppliers' products or the projects conducted by subcontractors must meet the relevant criteria specified by the State. Moreover, suppliers and subcontractors should avoid opportunistic behaviour and abide by all legal rules. Currently, in China, there is in place a relatively complete set of policies aimed at improving and controlling the quality of construction. A wide range of construction processes, including but not restricted to the material purchasing, inspection and acceptance, must comply with the relevant State's guidelines and policies to ensure the final project quality, and prevent safety accidents. Hence, the policy deployment from the SCQ office is also an effective way to manage suppliers. Moreover, the construction quality office also helps construction firms to conduct internal personnel management, for example, through running training courses for prompt delivery of up-to-date knowledge on relevant policies and regulations to all staff, thus improving their knowledge base in order to better control the project quality. Simultaneously, the quality office is also involved in benchmarking, because main contractors must respond to the new policies and standards it issues by continuously updating and improving benchmarking on both material purchasing and project supervision. Therefore, it can be concluded that the quality office has significant input into both personnel management and benchmarking.

As mentioned above, the construction SC is made up of main contractor, material suppliers and subcontractors. However, in addition to these parties, the third-party inspector is another vital element that should be included to ensure the quality of products and projects. The third-party inspector assists the main contractor to supervise the subcontractors' behaviour and work efficiency, and inspects and approves the quality of finished projects according to the relevant quality standards or policies issued by the State. With regard to material suppliers, the third-party inspector will provide professional inspection technology and equipment to distinguish the quality level of the materials. Furthermore, the third-party inspector also understands the quality information of different materials

or projects, thus contributing to the achievement of better management. Similarly, such information-related quality standards and policies are required by suppliers and subcontractors for the purpose of providing better materials and services. Beyond that, another common way for the main contractor to monitor and manage suppliers is through benchmarking. Therefore, the main contractor, suppliers and subcontractors are all associated with quality information, benchmarking and quality office, while the third-party inspector is linked to quality information and quality office.

Two sub-models of the fundamental model in the construction industry

The above analysis details the relations among each practice, as well as the relations between different members in the construction SC and these QM practices. Drawing upon this analysis, a fundamental model of SCQM-PF in the construction industry is proposed (see Figure 1), and then validated by case study. However, the available information from interviews also indicates that there are subtle differences when applying this model to material suppliers and subcontractors. Therefore, this article will research the different sub-models of SCQM-PF according to these two situations.

The material supplier and subcontractor selected for this case study are a plastic pipe supplier and cast-in-situ bored pile subcontractor, respectively. These were selected because they often experience unexpected quality issues, which present particular challenges for the main contractor's QM. For example, most plastic pipes used in the construction industry, such as water supply and drainage pipes, and power line pipes, are made of composite materials such as unplasticised polyvinyl chloride (UPVC), chlorinated polyvinyl chloride (CPVC) or polyethylene (PE), where the quality cannot be assessed through appearance alone. Furthermore, some counterfeit and shoddy products may carry qualified certification, in order to cheat customers. Since main contractors depend on their experience, visual inspection and the product qualification certificate to assess the materials, it is hard to control the real quality of this kind of product. However, there are some measures that can be taken to manage such suppliers and thus ensure the product quality as far as possible. For example, bored and cast-in-situ pile, one of the most convenient ways of laying foundations, involves a steel case that forms a void in the soil, which is then filled with concrete. The steel case is left in place to form a permanent casing and increase the reliability of the piles. Due to the concealed nature of this part of the project, there is potential for many quality problems during the construction, of which the most frequently encountered are hole wall sloughing, inclined hole, pit mud, quicksand and reinforcing cage up-floating. Faced with so many potential problems, the main contractor will have specific strategies to deal with them during the SCM activities. This paper compares the different QM activities of above suppliers in each practice that described in conceptual model, the following table (Table 2) details such comparisons.

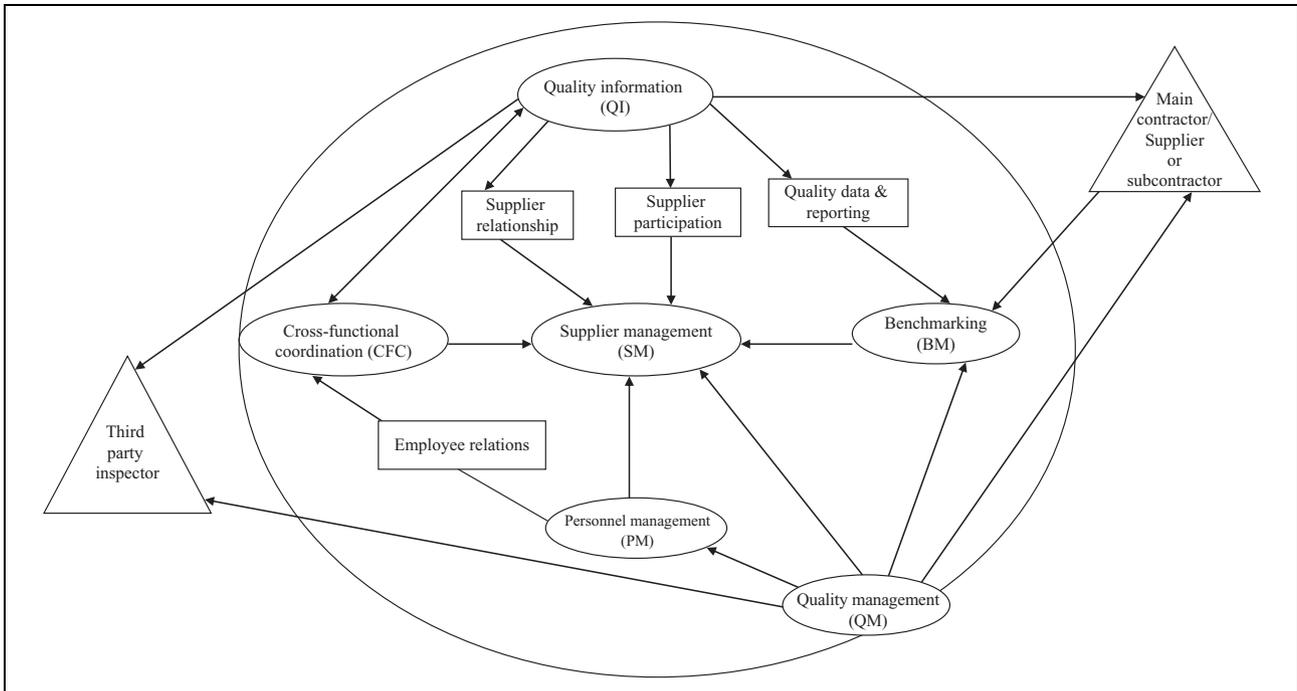


Figure 1. The fundamental model of SCQM-PF in the construction industry. SCQM: supply chain quality management; PF: purchasing function.

Material supplier QM in PF mode

The above case of a plastic pipe supplier indicates the links among QM practices with regard to material suppliers in construction activities. Each QM practice jointly supports better supplier management (Figure 2). First, main contractors specify their demands regarding the materials, including the quantity, type, quality and class. Then the supplier provides their personal information, such as their previous performance or rewards, and information on their product (e.g. certifications, specifications), such that the main contractor can be assured as to their policies about the product quality. Based on this information, main contractors are then able to make the supplier selection and purchase the materials. Inspection and acceptance will provide the results of product inspection to main contractors and suppliers, thus allowing the main contractor to determine whether the quality information from the suppliers is consistent with that from inspection. Furthermore, inspection and acceptance is also beneficial to supplier evaluation, because the quality of product represents the supplier's performance. Through evaluation, the main contractor can establish a database of supplier information, which will help in the next supplier selection. Quality information from both parties (supplier and main contractor) also contributes to the contract signing process via the quality data report, where the main contractor can set contract terms according to their requirements for various products.

As to benchmarking, main contractors gather the previous supplier information and contract information through

quality data reporting. Moreover, according to new criteria issued by the quality office, they continuously update their standards in selecting suppliers and revise the contract terms or set up new benchmarking in the contract to better manage the suppliers, thus giving greater assurance on the quality of products. The continuous improvements in benchmarking allow the main contractor to select higher quality suppliers.

The quality office is crucial in quality control: it not only links to benchmarking, but also supports personnel management. Through the quality office it is possible to issue policies and rules or stipulations to monitor the supplier's behaviour in trading. It gives the reference points to the main contractor in product inspection and acceptance, provides knowledge on inspection training in construction and sets new benchmarks according to updated quality standards for various products. While the third-party inspector in material supplier QM activities provides professional inspection of product quality, such as laboratory examination of product ingredients, specifications and relevant quality index, which cannot be conducted by the main contractor, the inspection must take place according to the regulated processes of the quality office, and only when all indices of the inspected products meet the standards of the State can they be qualified and approved for use in construction. Meanwhile, material suppliers also like to gather information about selection standards used by main contractors, and the new policies or rules issued by the quality office, so that they can improve themselves accordingly and become more competitive in the market.

Table 2. The QM practice comparisons of plastic pipe suppliers and bored and cast-in-situ subcontractors.

QM practices	Plastic pipe supplier	Bored and cast-in-situ pile subcontractor
QI	<p>Supplier selection:</p> <ol style="list-style-type: none"> ① Product quality: the information of the supplier's stable and favoured manufacturing process and standard; supplier's quality control system to control pipe quality. ② Supply ability: the information of the supplier's stable productivity and efficiency of transportation. ③ Information of supplier's reputation and previous performance. ④ Policy: information of supplier's quality assurance and compensation policy, the qualified certifications of the provided pipe. <p>Material purchasing</p> <ol style="list-style-type: none"> ① Information of plastic pipe specification: GB/T5836.1-2006 GB/T5836.2-2006 GB/T18993.2-2003 GB/T18993.3-2003 GB/T13663-2000 GB/T13663-22005 ② Plastic pipe index: external diameter, ring stiffness, impact resistance, coefficient of heat conductivity, flexibility and so on. <p>Contract</p> <ol style="list-style-type: none"> ① Relevant contract terms about quality issues. ② Information of compensation and penalty in the case of supplier default: <ul style="list-style-type: none"> -If the materials do not meet the quality standard, the main contractor will return all of them. -Supplier will be fined according to the quality default clause in the contract. -Main contractor has right to terminate the contract and report to governmental department in serious situations. <p>Inspection and acceptance</p> <ol style="list-style-type: none"> ① Inspect the plastic pipe index: external diameter, ring stiffness, impact resistance, coefficient of heat conductivity, flexibility. ② Provide information about the detailed index of the produced pipes. <p>Supplier evaluation</p> <p>Supplier selection</p> <p>Material purchasing</p>	<p>① Credit: the information of the subcontractor's market prestige, previous discipline violations, serious quality and safety accidents.</p> <p>② Quotation: the information of the subcontractor's financial ability, and the rationality of its quotation.</p> <p>③ Construction scheme: the information of the subcontractor's construction scheme design, its system structure of the project management, technology management and quality management.</p> <p>Construction scheme design, details discussion and communication</p> <ol style="list-style-type: none"> ① Technical disclosure: information of the project design intention, quality requirements of the project and subcontractor's suggestions as to the possible quality problems in design. ② Subcontractor's solutions to the possible quality problems due to any kinds of changes during the cast-in-situ bored pile construction. ③ The information about the equipment configuration, staff preparation, purchasing situation, quality control objects, quality inspection standards and means. <p>① Relevant contract terms about quality issues.</p> <p>② Information of compensation and penalty in the case of default by subcontractor: <ul style="list-style-type: none"> -If subcontractor's purchasing materials are not qualified, a fine will be payable of double the value of those materials. -If any action or failing on the part of the subcontractor leads to pile fracture, perforation, change of length or diameter, all losses (e.g. postponement of construction, increased cost) should be borne by the subcontractor. -Quality maintenance will be executed by relevant stipulations of the State. </p> <p>① Provide information of the material quality, excavated hole quality and pile quality during the construction.</p> <p>② Provide information such as position of pile and elevation of the top pile, including the stability of the pile foundation.</p> <p>Evaluate the suppliers according to the quality of their provided materials, the quality of the finished projects and their general performance during the construction activities. Provide the information for the next supplier selection.</p> <p>Project manager will communicate with top manager and technical engineering department for purchasing staff to select the material suppliers.</p> <p>Material equipment department will coordinate with purchasing department to carry out relevant procurements according to the requirements from the construction group.</p> <p>Top manager, project manager, chief engineer, project designer, purchasing staff and inspection group will attend communication</p>
CFC		

(continued)

Table 2. (continued)

QM practices	Plastic pipe supplier	Bored and cast-in-situ pile subcontractor
		the meeting with suppliers about the scheme design and details discussion.
	<p>Contract signing Inspection and acceptance Evaluation</p> <p>Top managers will instruct each department director to discuss the details of contract signing. Inspection department will cooperate with purchasing staff to do the material inspection and acceptance. Top managers will organize relevant departments to evaluate the suppliers according to their performance in each part of the construction activities.</p>	<p>Security department director and quality inspection department director will attend the project inspection and acceptance. Internal inspectors, top manager, project manager and chief engineer will coordinate with third-party inspector to do the comprehensive evaluation of the subcontractor based on the results of finished project quality.</p>
PM	<p>Supplier selection Material purchasing Warehousing</p> <p>Training the relevant personnel in the knowledge and standards relevant to material supplier and subcontractor selection. Training purchasing staff to improve ability and knowledge to distinguish different materials and their quality level. Staff's knowledge on the storage conditions of plastic pipes.</p>	<p>Construction scheme design and details discussion Raise the staffs recognition of teamwork and improve their ability to identify and solve problems.</p>
	<p>Contract signing Inspection and acceptance</p> <p>Publicizing the importance of the contract, training staff on the details and process of contract signing. Professional skills training, for example, how to determine whether the material or project is qualified, and if not, how to deal with it in a timely manner. Awareness of individual responsibility in the quality assurance process.</p>	
QO	<p>Inspection and acceptance</p> <p>Technical requirement for environmental labelling of products – plastic pipes for construction: HJ/T 226-2005</p>	<p>Inspection and acceptance Construction scheme design, details discussion and communication</p> <p>GB 20202-2002: Quality acceptance standards of construction foundation. GB 50300: Uniform quality acceptance standards of construction.</p>
BM	<p>Supplier selection Contract signing</p> <p>Main contractor will set up new BM according to its previous experiences and standards for better selection of the material suppliers and subcontractors. Main contractor will continuously revise and improve the contract terms, set up new BM in contract about quality issues so as to better control the quality of materials and the project.</p>	

QM: quality management; CFC: cross-function coordination; PM: personnel management; QO: quality office; BM: benchmarking; QI: quality information.

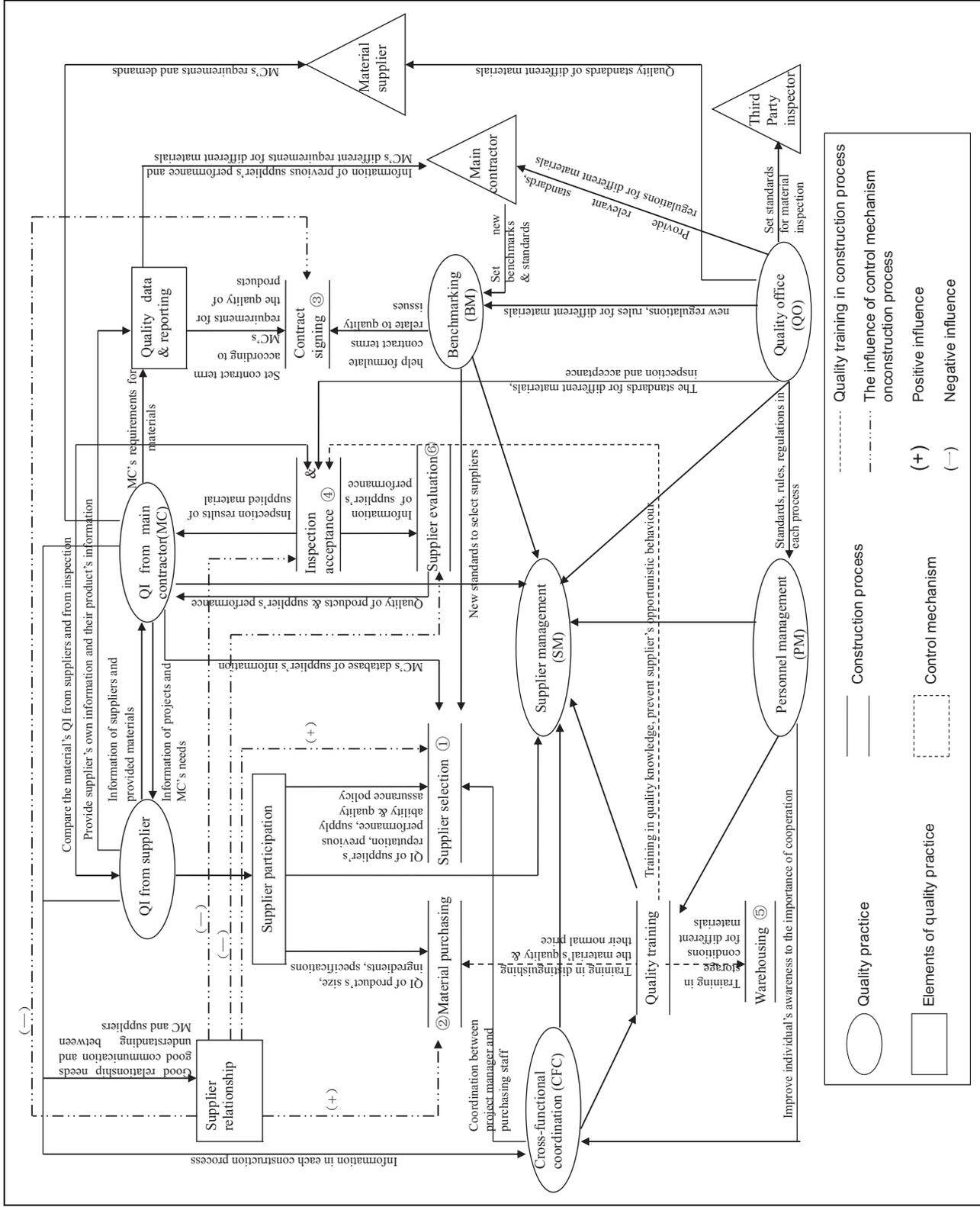


Figure 2. Material supplier SCQM-PF mode. SCQM: supply chain quality management; PF: purchasing function.

Personnel management mainly refers to quality training for staff; it contributes to improving individuals' ability and professional skills in different functions, and builds their awareness on the importance of quality issues and teamwork, thereby promoting exchanges and cooperation across different departments for better supplier management. In construction processes, the staff who conduct the material purchasing (training in distinguishing the products' quality and their quotation), product inspection and acceptance (training in quality knowledge, prevention of supplier's opportunistic behaviour) and warehousing (training in different storage conditions for different materials) are most likely to be accepted for quality training, because these are critical factors to ensure the product quality. Nevertheless, effective cross-functional coordination also requires a wide range of quality information provided by both supplier and main contractor during construction activities. The sharing of such information helps staff from different functions to become familiar with every phase in each activity, thus facilitating better communication and efficient problem-solving.

In addition to the QM practices analysed above, the supplier relationship is an equally important element in construction SC, which will exert either a positive or negative influence on the construction processes. First of all, good communication and understanding between the main contractor and supplier are prerequisites to establishing a good relationship, so it is essential that both parties provide the required quality information. Secondly, once trust is established, the main contractor will be more willing to engage in long-term cooperation, while suppliers will be more likely to provide high-quality products. Hence, such a relationship can have a positive impact on material purchasing and supplier selection. However, in terms of contract signing, inspection and acceptance and supplier evaluation, a strong supplier relationship may have a negative influence, since a high level of trust might mean that the main contractor is less cautious or less rigorous in these processes, which could lead to some unexpected quality problems.

Subcontractor QM in PF mode

The relationships among the QM practices with regard to subcontractors are presented in Figure 3. Initially, the main contractor provides the project information and their requirements to the subcontractor. In turn, the subcontractor offers their own information to the main contractor, such as reputation, previous rewards or past experience in carrying out relevant projects. Subsequently, the subcontractor participates in a quality meeting with the main contractor to discuss the construction scheme design and project details; this is also an opportunity for the main contractor to obtain further information in order to judge whether that subcontractor is competent to undertake the project under discussion, and whether to enter into a

partnership with it. This meeting also establishes the quality details of the project, which will form part of the contract terms. Moreover, the exchange of quality data between main contractor and subcontractor acts as an impetus for the main contractor to set up new benchmarking according to previous quality information and new standards from the quality office, thus achieving continuous improvements in the subcontractor's quality. Likewise, quality information and new standards or policies are also critical to subcontractors, who will establish new norms and criteria in conducting the projects accordingly.

As with the material supplier situation, personnel management in subcontractor QM in construction processes is important to cultivate individuals' ability to do their job, while simultaneously promoting coordination among different functional departments, which will serve to improve supplier management. Therefore, quality training is an indispensable part of subcontractor QM, especially with regard to monitoring and construction scheme design and details discussion. Monitoring staff need to know the monitoring flow, phases, standards, quality information of the project and project acceptance standards. Similarly, staff involved in the construction details discussion should receive training in quality knowledge, specific construction conditions and problem-solving ability. Such training will greatly improve individuals' capability as well as the project quality. However, better personnel management relies on the training information provided by the quality office, which is necessary to evaluate subcontractor performance and ensure project quality.

Monitoring is the most critical process in construction, because it directly relates to the quality of the final project. It also provides the information for subcontractor evaluation, which will help the main contractor to set up the subcontractor database for the next round of selection. Consequently, monitoring requires impartial supervision, and should include both intra-organizational inspection personnel and third-party inspectors, responsible not only for the monitoring of subcontractors but also for controlling the quality in each process in construction. Such third-party inspectors need the information of the subcontractors, such as their reputation, equipment configuration, staff preparation, purchasing situation, quality control objects and quality inspection standards and methods. Additionally, project information such as project design, schedule and budget is crucial to allowing the third-party inspector to carry out effective inspection during construction. Furthermore, the third-party inspectors are obliged to be fully familiar with all governmental policies, rules and standards relevant to each project, so that they can conduct effective supervision and ensure that the finished projects will be consistent with the national standard.

Once having achieved a comprehensive understanding of the subcontractor QM in the PF, the control mechanism in construction is vital, because most quality problems in Chinese construction are caused by improper control

measures. Therefore, we will consider two components of control mechanism, namely subcontractor relationship (SR) and standard operation procedure (SOP). The former is a type of social control while the latter belongs to the category of formal control. These two components have vastly different influence on each construction process and will lead to different outcomes with regard to the project quality. In SR, quality information from the subcontractor and main contractor can promote mutual understanding, thus producing impacts on construction processes. SR has both positive and negative influence on subcontractor selection: on one hand, SR will help to establish long-term cooperation, which will improve the efficiency of selection; on the other hand, the main contractor may miss out on finding higher quality subcontractors. By contrast, SOP is invariably good for subcontractor selection, because the principle of impartiality will offer more opportunities to the main contractor. In construction scheme design and details discussion, SR and SOP have opposite effects: SR enables better communication between the two parties, which is helpful to problem-solving and reaching agreements on most issues; however, SOP lacks flexibility, which can hinder problem resolution. Similarly, SR and SOP have opposite influences in contract signing, monitoring and subcontractor evaluation: SR has negative impacts in these areas, because good relationships can obscure the vision of main contractors, leading them to lower their requirements or allow subcontractors to slack off in their work; conversely, SOP compels subcontractors to do their work according to the relevant standards, in order to avoid penalties for non-compliance. Therefore, SOP can effectively prevent the opportunistic behaviour of subcontractors. Main contractors should select the proper control mechanism in each construction process, thereby achieving the best outcome in subcontractor management.

Discussion and conclusion

With the rapid development of urbanization in China, the number and size of construction projects are growing rapidly. Meanwhile, the increasing number of construction accidents has attracted much public attention.¹ This research on managing QM in the construction SC has been conducted to provide insights for Chinese construction firms on how to improve the quality and safety of construction projects. Specifically, this article focuses on two main participants in construction project management, namely material supplier and subcontractor, on the grounds that they are key concerns in project quality control to promote work efficiency and ensure personal safety.

The comprehensive literature review identifies the main research gap in SCQM in construction, which is the lack of studies on QM of material suppliers and subcontractors in the construction SC.³⁷ Furthermore, because a large number of SCM activities in construction are ultimately part of the purchasing process, quality issues are more likely to

happen when interacting with other participants; therefore, this research discusses the QM practices in the PF.³⁸

The article proposes a specific and refined conceptual model of SCQM-PF applicable in the construction industry and made up of six QM practices: cross-functional coordination, personnel management, supplier relationship, quality information, benchmarking and QM. Among these six practices, supplier management is shown to be supported by the other five, while they also work together or separately to control the quality in purchasing. Then, by means of a case study on a typical Chinese construction firm, the links among different QM practices are found to complete the conceptual model. First of all, a relationship triangle can be identified among supplier management, quality information and benchmarking, where supplier management, supplier relationship and supplier participation are particularly related to quality information, and benchmarking connects to quality information through controlling quality data and reporting, while supplier management is also affected by the processes and performance metrics of benchmarking to pursue best practices. Secondly, cross-functional coordination not only interacts with quality information, but also connects to personnel management through employee relations. Thirdly, the policy deployment in QM is an effective way to manage the suppliers, while also offering assistance to personnel management and benchmarking. Finally, main contractors, suppliers and subcontractors are all associated with quality information, benchmarking and QM, while the third-party inspector is linked to quality information and QM. These relationships help to develop the fundamental model of SCQM-PF in construction.

Next, when considering the two different factors in construction SC, that is, material suppliers and subcontractors, this research studies the cases of a plastic pipe supplier and cast-in-situ bored subcontractor, respectively, in order to find the differences between them in QM in PF. Based on the information provided by the case-study company in this study, two different models are derived from the fundamental model, to represent separately the material supplier and subcontractor in construction SC. These two sub-models provide construction firms with some insights to better manage different suppliers in construction SC, thereby controlling and improving project quality. However, in view of the many variables in construction SCQM, such as different levels of importance of material suppliers and subcontractors, and different size and duration of projects, the article also discusses two situations for each party and proposes the SCQM-PF sub-models accordingly.

The objectives of this study are to understand SCQM practices in the Chinese construction industry and to investigate the way QM connected with the PF influences the construction SC performance. After reviewing the literature and conducting an in-depth case study, a fundamental model of SCQM-PF and two SCQM-PF sub-models are developed. The proposed model not only comprehensively

illustrates the relationships between main participants and important factors, but also makes a significant practical contribution as a basic tool for managers to understand how different elements influence each other, and the mechanisms among elements. Firstly, the SCQM-PF fundamental model can be used as a building block of SCQM strategy. The main decision makers can develop a meticulous layout of the overall purchasing operation based on our proposed model before the project is implemented. This is particularly important for the managers to analyse the operations in each main element of QM in PF in the planning stage of the project. By referring to the SCQM-PF model, directors and managers will avoid overlooking important operations. In addition, the two sub-models will be helpful for developing the selection and evaluation practices with regard to suppliers and subcontractors; that is, the investigation of quality information of suppliers' reputation, previous performance, supply ability and quality assurance policy, to evaluate whether the suppliers have the ability and reputation to cooperate. Secondly, this model can facilitate the better allocation of resources to different QM-PF activities in order to increase operational efficiency. More specifically, when managers assign tasks to operators, it can help those operators to understand the mechanisms among their different tasks, and to be clearer about how to increase construction quality. The SCQM-PF sub-models can also explain the reasons why certain monitoring and standards are executed. Meanwhile, as the sub-models show, some quality training about storage conditions for different materials and monitoring procedures are necessary to increase operators' ability of QM. Last but not least, the models, especially the SCQM-PF sub-models, can play significant roles in maintaining a good relationship between the construction firm and its suppliers. This is because, when interacting with material suppliers and subcontractors, managers can have a thorough insight into what factors affect the relationship. In addition, quality information generated by quality data and reporting and benchmarking in each construction process exert a significant influence on the cooperational relationship. If suppliers are involved in the formulation of benchmarking and able to access quality data and reporting, the trust between construction companies and their suppliers will be strengthened. At the same time, good communication and understanding among participants also helps to improve the cooperational relationship. In short, the models have considerable practical value to help understand the linkages between participants and main elements, and by referring to it construction firms will be able to promote SCQ.

Although this study has made efforts to solve practical issues, based on a review of prior literature relating to SCQM in construction and the conduct of a case study in the context of the Chinese construction industry, it does suffer from the restriction that the two SCQM-PF models of material suppliers and subcontractors are not

constrained, which means they could change according to the inclusion of different variables. Moreover, although the single case provides a rich picture of a particular situation, it is also limited by inadequate evidence across different situations. Therefore, it is suggested that future research should undertake a multiple case study.

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