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Doctoral Dissertation

EXPLORING CONSTRUCTION SUPPLY CHAIN MANAGEMENT: A SYSTEMATIC PERSPECTIVE FOR CREATING SUSTAINABLE PERFORMANCE

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The PhD journey was the greatest challenge in my life. People often said that

"Challenges are what make life interesting and overcoming them is what makes it meaningful" - Quote by Joshua J. Marine.

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Executive Summary

At the global level, it is well acknowledged that the concept of sustainable development has particularly become a major development policy for the industry, especially for the construction industry. This is because the construction industry plays an important role in the economic development of the country. Besides the economic development, the construction industry also has negatively environmental impacts regarding intensive resource usage, high contribution of CO_2 emissions over the building lifecycle, and excessive energy consumptions.

The development towards sustainability in construction industry requires active policies to ascertain the common directions in which, processes/activities need to be improved in order to generate a positive contribution for more sustainable patterns in a long-term perspective. Consequently, numerous building regulations and policies have been formulated to control the construction performance, called as "*sustainable construction*". And these regulations and policies intensely influence on the adoption of construction practices. Coupled with sustainable development policy, various sustainable rating systems for construction (such as LEED®, SBTool, BREEAM, and CASBEE®) have been developed to actively provide some guidance on the way forward for mature practices.

In addition to the regulations imposition, sustainable construction is also becoming a business marketing strategy for a long-term competitiveness. As a result, construction industry around the world is attempting to perform their tasks in a more sustainable way, responding to the regulations pressure along with the marketing pressure.

Traditionally, the construction industry has been seriously facing the performance-related problems, which need a systematic view for the successful management of construction activities throughout the building lifecycle phases. For this reason, there is an increasing interest in the adoption of supply chain management (SCM) principles for improving construction processes as more effective and efficient (Thunberg and Persson, 2013). The construction supply chain typically focuses on the beginning phase of building lifecycle, considering its mission accomplished once the building has been completed. However, it has been found that most of the research is focused on the short-term objective of construction supply chain, which may not respond to the overall building performance. Focus of these research studies is mainly limited to the improvement of specific processes and activities such as logistics process, production process and procurement process.

To effectively improve the sustainability in the long-term perspective, numerous studies have indicated that construction companies require the active role of different actors in a construction supply chain, with a collaborative working relationship (Bankvall *et al.*, 2010; Lönngren *et al.*, 2010; Nwokoro and Onukwube, 2011; Palaneeswaran *et al.*, 2003; Pan *et al.*, 2010) and address sustainability-related issues to the construction activities throughout the building lifecycle (Bribián *et al.*, 2009; Lönngren *et al.*, 2010; Ortiz *et al.*, 2009; Sev, 2009; Verbeeck and Hens, 2010). Consequently, the move towards sustainability in construction industry necessitates a systematic management of the whole process of building lifecycle phases through the collaboration among different construction actors and all stakeholders.

Research Objective And Research Questions

From this point of view, the research aims to provide a systematic perspective for managing the construction supply chain and highlighting its practices towards a long-term sustainability. The systematic perspective would reduce the risk of myopic decisions, which may effect on the overall sustainable performance throughout the building lifecycle. Hence, the objective of this study is to investigate how to improve the construction supply chain management, which may support the design, realization and operation of sustainable buildings. With this objective, a set of interrelated research questions is addressed as following:

Research question 1:

How can supply chain management support the sustainability in construction industry? And, what are the main elements to be considered to manage the construction supply chains, which will ensure the sustainable performance along the entire lifecycle of a building?

Research question 2:

How does construction industry manage its supply chain? What are the existing practices adopted in managing the construction supply chain?

Research question 3:

What is construction industry lacking in managing its supply chain? And how can construction supply chain management be improved towards the achievement of sustainability?

Methodology

With this set of research questions, the research has been conducted into two main parts.

The first part is an extensive literature review, which aims to respond to the first research question. The research has reviewed the literature relevant to the sustainable development in construction and construction supply chain management. Using the culmination of these research findings, a descriptive framework has been proposed in order to provide a systematic view on how to effectively manage the construction supply chain towards a long-term sustainable performance.

In the second part, the research has been conducted through the multiple case study methodology, which aims to answer the second and third research questions. In this research, case studies have been performed to investigate the construction supply chain processes and its practices in different business cultures; carried out in Italy, Brazil, and

Australia. This is because the supply chains in different cultures have been enforced by the local building regulations and sustainable development policies, which may give the priority on different aspects. Moreover, practitioners may have different viewpoints in supply chain management perspective and adopt various practices to manage their supply chain.

A total of 11 respondents from 6 companies involved in construction supply chain have been interviewed, in which two organizations were from each country. The respondents were from different functions at different levels of supply chain; including CEOs, corporate controls, procurement officers, safety and quality control, project managers, site managers, construction planners, construction managers, civil engineers, and marketing managers.

To perform the multiple case studies through interview method, a case study protocol has been first developed as a pilot to conduct the case study actively. Semi-structured questions with probes have been undertaken to elicit relevant information. In addition to interview method, the multiple sources of evidence and a variety of data collections are also included as well as official documents about organizations, project reports, and direct observation to increase construct validity.

The data from multiple-case studies have been analyzed through the cross-cases analysis with a support of NVivo10 (the qualitative research software) to describe the current construction supply chain processes and their practices as well as to explore how construction industry manages its supply chain towards sustainability.

The Structure Of The Thesis

A brief overview of the thesis structure, considering seven chapters, is described below:

Chapter 1 Sustainability In Construction Industry

This chapter has provided an introduction to sustainable development in construction industry and explained the terms of sustainability in construction including standardization in construction industry and sustainable building labels.

At the end of this chapter, the main characteristics of sustainability in construction industry have been provided by comparing four well-known sustainable rating systems (LEED®, SBTool, BREEAM, and CASBEE®). These main characteristics are (1) Energy efficiency (2) Resource saving (3) Materials selection (4) Construction site development (5) Pollution and waste management (6) Service quality (7) Health and wellbeing (8) Management, and (9) Innovation opportunities.

Chapter 2 Construction Supply Chain Management

This chapter has provided a literature review in the concept of supply chain management, sustainable supply chain management, construction supply chain, and construction supply chain management. Regarding supply chain management, SCOR model has been used to describe supply chain management practices; Plan, Source, Make, Deliver, and Return.

At the end of the chapter the unique characteristics of construction industry against the adoption of supply chain management have been discussed. These characteristics can be schematically divided into two main categories: structural characteristics and managerial characteristics. Structural characteristics include project-based industry, high fragmentation, and interdependency of all tasks. Managerial characteristics involve collaboration between several construction actors, customer-centricity, and high need of information and communication technologies.

Chapter 3 Research Methodology

This chapter has identified the research gaps and it has been found that most scholars in the field of supply chain management and civil engineering usually limit their research on the improvement of specific processes and activities. To achieve a sustainable performance in a long-term perspective, construction industry needs a systematic view and a strategic view for the successful management of activities throughout building lifecycle phases.

With these research gaps, this chapter has introduced the set of research questions in order to investigate how construction companies manage their supply chain towards sustainability. At the end of this chapter, the research design, research methodology and data analysis have been described.

Chapter 4 Construction Supply Chain Management For Sustainability - A Descriptive Framework

In this chapter, the descriptive framework for construction supply chain management towards sustainability has been proposed to answer the first research question. From literature review on construction supply chain management, the consolidated outcomes have discussed about two main elements to manage the construction supply chain towards sustainability, the role of construction actors with collaborative relationship, and the lifecycle perspective.

A descriptive framework termed as "*ISCAB*" framework has been developed with the integrated consideration of these two elements to provide a systematic view for managing the construction supply chain towards sustainable construction. With this descriptive framework, it can be explained that the most effective configuration of the supply chain would be achieved through a proper integration of system components, namely the construction actors and the decision-making processes involved throughout all the phases of the building lifecycle. The movement towards a more integrated system requires joint efforts of all the relevant actors.

Chapter 5 Supply Chain Management In Construction Industry - Case Studies

This chapter aims to answer the second research question. Based on the case studies (the Italian case, the Brazilian case, and the Australian case), the current construction supply chain processes and their practices have been described through the SCOR model level 1, 2, and 3.

From the cases studies, it is interesting to note that construction industry across the world is principally based on a traditional approach. The construction activities along the project path are completed independently. General contractor holds full decision-making authority in response to the overall construction process.

Moreover, it has been found that the similar performance-related problems have occurred in managing the construction project. To improve a better construction performance, construction companies need a more collaborative working along the path, an effective communication, and a positive long-term relationship with suppliers and subcontractors.

Chapter 6 Supply Chain Management And Its Practices Towards Sustainable Performance

In this chapter, the third research question has been answered. This chapter has started with the building regulations and sustainable policies in Italy, Brazil, and Australia and describes the construction supply chain management and its practices towards sustainability.

From the review of the regulations and policies, it has also been found that the regulation and policies in each country give the priority in different aspects based on the current needs and climate zone. In addition, these building regulations and policies have direct influence on the practices that construction companies have adopted to manage their supply chain.

The findings of this chapter have been used to develop a portfolio of construction supply chain practices towards sustainability. Based on the integrated analysis of practices from the three cases and the practices from the literature review coupled with the consideration of building lifecycle; the five main supply chain management practices have been defined for the portfolio. These practices include (1) adopting sustainable criteria, (2) considering the sustainable source availability, (3) collaborative working for planning and design, (4) building a positive relationship with all stakeholders, and (5) implementing the adequate management techniques.

Chapter 7 – Conclusion And Future Research

This chapter has presented the conclusion of this research including the scientific implications, practical implications, and the future research.

For the scientific implications, this research extends the implementation of supply chain management approach into the construction field by:

- Defining the main elements that need to be considered in managing the construction supply chain;
- Defining the unique characteristics of construction industry, which make the construction supply chain management more complex;
- Exploring the construction supply chain management practices towards sustainable performance.

For the managerial implications, this research provides the practical guideline to help construction companies in managing their supply chain towards sustainability as:

- Building a better understanding on construction supply chain management;

- Extending the sustainable thinking throughout the building lifecycle;
- Developing a portfolio of construction supply chain practices towards sustainability.

For the limitation of this research, the research has considered the improvement of construction supply chain management at the beginning phase of building lifecycle. The case studies have been conducted in specific regional areas of each country; Bergamo in Italy, Porto Alegre in Brazil, and Adelaide in Australia. Moreover, data and information from interviews are mostly based on the opinions and experiences of respondents.

For future research direction, this topic can be carried out to evaluate each practice in the portfolio in order to seek the most suitable construction supply chain management practices towards each sustainable construction area. The future research can be separately focusing on each type of construction project: residential building, commercial building, and infrastructures.

Chapter 1 Sustainability In Construction Industry

This chapter presents a systematic review related to sustainability in construction industry. The objective is to clarify the sustainable development in the construction industry. It starts with the concept of Sustainable Development according to Brundtland report – *Our Common Future*. Along with the concept highlighted in this report, the importance of construction industry towards sustainability is then disclosed. Some definitions about sustainable construction and sustainable building are provided. Moreover, the description of standardization in construction industry and sustainable building labels gives a picture of the main characteristics and the requirements of sustainability in construction industry. These main characteristics of sustainable construction are presented at the end of the chapter and considered as the key performance indicators for improving the construction supply chain management.

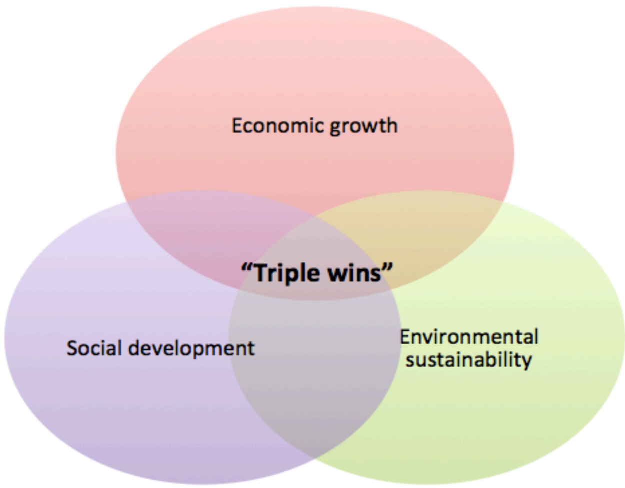
1.1 Sustainable Development

In many parts of the world, the increased human population has been reflected almost at every level of development. As recently in mid-2013, the world human population has reached over seven billion according to the Population Division of the Department of Economic and Social Affairs, United Nations (2013) and the number is projected to increase four billion more by 2050. This population explosion has put the immense pressures on an increased demand for food, clothing, shelter and jobs. As demand is increasing along with scarce resource condition, the satisfaction of essential human needs becomes the major objective of development at the global level.

In the 1980s, the concept of sustainable development (SD), or sustainability was first coined by the World Commission on Environment and Development (WCED); also known as the Brundtland report – *Our Common Future* (UN, 1987). This concept has been defined as the proactive response to a population expansion. Sustainable development is a strategic framework aiming to increase the ability to meet present requirements without compromising future needs for a better life with equity for all. With respect to our common future, the importance of conservation and management of resources has also been recognized due to a finite resource condition (UN, 2011) . This challenge has led to an increasing consideration towards a concept of sustainable development across the world at national level and global level involving notably governments, international agencies, and business organizations.

Sustainability has become a development policy, which allows nations to enhance their sustainable growth rate coupled with reduced resource dependence. Such a growth rate can be attained through the improvement for standards of living by all-around balancing across the environmental sustainability, social development and economic growth called as "*triple wins*" presented in Figure 1.1 (UN, 1987; UNDP, 2012).

Figure 1.1: Sustainable development and "triple wins" outcomes



Source: Adapted from UNDP (2012:pp.5)

In the real world, most of the nations have been facing these challenges (population expansion) at a large scale. They have generally focused their attention to the development of housing, health care, food security and resource supplies in order to create greater willingness for their citizen. Yet, the ability to meet a number of essential human needs requires goods and services provided by industry. It is becoming increasingly clear that the industry sectors play a significant role in the development on a more sustainable basis. However, industrial activities and its products usually have negatively environmental impacts from raw materials extraction, production to the disposal of products. And, it has been found that heavy industries consume a large amount of energy and raw materials, as well as, contribute to a high level of pollution comparing to the light industries (UN, 2007).

Hence, a high level of coordination between government and industrial sectors is required to create the active industrial development policies in order to improve resource efficiency and productivity as "*producing more with less*" (UN, 1987). In many countries, regulations have been used as a policy instrument based on sustainable industrial development framework. These regulations are more centered on pollution-intensive and resource-based industries (such as food, transportation, construction, etc.) with the objective to shift the production patterns and consumption practices for advancing sustainability. In the EU industry, for instance, the overall picture of the EU industrial regulations has been progressing towards sustainable industrial growth and resource efficiency (Rademaekers *et al.*, 2011). The public regulations and policies - including energy labeling and energy taxes, domestic material consumption (DMC) and waste treatment - are created to promote more sustainable consumption and production. With a better sustainable industrial performance, there are opportunities for economic growth at a regional level and the new competitive challenges in markets.

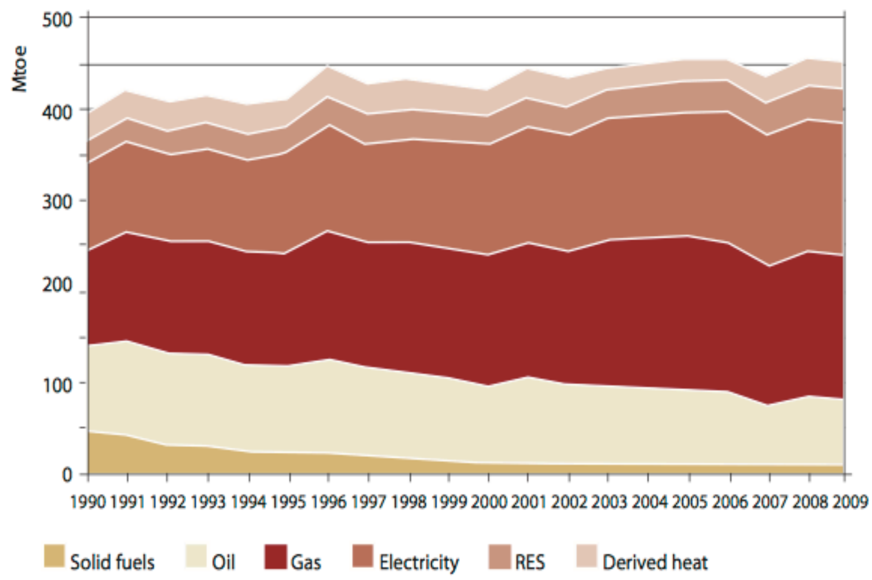
In many cases, shifting industrial activities towards sustainability have been proceeding in different tracks. It is important to ascertain the common directions in which processes need to be improved according to a sustainable development framework. To transform regulatory policies into actions, industries need complementary efforts to insert environmental consideration into industrial activities based on the product lifecycle approach (UN, 2011). High-value-added actions taken by industries throughout product lifecycle would create a positive contribution for more sustainable patterns over the long-term perspective.

1.2 Sustainability In Construction Industry

It is well acknowledged that the construction industry plays a significant role in the economic development of a country. Governments use construction investments as a tool to stimulate the economic growth. Since large quantities of materials, capital and labors are supplied for construction activities, the expansion of construction investment considerably raises the efficiency of the economy in both the goods and the employment market (Giang and Pheng, 2011).

Beside the economic growth, the construction industry also has a deep impact on environmental and social concern. In the European context, for example, the construction industry accounts for almost 10% of the European GDP, and employs approximately 20 million workers. It is characterized by a great share of natural-resource intensive industries, the largest energy consumption at European level about 40% in 2009, as shown in Figure 1.2 (BPIE, 2011; EC, 2012).

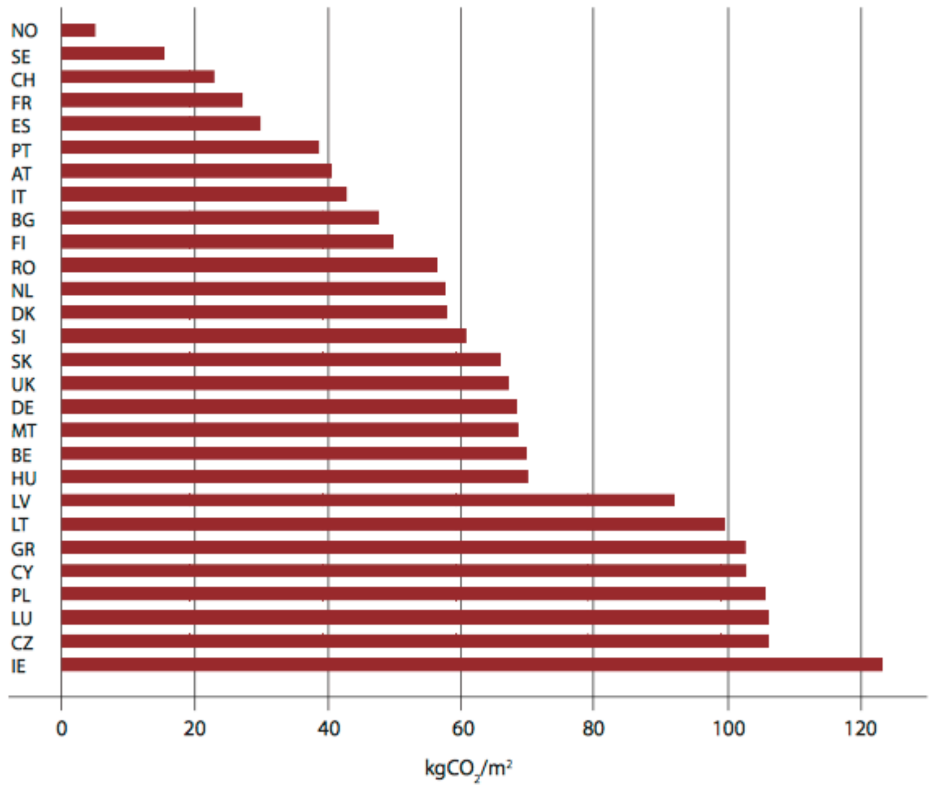
Figure 1.2: Historical final energy consumption in the building sector for the EU27, Switzerland and Norway



Source: BPIE (2011:pp. 43)

Regarding CO_2 emissions, construction industry has a high contribution of all CO_2 emissions over the lifecycle of building compared to all other industrial sectors. It accounts for 36% in 2009 or approximately 54 kg CO_2 $per\ square\ meter$ (CO_2/m^2), as presented in Figure 1.3 (BPIE, 2011; EC, 2012).

Figure 1.3: CO_2 emission per area in EU



Source: BPIE (2011: pp. 44)

Therefore, the role of construction industry has been brought to discussion for promoting Sustainable Human Settlement Development in the 1992 Rio Earth Summit on environment and development in Agenda 21 (UNEP, 1992). According to Agenda 21, the objective of human settlement is to improve the quality of living and working environments through the 8 program areas as highlighted in Table 1.1.

Table 1.1: The program areas for sustainable Human Settlement Development

- Providing adequate shelter for all
- Improving human settlement management
- Promoting sustainable land use planning and management
- Promoting the integrated provision of environmental infrastructure: water sanitation, drainage, hazardous, and solid waste management
- Promoting sustainable energy and transport systems in human settlements
- Promoting human settlement planning and management in disaster-prone areas
- Promoting sustainable construction industry activities
- Promoting human resource development and capacity-building for human settlement development

Source: (UNEP, 1992)

Following the Sustainable Human Settlement Development program in Agenda 21, the Habitat II Agenda has developed the goals and actions, specifically addressed for the construction industry. In order to promote sustainable construction industry activities, the Habitat Agenda stated that there is a need of policies/standards adoption, technologies support, and the strong collaboration between government bodies and private sector (CIB, 1999).

1.3 Terms Of Sustainability In Construction Industry

The move towards sustainability in construction industry has broadly discussed the terms sustainable construction and sustainable building. The terms are usually defined differently regarding different priorities. Therefore, the understanding of sustainability in construction industry activities still needs to be clarified.

As mentioned above in the previous section, it has been understood that the construction industry activities have impacts on nearly all aspect of human settlement. According to the Habitat II Agenda, the context of sustainability in the construction industry has been thoroughly discussed in Chapter III- Commitments:

....(f) Promoting locally available, appropriate, affordable, safe, efficient and environmentally sound construction methods and technologies in all countries, particularly in developing countries, at the local, national, regional and sub-regional levels that emphasize optimal use of local human resources and encourage energy-saving methods and are protective of human health; (UN-HABITAT, 2003: pp. 11)

From this context, there are variety of terms used to define sustainability in the construction industry, including green building, sustainable building, and sustainable construction, as shown in Table 1.2. The definitions mostly concentrate on proactive actions for advancing performance of all construction activities regarding planning, design, construction, maintenance, and rehabilitation. Such actions will be evaluated in terms of the sustainable building performance as a major part of construction output. It is important to highlight that the scope of building with sustainable performance is specific enough for practitioners to adopt good practices to achieve this performance. In this regard, the construction regulatory and sustainable building labels have been undertaken to standardize the sustainable performance of buildings.

Table 1.2: The terms of sustainability in the construction industry

Term	Definition	Source
Green building	"A building that provide the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life."	Watermeyer (2002)
Green buildings	"Buildings that are designed, constructed, and operated to boost environmental, economic, health, and productivity performance over conventional building."	U.S. Green Building Council (2003)
Green building	"The careful design, construction, operation, and reuse or removal of the built environment in an environmentally, energy-efficient, and sustainable manner; may be used interchangeably with high performance building, green construction, whole building design, sustainable building, and sustainable design."	McGraw-Hill Construction (2006)
Green building	"A philosophy and associated project and construction management practices that seek to: (1) minimize or eliminate impacts on the environment, natural resources, and nonrenewable energy sources to promote the sustainability of the built environment; (2) enhance the health, wellbeing and productivity of occupants and whole communities; (3) cultivate economic development and financial returns for developers and whole communities; and (4) apply life cycle approaches to community planning and development."	Robichaud and Anantatmula (2011)
Sustainable building	"A building that incorporates green building principles and also maintains or improves the quality of life and harmonizes, with the climate, tradition, culture and the environment in the region."	Watermeyer (2002)

Sustainable construction	"A holistic process aiming to restore and maintain harmony between the natural and built environments, and create settlements that affirm human dignity and encourage economic equity."	CIB and UNEP-IETC (2002: pp.8)
Sustainable construction	"A dynamic of developers of new solutions, investors, the construction industry, professional services, industry suppliers and other relevant parties towards achieving sustainable development, taking into consideration environmental, socio-economic and cultural issues. It embraces a number of aspects such as design and management of buildings and constructed assets, choice of materials, building performance as well as interaction with urban and economic development and management. Different approaches may be followed according to the local socio-economic context; in some countries, priority is given to resource use (energy, materials, water, and land use), while in others social inclusion and economic cohesion are the more determining factors."	European Union (2007: pp. 4)

1.4 Standardization Of Sustainability In Construction Industry

There is an active standardization going on aiming to set the framework of sustainability aspects of buildings and building products. The ISO framework by International Standardization Organization (ISO) defines the sustainable building initially under the section ISO TC59 (Building construction) and SC17 (Sustainability in building construction) in 2002. Based on the principle of sustainable development, ISO/TC59/SC17 has developed a general viewpoint of the sustainable building as for international standard. There are five working groups:

WG1 General principles and terminology
WG2 Sustainability indicators
WG3 Environmental declaration of products
WG4 Environmental performance of buildings
WG5 Civil engineering works

According to ISO/TC59/SC17, sustainability standards in building construction are published (Krigsvoll *et al.*, 2010):

ISO 15392:2008 Sustainability in building construction – General principles

This principle in ISO 15392:2008 has introduced the basis of sustainable aspects in building construction from the cradle to the grave, understood as "*building lifecycle*". It provides a broad context of construction on sustainability regarding to materials, products, services and processes.

ISO/TR 21932 Building and constructed assets – Sustainability in building construction -- Terminology

This is the report of terminology used in the standards related to building and construction.

ISO/TS 21929-1 Sustainability in building construction – Sustainability indicators--Part 1: Framework for development of indicators for buildings

It provides recommendations and a framework for the assessment impacts of buildings including selection, indicators usage, and assessment tools development.

ISO 21930 Sustainability in building construction – Environmental declaration of building products

Based on the Life Cycle Assessment, ISO 21930 provides the guidelines for implementing environmental product declaration (EPD) of building products. EPD is used as a communication tool between business to business for standard specifications and requirements of building products.

ISO/TS 21931-1 Sustainability in building construction – Framework for methods of assessment for environmental performance of construction works --Part 1: Framework for development of Indicators for Buildings

This framework describes key factors for environmental performance of buildings, both for new and existing buildings. It considers all stages of the buildings including the design, construction, operation, refurbishment, and deconstruction stage.

Beside ISO standardizations, building assessment systems are currently recognized to develop a better understanding of the sustainable construction context. Using the sustainability assessment and sustainability rating system actively provide some guidance on the way forward for a mature practice.

1.5 Sustainable Building Label And Sustainability Assessment

Nowadays, numerous sustainability assessment and rating systems are available worldwide, as shown in Figure 1.4.

Figure 1.4: Example of sustainability assessment and rating systems

Among the plethora of assessments and labels, the four most commonly applied and discussed in the literature are BREEAM, LEED®, SBTool and CASBEE® (e.g.Alyami and Rezgui, 2012; Berardi, 2012; Reed *et al.*, 2009; Warnock, 2007):

BREEAM (Building Research Establishment Environmental Assessment Method)

It is the first sustainability rating system for the construction industry formally released by the British Research Establishment (2011). This assessment system is a multi-criterion system, which evaluates the overall performance of a construction in terms of energy, water, waste, transport, materials, land use and ecology, pollution, health and wellbeing, management, and innovation. At the beginning, the system has been used only in the United Kingdom. As a consequence of a growing movement towards sustainable construction at the global level, this system has been then adapted in other countries such as Canada, Australia and Hong Kong.

LEED® (Leadership in Energy and Environment Design)

LEED® is the most widely used rating system, developed by the US Green Building Council (2002). The system evaluates the construction sustainability performance in six categories: sustainable sites, water efficiency, energy and atmosphere, materials and resource, indoor environmental quality, and innovation in the design process. Currently, LEED® is internationally registered over a hundred countries in Europe, Africa, America and Asia.

SBTool (Sustainable Building Tool)

In the late 1990s, the leadership of National Resources Canada released the SBTool to foster an internationalization of rating systems (Larsson, 2012). This system assesses the construction in eight categories: (1) site location, available services and site characteristics; (2) site regeneration and development, urban design and infrastructure; (3) energy and resource consumption; (4) environmental loadings; (5) indoor environmental quality; (6) service quality; (7) social, cultural and perceptual aspects; (8) cost and economic aspects. With a wide range of sustainability issues, some countries implemented the general scheme for their own national versions, such as Verde in Spain, SBTool PT in Portugal, SBTool CZ in the Czech Republic and ITACA in Italy. This assessment methodology has also been developed according to the work of international bodies, including ISO: TC 59/SC 17 - Sustainability in buildings and civil engineering works (International Organization for Standardization: ISO, 2010; ISO, 2011) and the European standard body CEN (European Centre of Normalization) on sustainability of construction works (European Committee for Standardization, 2011)

CASBEE® (Comprehensive Assessment System for Built Environment Efficiency)

In 2002, a Japanese rating system, called CASBEE® was publically launched. The system comprises four assessment tools based on the building lifecycle: pre-design, new construction, existing building and renovation. The concept of closed ecosystem is considered in this system with two main assessment categories: built environment quality, and built environmental load. Built environment quality refers to indoor environment, quality of service, and outdoor environment on site. Built environmental load indicates energy, resource and materials, and off-site environment (JaGBC/JSBC, 2011). Therefore, a sustainable construction for CASBEE® encompasses the minimum environmental loads with maximum quality. Although the system seems new compared to others, the International Organization for Standardization (ISO) also includes CASBEE® in the ISO 21931-1:2010, Sustainability in building construction.

Among these four sustainability assessment and rating systems, the different criteria are used to assess the sustainable construction. Table 1.3 summarizes all criteria and categorizes them into nine main areas throughout the building lifecycle.

Table 1.3: The main sustainable areas for the construction industry

Assessment Area	Descriptions
Energy efficiency	- Maximize the building energy performance through the entire building phases. - Encourage the use of renewable energy sources.
Resource saving	- Reduce the use of non-renewable resources: use captured rain or recycled site water. - Efficient use of resources: natural water, potable water. - Protect all existing features of ecological value surrounding the construction zone.
Materials selection	- Consider renewable/reused/salvaged/refurbished materials, recycled content, local/regional materials. - Use low-emitting materials and avoid hazardous chemicals.
Construction site development	- Avoid development of inappropriate sites and limit all site disturbances. - Protect green fields and preserve natural environment.
Pollution and waste management	- Prevent environmental pollution: water quality, lighting and illumination, indoor/outdoor air quality, thermal comfort and acoustic performance. - Reduce the construction, operation and demolition waste.

Service quality	- Design a building for functionality and usability of its spaces. - Be structurally flexible and provide a sufficiently adaptable layout. - Enhance service ability for maintenance.
Health and wellbeing	- Contribute to the comfort and well being of construction workers and building occupants. - Create a better living environment.
Management	- Adopt proactive strategies in management for a sustainable construction throughout the lifecycle of a building.
Innovation opportunities	- Innovate in advanced techniques to increase the sustainability.

Source: Adapted from (BRE, 2011; JaGBC/JSBC, 2011; Larsson, 2012; USGBC, 2002)

Comparing the four assessment systems as presented in Table 1.4, it is interesting to see that critical areas from each system do not completely overlap, and no system can cover all areas. For this reason, each given area should be considered as a part of the sustainable construction context in order to seek a mature practice.

Table 1.4: Sustainable building by assessment areas from rating systems

Assessment Area	BREEAM	LEED®	SBTool	CASBEE®
1. Energy efficiency	X	X	X	X
2. Resource saving	X	X	X	X
3. Materials selection	X	X		X
4. Construction site development	X	X	X	X
5. Pollution and waste management	X	X	X	X
6. Service quality			X	X
7. Health and wellbeing	X		X	
8. Management	X		X	
9. Innovation opportunities	X	X		

To do so, there is a need for a systematic and strategic view for the successful management of activities through the building lifecycle phases, which can be supported by supply chain management (SCM) principles. Therefore, it is noteworthy that constructing the sustainable building entails consideration of SCM and incentives of involved actors in construction in order to develop and promote highly sustainable construction practices.

1.6 Conclusion

It is widely accepted fact that the term "*sustainable development*" or "*sustainability*" is attracting the attention in all countries in order to deal with their citizens' better quality of life. To some extent, it is becoming increasingly evident that achieving sustainability at the global level significantly requires the positive contributions of industry. Therefore, policies under the sustainable development currently focus on industrial development by increasing resource efficiency and productivity in production activities and consumption across a product lifecycle.

Generally, the construction industry has significant environmental and social impacts compared to other industrial sectors, mainly due to a great share in non-renewable resources usage and workforce employment. Towards the sustainable growth, the shift towards a resource efficient, sustainable and competitive economy appears to exert a dramatic pressure on the construction industry.

To achieve sustainable development in construction industry, the terms of sustainable construction and sustainable building are broadly discussed and a range of definitions is provided. There is still significant ambiguity around the best practices adopted for delivering a sustainable construction. For the sake of simplicity, we compare four well-known sustainable rating systems in order to summarize the main criteria for sustainable construction. These are (1) Energy efficiency (2) Resource saving (3) Materials selection (4) Construction site development (5) Pollution and waste management (6) Service quality (7) Health and wellbeing (8) Management, and (9) Innovation opportunities.

To achieve sustainability, the supply chain management has thus become a major focus in the construction industry. There is a need of collaborative arrangements along with the involvement of all construction actors across the supply chains in each stage of the building lifecycle.

Chapter 2 Construction Supply Chain Management

This chapter presents a literature review about the concept of supply chain management, sustainable supply chain management, construction supply chain, and construction supply chain management. In terms of supply chain management, SCOR model is used to describe supply chain management practices along with the Plan, Source, Make, Deliver and Return scheme. Then, sustainable supply chain management practices are presented. At the end of the chapter the unique characteristics of construction industry against the adoption of supply chain management are discussed.

2.1 Supply Chain Management

The concept of supply chain management (SCM) has flourished for more than a decade in various industries, especially in the manufacturing industry. The supply chain management is a systematic view on the flow of activities and provides a strategic view for adding values in these activities. In a supply chain perspective, the network of organization from upstream to downstream aims to increase the effectiveness in managing the different processes and activities (Vrijhoef and Koskela, 1999). To improve and analyze supply chain performance, many supply chain management approaches have been proposed and the Supply Chain Operations Reference (SCOR) model has been extensively implemented by the leading companies in various industries throughout the world (Zhou *et al.*, 2011).

2.1.1 SCOR Model

The Supply Chain Council (SCC) has developed the Supply Chain Operations Reference (SCOR) model in 1996 for defining, measuring and improving supply chain systematically (Bolstorff and Rosenbaum, 2003; Thunberg and Persson, 2013; Zhou *et al.*, 2011). The SCOR model has been widely used in many industries for supply chain processes analysis by enlarging the supply chain management perspective from supplier's supplier to customer's customer. These supply chain processes are Plan, Source, Make, Deliver and Return (as presented in Figure 2.1).

Figure 2.1: The SCOR model framework

Source: Supply Chain Council (2010)

Plan refers to planning. This process is a supply chain planning process in order to balance demand and supply for all requirements. The processes include communication plan, supply chain performance management and financial plan. Therefore, information sharing is essentially required for supply chain planning to improve the overall performance.

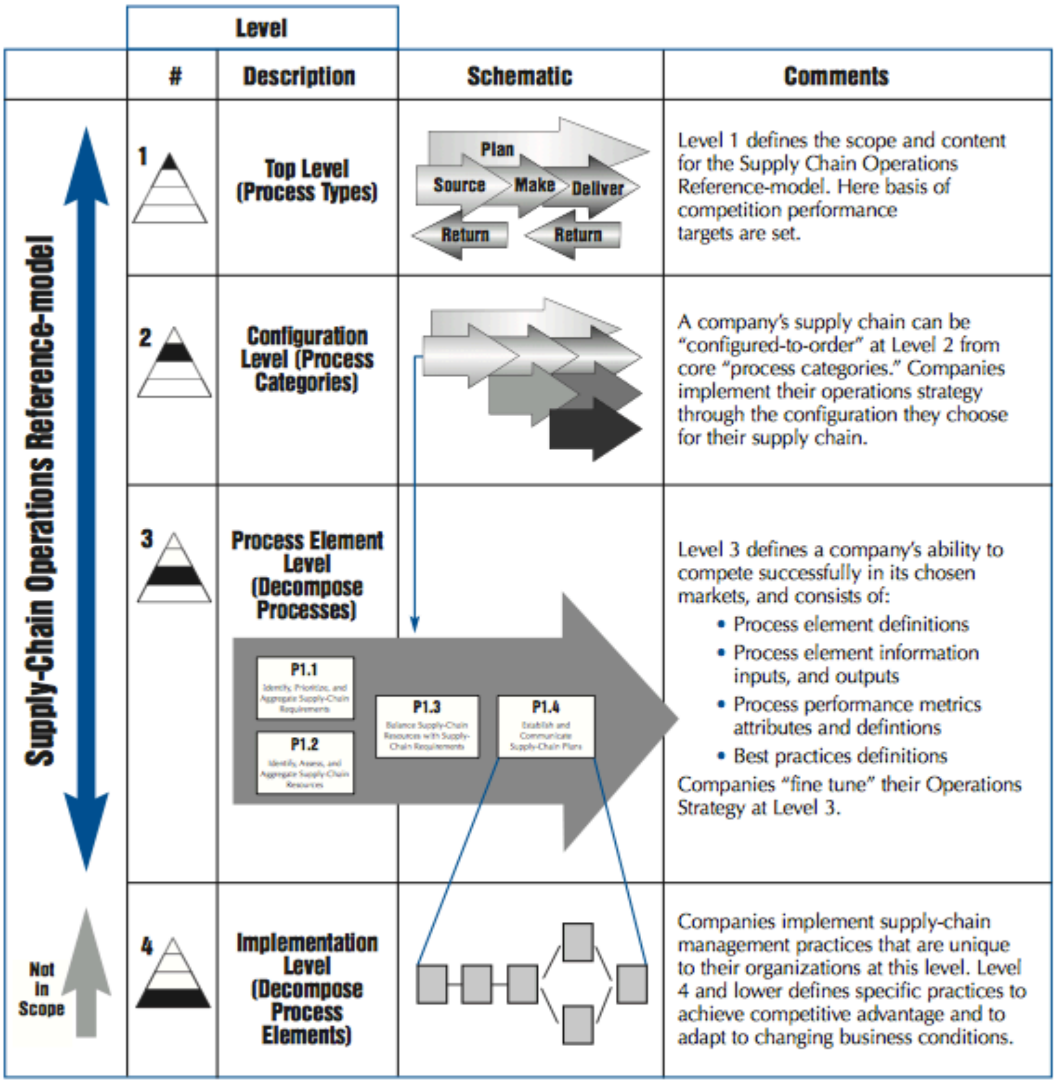
Source refers to the buyer-supplier relationship. Sourcing practices include establishing buyer-supplier relationship in the long-term perspective. It can be in the form of long-term contracts and/or the supplier's performance evaluation. Moreover, source process includes scheduling deliveries, inventory management, and supplier selection process.

Make is a production or manufacturing process. It is a process that transforms raw materials into finished products. That includes managing production schedule, rules and standards, production network, and equipment. Currently, waste management and disposal, recycling and remanufacturing are also in this process.

Deliver is a logistics process. It also includes order management, transportation management (routing shipment), warehouse management, contribution management, and product lifecycle management.

Return is process of returning the products both raw materials and finished products. It includes return maintenance and return business rules.

Figure 2.2: Four levels of SCOR model process



Source: Supply Chain Council (2010)

In the SCOR model, there are four levels of process as presented in Figure 2.2. Level 1 describes the scope of supply chain and its performance. Level 2 describes the planning and execution process under the supply chain strategy. Level 3 defines the business process and the ability to improve an overall supply chain performance. Level 4 defines the specific supply chain management practices to increase competitiveness in the market. With these four levels, the SCOR framework can be a practical tool for providing a basis for managing activities along the entire supply chain.

2.2 Sustainable Supply Chain Management

An effective management of a supply chain is not limited to profit maximization/cost minimization; a variety of environmental uncertainties and societal concerns are also being included in the classic problems of supply chain. Therefore, the objective of supply chain management may lead ultimately to achieve sustainability.

Sustainable supply chain management (SSCM) is the integration of two independent concepts: sustainability and supply chain management (Krause *et al.*, 2009). Seuring and Muller (2008) have defined sustainable supply chain management as the collaboration between partners along supply chain to manage materials, information and capital flow for an achievement of sustainability along with environmental, economic and social dimensions.

From the perspective of sustainability, the pressures tend to effect throughout the entire product lifecycle along the supply chains; from product design, sourcing, manufacturing, distribution, product use, to product end of life and recovery process (Halldórsson *et al.*, 2009; Linton *et al.*, 2007). There are number of key implementations taken into account such as process innovation, clean production, reverse logistics, closed-loop supply chain, sustainable procurement or green purchasing, and life cycle management (Halldórsson *et al.*, 2009; So *et al.*, 2012). Therefore, a sustainability-oriented management of a supply chain often requires the collaborative working with their supply chain partners in order to develop strategic actions for a greener production and product (Störmer, 2008).

With collaboration, the greatest value can be added in every single process, which contribute to the collaborative advantages in the form of process efficiency, improved flexibility, business synergy, quality and innovation (Cao and Zhang, 2010).

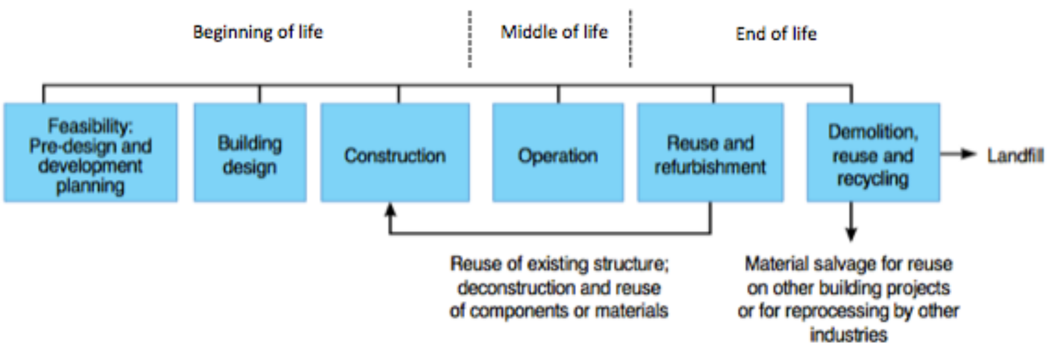
2.3 Construction Supply Chain

The peculiarity of the construction supply chain is that it normally operates during the beginning phase of the building lifecycle, considering its mission accomplished once the construction has been erected.

Given its lengthy, the building lifecycle can be divided into three main phases; the beginning of life, the middle of life and the end of life (as shown in Figure 2.3). Each main phase comprises of several activities and processes:

- The beginning of building lifecycle: refers to the processes from start until the construction has been erected; that is planning, design and construction;
- The middle of building lifecycle: includes operation of buildings and refurbishment;
- In the end of life: the overall processes involve demolition and disposal/recycle of buildings or material.

Figure 2.3: The lifecycle of a building



Source: Adapted from UNEP (2009: pp. 11)

Along the entire building lifecycle, there are various stakeholders and construction actors involved and working together in order to accomplish the project. Table 2.1 shows the number of actors in each phase of the building lifecycle.

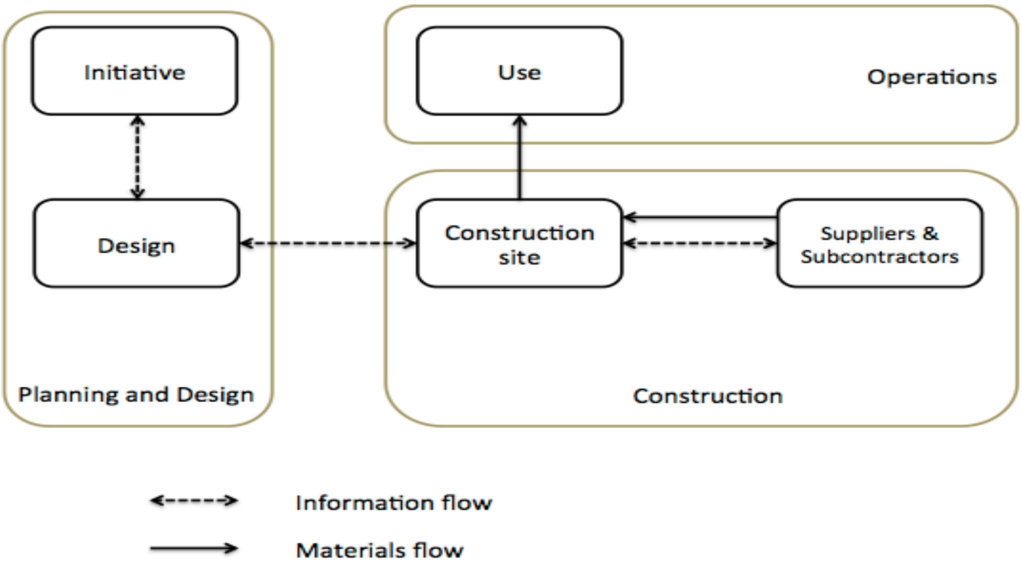
Table 2.1: Actors along the building lifecycle

Planning and Design	Construction	Operations	Reuse and Refurbishment	Demolition
- Client - Project manager - Safety/Quality consultant - Architectural designers - Civil designers - Structural designers - Mechanical designers - Specialist designers - Cost consultant	- Main contractor - Project manager - Material suppliers - Equipment suppliers - Regulatory bodies	- Client - In-house management - Maintenance contractors - Facilities consultant	- Client - Project manager - Safety/Quality consultant - Architectural designers - Civil designers - Structural designers - Mechanical designers - Specialist designers - Cost consultant - Regulatory bodies - Main contractor - Material suppliers - Plant/equipment suppliers	- Demolition constructor

Source: Adapted from Edum-Fotwe *et al.* (2001: pp. 157)

As the building normally has a long lifespan, more supply chains can be involved throughout its lifecycle. Figure 2.4 presents a generic construction supply chain including information flow (orders, schedules, forecasts, etc.) and materials flow (supplies, production, delivers, etc.) (Vrijhoef and Koskela, 2000).

Figure 2.4: A generic construction supply chain



Source: Adapted from Vrijhoef and Koskela (1999)

The construction industry is the old industry sector in which its activities are still managed through the traditional method. Along the construction supply chain, the traditional construction leads to number of generic problems that create the performance-related issues along the building lifecycle.

2.4 Construction Supply Chain Management

While the business world acknowledges the importance of supply chain management (SCM) principles and practices to enhance the overall performance on the efficiency and productivity, it has been found that construction industry pays inadequate attention to apply such principles and practices (Akintoye *et al.*, 2000; Hadaya and Pellerin, 2010; Ofori, 2000; Vrijhoef and Koskela, 2000).

The construction industry is an industry where activities are still managed by adopting the traditional empirical methods. This leads to a number of generic problems due to a lack of network planning, negligence of performance control and improvement, waste and non-value adding activities.

In general, the construction industry has endured from the poor performance due to inefficiencies, the delays, production of a huge amount of waste, high fragmentation and adversarial relationships (Love *et al.*, 2004). To have a clear picture of supply management in construction, the definition of construction supply chain is well defined as:

"… the network of facilities and activities that provide customer and economic value to the functions of design development, contract management, service and material procurement, materials manufacture and delivery, and facilities management (Love et al., 2004: pp. 44)."

In the construction literature, it has been found that a growing number of construction organizations have been implementing supply chain management practices for improving the construction performance and developing the inter-organization relationships (Saad *et al.*, 2002). London and Kenley (2001) have recognized the importance of collaboration in supply chain to improve the overall performance including distribution, production, and procurement management. However, the collaboration in construction supply chain appears to be quite limited due to lack of trust and unwillingness of information sharing between a contractor and its suppliers (Saad *et al.*, 2002).

Hartmann and Caerteling (2010) and Palaneeswaran *et al.* (2003) have highlighted the importance of procurement management. Generally the constructors, subcontractors or suppliers are selected based on trust and price. To improve sustainability, green procurement has been proposed to promote stronger buyer-supplier relationships through the set of activities as shown in Table 2.2. These activities aim to improve the project processes and supply networks, including procurement and contracting strategies in order to increase the degree of collaboration and overall sustainability levels of construction projects (Ofori, 2000; Palaneeswaran *et al.*, 2003).

Table 2.2: Procurement strategies and it activities

Category	Activity
Product standards	Purchase products with environmentally friendly attributes, such as recycled materials, and those with non-toxic ingredients.
	Purchase products that disclose their environmental attributes, such as those, which have been eco-labeled.
Behavior standards	Require suppliers to disclose information about their environmental practices, pollution discharges, and so on.
	Audit suppliers to evaluate their environmental performance.
	Require suppliers to implement and maintain environmental management systems.
	Require suppliers to obtain certification of their environmental management systems to a recognized standard such as ISO 14000.
Collaboration	Work with suppliers to help them reduce environmental impacts through changes in product design and materials use.
	Implement product stewardship programs throughout all stages of a product's life cycle.
Development	Institute training programs for suppliers to increase their knowledge of environmental implications of the company's, and their own activities.
	Inform suppliers regarding technological developments related to their operations.

Source: Ofori (2000: pp. 203)

Regarding the execution of construction supply chain activities, the lean philosophy is extensively adopted in order to improve the production process and optimize the timely information flow and in-process quality control (Bankvall *et al.*, 2010; Sacks *et al.*, 2009). Lean Construction has been influenced by the principle of *"Lean Manufacturing"* as the Toyota production system. The concept is based on two important approaches; Just In Time (JIT) and Total Quality Control (TQC). The JIT approach focuses on waste elimination and inventories reduction along a construction process (Koskela, 1992; Sacks *et al.*, 2010), whilst TQC is a quality program through process control. These approaches require the adoption of some techniques: including flow variability, process variability, transparency and continuous improvement. These techniques support the adoption of lean construction practices as shown in Table 2.3.

Integrated to the principle of lean construction, ICT and computer-aided visualization play a relevant role. The Building Information Modeling (BIM) technology is the one of information technology solutions to master the variability of construction process resulting in a better building performance.

Table 2.3: Lean Construction tools

Scope	Technique	Requirements	Criteria/change
Flow variability	Last planner	Reverse phase	Pull approach
		Scheduling	Quality
		Six-week look-ahead	Knowledge
		Weekly work plan	Communication
		Reasons for variance	Relation with other tools
		PPC Charts	
Process variability	Fail safe for quality	Check for quality	Actions on the job site
		Check for safety	Team effort
			Knowledge
			Communication
			Relation with other tools
Transparency	Five S's	Sort	Action on the job site
		Straighten	Team effort
		Standardize	Knowledge
		Shine	Communication
		Sustain	Relation with other tools
	Increased visualization	Commitment charts	Visualization
		Safety signs	Team effort
		Mobile signs	Knowledge
		Project milestones	Communication
		PPC charts	Relation with other tools
Continuous improvement	Huddle meetings	All foreman meeting	Time spent
		Start of the day meeting	Review work to be done
			Issues covered
			Communication
			Relation with other tools
	First-run studies	Plan	Actions on the job site
		Do	Team effort
		Check	Knowledge
		Act	Communication
			Relation with other tools

Source: Salem *et al.* (2006: pp. 172)

The development of a sustainable construction requires time; for every project, a thorough understanding of the specific construction supply chain to be purposely built up is required. Since supply chains greatly differ depending upon the building processes, it is necessary to consider the cradle-to-grave impacts through the lifecycle of building. The lifecycle approach divides the building lifecycle into phases, including design, construction, operation, and end of life (demolition and disposal). This approach is widely used in the construction research to review the building performance corresponding to the performance specifications for sustainable constructions (Nwokoro and Onukwube, 2011; Ortiz *et al.*, 2009). With the complete consideration of the full building lifecycle, there is no doubt that a systematic study along the whole life span is required to promote the best practical methodologies and to prevent any impact in achieving the sustainable performance of buildings.

Further, several studies have reviewed the peculiarity and the main features of the construction supply chain, which require the adoption of specific supply chain management practices.

Such characteristics can be schematically divided into two main categories: structural characteristics and managerial characteristics, as summarized in Table 2.4.

Under structural characteristics, it is argued that the construction industry is a discontinuous and project-based industry (Segerstedt and Olofsson, 2010). With this structural nature, the traditional design-bid-build process is commonly used for selecting suppliers and contractors. This selection process leads to a price-based selection that reflects the low quality of materials and unskilled workers (Hartmann and Caerteling, 2010).

High fragmentation is also one of the characteristics that can generate sharp disconnections throughout a construction supply chain (Cavalieri *et al.*, 2012; Vrijhoef and Koskela, 2000). Within the traditional design-bid-build selection process, a plethora of small-medium sized actors is normally involved between the design and the construction phase.

Additionally, most construction activities are a highly complex decision-making process due to the interdependency of all tasks/parts/processes along the supply chain, meaning that the failure of one task can negatively impact the following task or the whole process (Bankvall *et al.*, 2010; Cavalieri *et al.*, 2012).

Table 2.4: Key characteristics of the construction sector

Categories	Descriptions	Authors
Structural characteristics	Project-based industry	Segerstedt and Olofsson (2010); Hartmann and Caerteling (2010).
	High fragmentation	Vrijhoef and Koskela (2000); Cavalieri *et al.* (2012).
	Interdependency of all tasks	Bankvall *et al.* (2010); Cavalieri *et al.* (2012).
Managerial characteristics	Collaboration between several construction actors	Palaneeswaran *et al.* (2003); Xue *et al.* (2005).
	Customer-centricity	Akintoye *et al.* (2000); Love *et al.* (2004); Saad *et al.* (2002).
	High need of information and communication technologies	Hadaya and Pellerin (2010) Lönngren *et al.* (2010)

On the other hand, there are some managerial characteristics with regard to the organizational and technological factors. In construction, every project aims to maximize the client's satisfaction. Therefore all activities are performed according to their requirements through the guidance from designers and engineers. To operate a single project, numerous construction actors with different background and professional expertise participate throughout the building lifecycle phases (e.g. land owner, architects, engineers, government agents, contractors and suppliers) (Xue *et al.*, 2005). Moreover, different companies are usually jointly working, which may have not worked together before (Vrijhoef and Koskela, 2000). It is not surprising that conflicts may occur between these actors, considering also the relevant role of the same customer in the co-design of the most suitable solution (Akintoye *et al.*, 2000; Love *et al.*, 2004; Saad *et al.*, 2002). On the other hand, construction sector is less developed in ICT system and information technology infrastructure for optimizing its supply chain processes (Bankvall *et al.*, 2010).

Considering the aforementioned characteristics, sustainability needs to come foremost from the customers and the top management commitment (downstream) and to be achieved by the support of upstream activities (Hadaya and Pellerin, 2010). Setting up a partnership between the actors in a supply chain is required in accordance with the best practice on customer-supplier focus for construction development. Hence, a more integrated supply chain between constructors, suppliers and clients is required in terms of collaborative agreements (Segerstedt and Olofsson, 2010).

2.5 Conclusion

The principle of supply chain management has been used in most industrial sectors across the world including the construction industry. However, the construction companies still lack a systematic and strategic approach to improve its supply chain. The most common approaches to intensively manage a sustainable construction supply chain are green procurement and lean construction. With these approaches, the sustainability seems to be restricted on a single phase (namely, the construction phase) without any explicit consideration on its impact on the other lifecycle phases. Perhaps because of the unique characteristics of the construction industry, it results to the problematic issues by adoption of supply chain management practices.

This chapter has shown how the construction industry is lagging behind the other typical industries usually investigated in the supply chain management literature. The reasons are due to the project-specific nature of this industry, and to its peculiar structural and managerial characteristics. The adoption of appropriate supply chain management practices for a sustainable construction requires a systematic consideration of the role of involved actors in the construction industry and the processes in each building lifecycle phase.

Chapter 3 Research Methodology

This chapter identifies the research gaps. Along with these gaps, the set of research questions is addressed. Moreover, the research design, research methodology and data analysis are presented in order to answer the research questions and achieve the main objective of this study. The chapter reports a literature review structure, the methodology adopted for the case studies and the data analysis through a cross-case analysis approach.

3.1 Research Gaps

Within the past decade, the sustainability concept has been gaining full momentum in the construction industry. As underlined by the sharp increment in the number of sustainable building labels and national construction regulations, it is understandable that the multiple actors involved in construction projects are enforced to increase the sustainability of their activities throughout the entire building lifecycle (Akbiyikli *et al.*, 2012; Robichaud and Anantatmula, 2011). With this enforcement, it indicates a major change in construction management practices.

However, the debate on what construction should consider for achieving a sustainable performance is under argument at the moment. It has been found that the construction industry needs a systematic and a strategic view for the successful management of activities throughout the building lifecycle phases. For this reason, there is an increased interest in the adoption of supply chain management (SCM) principles for making its process more effective and more efficient (Thunberg and Persson, 2013).

As per the literature review, a number of studies have offered the solutions for existing construction problems and improved sustainable construction performance. Nevertheless, most scholars in the field of supply chain management and civil engineering usually limit their research on the improvement of specific processes and activities such as logistics process, production process, and procurement process.

In the logistic process and its movement, computer simulation techniques are extensively implemented for the transportation analysis and efficient inventory management based on the concept of JIT (Vidalakis *et al.*, 2011). From the perspective of construction process, lean construction practices are taken for waste reduction and process flow improvement along the construction supply chain in terms of reducing resource usage and pollution (Koskela *et al.*, 2010). Some scholars have also applied computer simulation techniques (Mao and Zhang, 2008) and building information modeling (BIM) (Sacks *et al.*, 2010; Sacks *et al.*, 2009) integrated with the lean principle, to optimize and improve the construction process. The procurement process usually focuses on reducing harmful materials and encouraging the use of green products towards sustainability targets (Haake and Seuring, 2009; Ofori, 2000).

On the other hand, in the strategic perspective, research studies have given a particular emphasis on the improvement of relationships along construction supply chain in term of collaboration and long-term relationships (Cao and Zhang, 2011; Eriksson, 2010).

From the above discussion, it seems most research focus on the short-term objective of construction supply chain, which may not respond to overall building performance. In addition, there are a limited number of researches identifying which process or activities significantly require a long-term improvement for sustainability along the entire building lifecycle.

For the long-term perspective, the organizations in construction industry should improve their whole construction performance continuously. The lifecycle point of view should be considered not only on the construction materials or products, but also on the complete building performance. To develop and promote highly sustainable construction practices, however, it is necessary to study each process in a systematic view through an overall building lifecycle (Edum-Fotwe *et al.*, 2001). With a systematic view, it can be possible to contribute to a long-term sustainability from building erection to its management, refurbishing, demolition, and final disposal of waste building materials.

Practically, the recent research has suggested out that numerous actors involved in construction projects as practitioners are still inexperienced on increasing the sustainability, having not defined practices and processes (Berardi, 2012). With this issue, the research aims to fill these gaps by providing a systematic perspective for managing construction supply chain and highlighting its practices towards a more sustainable performance.

3.2 Research Objective And Research Questions

According to the research gaps, the objective of this study is to investigate how to improve the construction supply chain management, which may support the design, realization and the operation of sustainable buildings. With this objective, a set of interrelated research questions is addressed as following:

Research question 1: How can supply chain management support the sustainability in construction industry? And, what are the main elements to be considered to manage the construction supply chains, which will ensure the sustainable performance along the entire lifecycle of a building?

Research question 2: How does construction industry manage its supply chain? What are the existing practices adopted in managing the construction supply chain?

Research question 3: What is construction industry lacking in managing its supply chain? And how can construction supply chain management be improved towards the achievement of sustainability?

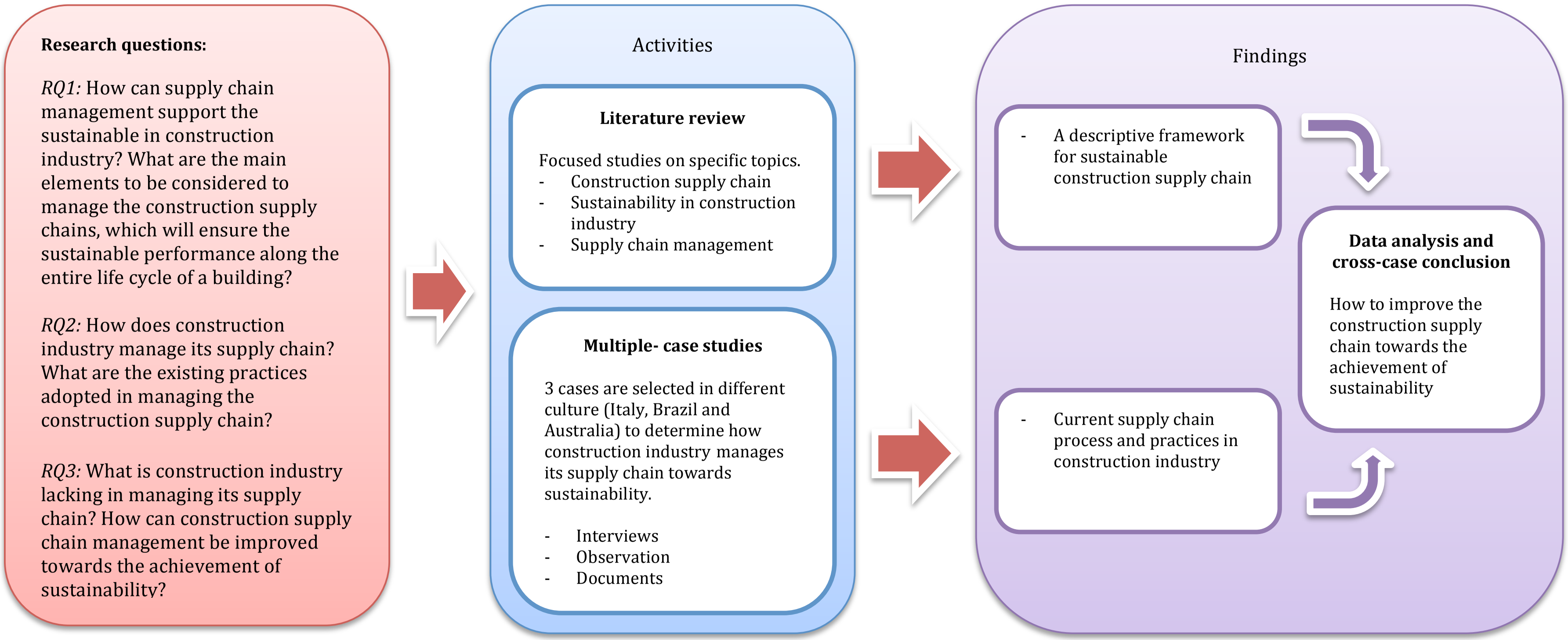
3.3 Research Design

With this set of research questions, the research combines into two parts.

The first part aims to answer the first research question. In this part, an extensive literature in accordance with the sustainability in the construction industry and the construction supply chain management are collected and reviewed. Using the culmination of these research findings, a descriptive framework is proposed in order to provide a systematic view on how to relate all the main elements of a construction supply chain for getting a more sustainable performance.

The second part of research is designed for answering the second and third research question. In this part, the research is conducted through a multiple case study methodology. The collected data from the multiple-case studies is analyzed to describe the existing supply chain management practices in construction industry and explore how the construction industry manages its supply chain towards sustainability. Figure 3.1 presents how this research is designed.

Figure 3.1: Research design



3.4 Research Methodology

This research study is conducted by using the case study as a research method, which allows researcher to understand a real-life context in depth (Yin, 2003). According to the research design, a case study protocol has been developed to increase the reliability of case study. A case study protocol is used as a pilot to guide the researcher on how to conduct the case study actively. In this research, a multiple-case studies based research methodology was adopted to investigate the construction supply chain practices in different business cultures; namely carried out in Italy, Brazil and Australia. This is because practitioners in different cultures may have different viewpoints in supply chain management perspective and adopt various practices to manage their supply chain.

To perform a research, the sample targets on the medium and large-size enterprise, which may be familiar with the concept of supply chain management. The target company must carry the project at the beginning of the building lifecycle phase and undertake a range of construction works. Based on this target, the sample can be construction planner, project manager, contract manager, supplier and construction site manager. Table 3.1 shows main targets of case studies selection.

Table 3.1: Main target of case studies

Target companies	• Medium to large size enterprises • Carrying the project at the beginning of building lifecycle phase • Undertaking a range of construction works
Target interviewees	Planning and Design • Construction planner • Project manager • Contract manager • Supplier Construction • Construction manager • Site manager • Site engineer

From the targeted sample, a total of 11 respondents from 6 companies involved in the construction supply chain were interviewed, in which two organizations were from each country. The respondents are from different functions at different levels of supply chain. The sample pool consists of CEOs, corporate controls, procurement officers, safety and quality control, project managers, site managers, construction planners, construction managers, civil engineers, and marketing managers. The description of the actual sample obtained is shown in table 3.2.

Table 3.2: Description of actual sample

Cases	Italy		Brazil		Australia	
Type	Construction company	Real estate company	Construction company	Construction company	Construction company	Construction supplier and construction waste management
Size	Medium	Large	Medium	Large	Medium	Large
Project	Commercial building	Commercial building Infrastructure	Residential building	Residential building	Commercial building Residential building	Cement supplier
Method	Personal Interview	Personal Interview	Group Interview	Group Interview	Personal Interview	Personal Interview
Positions	Cooperate controls	CEO Procurement officer Safety and Quality control	Project manager Site manager Construction planner	Civil engineer Construction manager	Construction manager	Marketing manager

The interviews were performed in 2013 and each interview took between 1 to 2 hours. Interviewees were asked about the current supply chain processes, supply chain management practices and sustainability issues. A semi-structured list of questions has been undertaken with probes to elicit relevant information. The interviews were recorded and transcribed for data analysis. In addition to interview method, the multiple sources of evidence and a variety of data collection are also including documents and direct observation to increase construct validity. Documented information includes official document about organizations and project reports.

All cases used the same set of questions for interview. Interview questions emerged from the literature review with a consideration of supply chain processes coupled with key sustainable building issues.

The interview questions start with general questions about job responsibilities, organization structure and an understanding of sustainability issue, then scoping down to questions about supply chain management process (Plan, Source, Make, and Deliver) based on sustainable building assessment areas.

1) General questions

Job responsibilities	Would you describe your job responsibilities and the workflow?
Organization structure	To whom do you work with? What are their job titles?
Sustainability	In your own words, how would you describe: (sustainability and sustainable construction/ sustainable building) Is there any standardization or building regulation that your organization following related to sustainability? Is your organization seeking to achieve green building or sustainable building certification? (LEED®, BREEAM, SBtool, CASBEE®)

2) Questions regarding to supply chain management and sustainable building assessment areas.

Sustainable building assessment areas	**Supply chain management process**			
	Plan	**Source**	**Make**	**Deliver**
Service quality	How do you ensure the building performance along a building lifecycle?		Do you have the evaluation system for measuring the performance of construction work?	
Energy efficiency			How do you improve energy efficiency in SC activities/process?	

Resource saving	How can you reduce the use of resource?		Which supply chain processes/activities need to be improved for resource saving?	
Pollution and waste management	How do you manage the waste of materials in construction process?		How do you reduce the pollution? (Indoor environmental quality, noise attenuation and light pollution) Which supply chain processes/activities have the potential pollution risks and wastes?	
Construction site development			How can you reduce the site disturbance (impact to neighborhood)?	
Material selection		What are the main criteria to select materials?		
Management	How can stakeholders support the achievement of sustainable performance of the project?	What are the main criteria to select supplier, contractor and sub-contractor? How do you perform the order management (inventory and supplier agreement)? How do you evaluate supplier performance, contractor or sub/contractor performance?		How do you perform the schedule deliveries? How do you manage the delay from supplier delivery and construction work? How do you evaluate customer satisfaction?
Health and wellbeing			How do you improve and control a safe and healthy workplace?	
Innovation opportunities	Do you consider the building lifecycle in the project planning?		What action, that you or your company has taken, has been most effective in encouraging a better performance related to sustainable building? Based on your experience, which supply chain process/activities need to be improved to make it better fit to sustainability performance?	

3.5 Data Analysis

In this research, the data from three case studies are analyzed according to two main objectives; current construction supply chain management processes and their practices, and supply chain management towards a sustainable performance. The data obtained from the interviews has been coded and analyzed using NVivo10. NVivo is the qualitative research software that is widely used for organizing and deeply analyzing the interview data and information through coding process. This process aided in cauterizing information in order to compare interview responses and identify common point of view, known as cross-case analysis technique. With this technique, it allows the research to strengthen its internal validity (Yin, 2003).

In order to identify current construction processes and its practices, data is categorized into four main supply chain processes (Plan, Source, Make, and Deliver) and the construction supply chain processes in each business culture are drawn regarding to the SCOR model level 1, 2 and 3. With the same set of data, it is coded regarding to sustainable building issues, which would clarify construction supply chain management practices for sustainable performance.

With the cross-case analysis, for each case study an individual report has been written with respect to the overall process of construction supply chain, the critical issues occurrence and existing practices adopted (Yin, 2003). Then cross-cases conclusion has been drown to investigate how to improve construction supply chain management in order to enhance a sustainability performance.

3.6 Conclusion

According to the literature review presented in the previous chapter, there is a limitation in research related to construction supply chain management towards sustainability. However, most literature states in the same direction that construction industry still lacks behind other industries in adopting the supply chain management. With the long lifecycle of a building, the construction actors need to manage its supply chain in a systematic way, while the improvement of construction supply chain management is currently cloudiness.

The objective of this is to investigate how to improve the construction supply chain management for a long-term sustainable performance. In order to conduct this research, the multiple-case study methodology is used through an interview process. The construction actors in three different business culture; Italy, Brazil, and Australia – have been interviewed with the same set of questions. The interview questions have been addressed related to the supply chain process and sustainable building characteristics. For the data analysis, the NVivo computer-assisted tool has been used to organize the data and support the cross-case analysis.

Chapter 4 Construction Supply Chain Management For Sustainability - A Descriptive Framework

This chapter aims to answer the first research question:

How can supply chain management support the sustainability in construction industry? And, what are the main elements to be considered to manage the construction supply chains, which will ensure the sustainable performance along the entire lifecycle of a building?

In order to answer the first research question, the descriptive framework for construction supply chain management towards sustainability; called as the ISCAB framework; is proposed based on the literature review. From previous research, two key contributions are discussed; that are the role of construction actors and the building lifecycle perspective. These contributions are used as the main elements to develop a descriptive framework, which is an integrated consideration of the role of construction actors coupled with the different processes along the building lifecycle. At the end of the chapter, a systematic view is provided on how to relate all the main elements for managing the construction supply chain in order to achieve a more sustainable performance.

4.1 Construction Industry Contributions Towards Sustainability

The shift in sustainable awareness is currently pushing construction industry to perform its activities in a sustainable manner. Such sustainable awareness similarly creates a greater motivation on academic interests. The same can be observed from many previous studies related the construction management towards sustainability. Researchers in these studies have investigated the critical success factors of construction projects and offered various solutions towards an improvement of sustainable performance.

As described in Chapter 1, the sustainable construction performance areas include energy efficiency, resource saving, materials selection, construction site development, pollution and waste management, service quality, health and wellbeing, management, and innovation opportunities. With these sustainable performance areas, it has been found that most of them rely on supply chain activities. For example, energy efficiency, materials selection, pollution and waste management, and health and wellbeing can be effectively managed through "*source*" process by selecting the construction materials and products with high sustainable performance specification. From this reason, it is not surprising that recent research on construction management towards sustainable performance has been growing interest in the principle of supply chain management.

According to studies on construction supply chain management, the consolidated outcomes have explained about the appropriate ways to manage the project successfully in two main conclusions; the role of construction actors with collaborative relationship and the lifecycle perspective.

4.1.1 Role Of Construction Actors And Its Collaborative Relationship

From the literature review, the first contributory study has declared that operational improvements require the active role of different actors in a construction supply chain, with a collaborative working relationship (Bankvall *et al.*, 2010; Lönngren *et al.*, 2010; Nwokoro and Onukwube, 2011; Palaneeswaran *et al.*, 2003; Pan *et al.*, 2010). The idea on collaborative working derives the most efficient way of making decisions openly and resolving problems, based on a mutual benefits and risk sharing. Consequently, this collaboration would best support construction companies for effectively improving their construction management (Cao and Zhang, 2010; Edum-Fotwe *et al.*, 2001).

Additionally, the level of collaboration usually relies on the effective communication through efficient system, in which the construction actors and stakeholders can easily access to accurate information timely in all detailed planning; such as inventory planning, scheduling and order delivery. The effective communication with openness and transparency will provide a clear understanding of project's goals and increase effectiveness to manage the overall processes.

This collaborative relationship can be developed in the long-term perspective for continuous improvements. The form of collaboration can be occurred both in contractual and non-contractual agreements. Nowadays, all construction actors and stakeholders tend to create collaboration platform and supply chain integration to make positive changes. The collaboration platform would allow actors along supply chain to jointly work on planning and execution activities that may promote innovation in the construction supply chain processes towards sustainable construction (Cao and Zhang, 2011).

4.1.2 Lifecycle Perspective

A second important outcome has focused on the building lifecycle perspective (Bribián *et al.*, 2009; Lönngren *et al.*, 2010; Ortiz *et al.*, 2009; Sev, 2009; Verbeeck and Hens, 2010). Most research has indicated that a construction project should address sustainability-related issues to the construction activities throughout the building's lifecycle. The lifecycle management approach is typically applied to evaluate the overall impacts at various stages in a building lifecycle through the system-related measures, namely Life Cycle Analysis (LCA) (Berardi, 2012; Verbeeck and Hens, 2010). LCA tool is internationally used as an assessment tool and integrated into the sustainable building rating systems. This analysis tool has become an alternative optimization technique in construction industry. The tool breakdowns a building into elementary construction activities (from materials, manufacture, production, transport and final disposal) and evaluates the environmental impacts over its lifecycle.

Lifecycle perspective has been broadly applied in the construction research today for optimizing the actual sustainable performance over the long lifecycle of a building in terms of the quality specifications of construction products and the value of construction project (Nwokoro and Onukwube, 2011; Ortiz *et al.*, 2009). Each process will be optimized in a systematic way to see overall impacts until the end of process as a whole, based on a supply chain point of view. With the complete consideration of the full building lifecycle, there is no doubt that a systematic study about the whole life span would support the decision-making, when selecting the appropriate practical methodologies to prevent any impacts in achieving the sustainable performance of buildings.

As mentioned above, it can be concluded that managing construction supply chain towards sustainable performance requires a systematic management of the whole process of a building lifecycle phase. This systematic management can be occurred through the collaboration among different construction actors and all stakeholders.

4.2 ISCAB - A Descriptive Framework

The construction industry needs a systematic and strategic approach to improve the sustainability in its processes. This is further exacerbated by the discontinuous and project-specific nature of this industry, which makes each building, and the related emerging supply chain, as one of a kind.

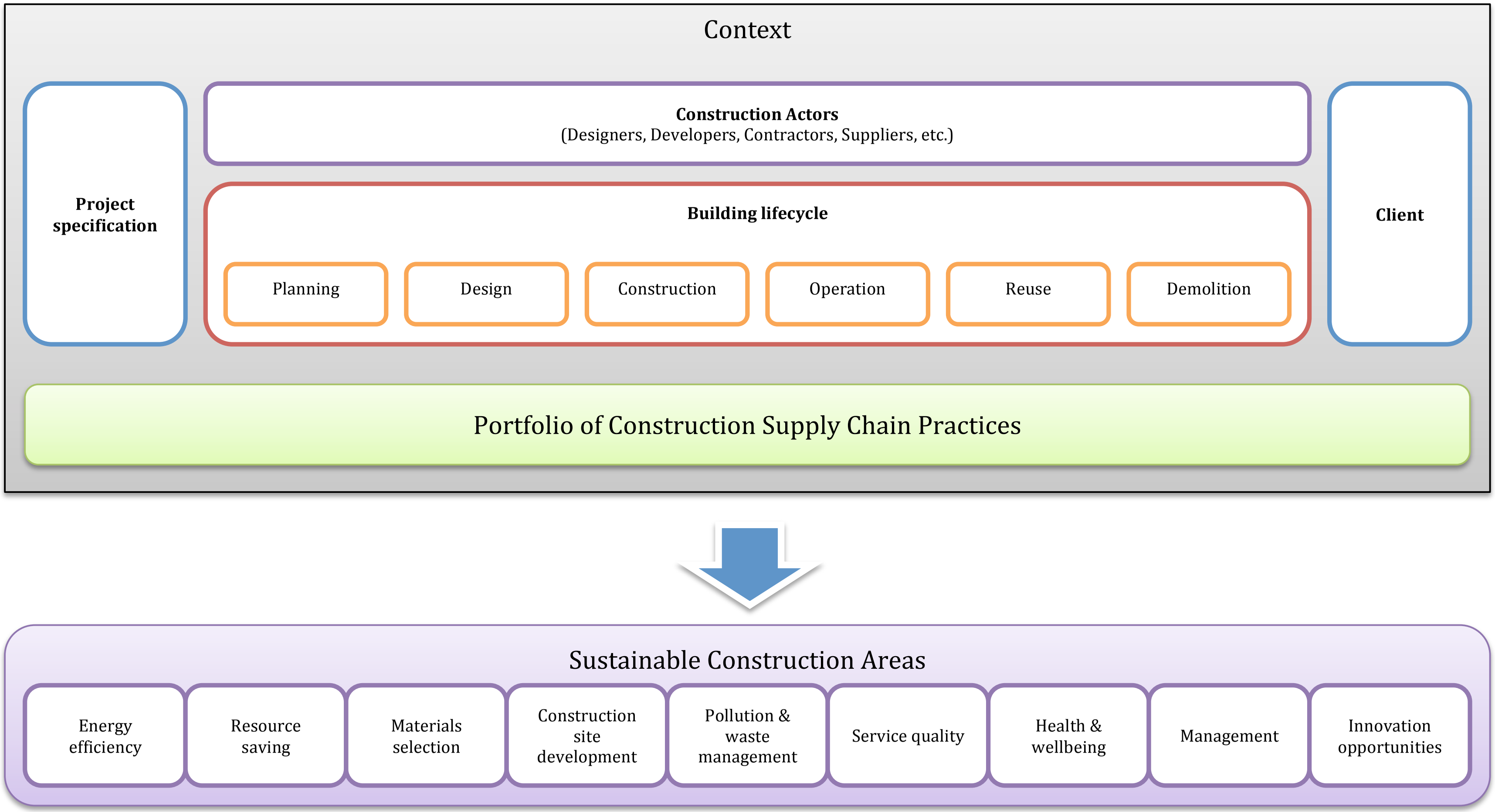
Drawing on the literature on the construction supply chain management and on the key characteristics of the construction industry has defined in the previous chapter. The main principles underlying a descriptive framework called as ISCAB (Integration of

Supply Chain and Building Lifecycle); are proposed to provide a systematic view on how to manage the construction activities with an integrated consideration of all the elements in a construction supply chain for achieving a more sustainable performance, according to the sustainable construction characteristics.

These main elements are the role of multiple construction actors involved in the construction project and building lifecycle perspective. Figure 4.1 shows an outline of the descriptive framework and its elements.

The ISCAB framework is proposed for seeking the appropriate practices for managing the construction supply chain towards sustainable construction and/or improving the existing practices in order to support the achievement of a high sustainability performance with a consideration of the main elements. This framework would guide practitioners on what they should consider in order to adopt the most suitable practice for each project specification, which may reduce the risk of myopic decisions.

Figure 4.1: The ISCAB framework



4.3 An Integrated Consideration Of Main Elements

The most effective configuration of the supply chain can be achieved through a proper integration of system components, namely the construction actors and the decision-making processes involved throughout all the phases of the building lifecycle. The movement towards a more integrated system requires joint efforts of all the relevant actors.

The actors who play a role in the project should understand the complete operational lifecycle of the whole processes because each process has some sustainability influence. For instance, Sev (2009) offered an exemplary series of methods in each stage of building lifecycle, which will improve the construction's sustainable performance.

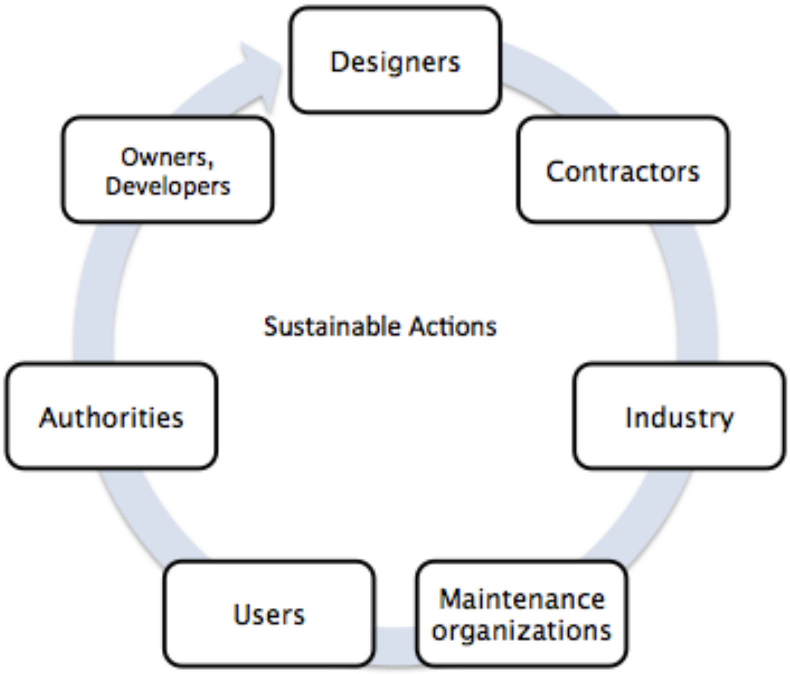
At the beginning of building lifecycle (planning, design and construction), the key strategies consist of selecting the appropriate site, selecting sustainable materials and products, and flexible and durable design. These strategies would increase a better sustainable performance and support a building development.

One of the most important techniques is materials selection. Each materials and products must be evaluated in its environmental impacts with LCA; from raw material source, production, transportation, installation, use, and finally disposal or reuse. Toxic construction materials and products must be avoided because they have a negative impact to the health and safety of construction workers during construction process and occupants when the building is operated.

During construction, adopted effective managerial techniques and methods enable to minimize site impact. A proper planning is absolutely needed in order to efficiently manage construction activities. At the site, an effective waste management program should be undertaken for minimizing the resource consumption and preventing pollution. Most waste expects to be recycled or returned to nature. When the building lifecycle is end, the demolition process should be the last option since this process significantly produces the air pollution. Therefore, the building components should be adaptable or reused in other buildings.

Along the construction supply chain, there are various construction actors involved in each phase. Working jointly and closely, to plan and execute supply chain operations has become a necessity as a result of a shift towards sustainable performance at the large scale. In practical, dealing to the numerous challenges towards sustainability requires the sustainable actions by all stakeholders and construction actors; especially by the main actors (as shown in Figure 4.2). These are owners/developers, designers, contractors, industry, maintenance organization, users, and authorities (CIB and UNEP-IETC, 2002).

Figure 4.2: Sustainable actions for sustainable construction



Source: Adapted from CIB and UNEP-IETC (2002)

Owners/developers plays a very important role in spreading sustainable construction awareness. They can set sustainable demand and sustainable issue such as energy saving and the use of renewable resources in buildings.

Designers should consider the sustainable performance and quality of materials at the starting point for their sustainable construction design. Moreover, they should pay careful attention on the exploitation stage along the building lifecycle during the design process (such as flexibility and adaptability in order to enhance the service quality of the building).

Contractors should consider the sustainability as a factor of competitiveness by setting up sustainable goals in their business model. For procurement process, sustainability issues should be considered in the selection criteria. Another important implication is efficient production in construction process that should be met according to the international standards and national building regulation.

Industry refers to construction materials and products manufacturers. The product development should actively minimize an environmental impact on their production process and improve the sustainable performance in their products based on life cycle analysis (LCA). In addition, they should provide users the product information in details on how to use the products and the recycle process.

Maintenance organization should develop their services and upgrade their processes based on sustainable thinking.

Users should consider the sustainable performance of the building over its lifecycle when they select spaces as selection criteria. Doing so will affect the productivity of space used and the level of comfort.

Authorities in pursuit of sustainable development in construction industry are dealing with regulation and sustainable labeling. Authorities can stimulate the innovation in the construction industry by increasing standards.

However, sustainability cannot be accomplished by actions in isolation. The collaboration among the main actors at the earlier phase (planning and design) will greatly enhance the major opportunities to create sustainability of the building (Lönngren *et al.*, 2010). In this stage, all the information according to project will be discussed and informed to all actors and stakeholders, regarding what should be performed in each activity for gaining sustainability (Love *et al.*, 2004; Nwokoro and Onukwube, 2011; Robichaud and Anantatmula, 2011).

Through the collaborative planning, the estimated sustainability impact of a project along the building lifecycle will be identified to seek the most suitable practices for managing the construction supply chain. The best practices must be balanced against ensuring an optimal sustainable performance for all phases in the long-term perspective.

In particular, the construction process is an inherently complex. Since the construction is a project-based industry, the specification of project will change according to clients' requirements. However, it has found that the core management process is still the same. A portfolio of construction supply chain management practices would be developed based on the past experience of the construction actors, construction standards and national building regulations. The adoption of the suitable actions, drawn from a portfolio of construction supply chain management practices, would provide a valuable contribution on reducing the level of fragmentation between the building lifecycle phases and on enhancing the overall construction sustainability performance.

However, the validity of each practice in the portfolio for that specific construction project would be explained in its response against a multi-dimensional sustainable area. Since each practice in the portfolio may provide a valid response to one or few assessment areas of the sustainable construction, a set of complementary practices would be needed in order to gain a balanced performance among the several dimensions of sustainability.

Moreover, the set of suitable practices to be adopted may be dynamically modified during the building lifecycle according to any change to the project specification, or to the need to upgrade a specific sustainable influence due to exogenous pressures (e.g. assimilation of new directives, availability of new best available technologies).

4.4 Conclusion

From the previous literature, it has shown that construction industry is lacking the systematic view to manage its construction process towards sustainable performance. And, it has been found that most sustainable construction areas are related to supply chain activities. Therefore, the principles of supply chain management and its practices are studied in this research for improving the sustainable construction performance.

To reach the construction sustainable performance, the most research studies have discussed the importance of lifecycle management and the role of construction actors with collaborative relationship. Based on these findings, a descriptive framework is developed to explain how to relate all the elements for effectively managing the construction supply chain towards sustainability.

With the ISCAB framework, the sustainable impacts of the complete building lifecycle would be fully explained through collaborative working among construction actors along supply chains. The high sustainable benefits would be achieved when the lifecycle thinking applied at an early stage of the project (planning phase).

In general, the sustainable development policies and building regulations in each area are designed differently, which directly influence construction industry and its performance. In this research, the practices for delivering a sustainable construction based on the practitioners' experiences from the previous projects will be proposed in a portfolio. The project may adopt a set of practices for a better sustainable performance depending on the specification of the project, client's requirement, and local building legislation and policy.

Chapter 5 Supply Chain Management In Construction Industry – Case Studies

The objective of this chapter is to answer to the second research question:

How does construction industry manage its supply chain? What are the existing practices adopted in managing the construction supply chain?

In this chapter, the current construction supply chain processes and the practices of three case studies are described. The three case studies were conducted through the interview methodology from different business culture and environment; the Italian case, the Brazilian case and the Australian case. These construction supply chain processes are then analyzed according to the SCOR model (Plan, Source, Make and Deliver). The final section of the chapter concludes with a critical comparison of construction supply chain management practices in order to ascertain which one could provide better performance.

5.1 Case Study 1 - Construction Supply Chain Management: The Italian Case

The recent crisis has forced the Italian construction industry in shifting towards international markets, due to the reluctance to finance the construction projects at national level. In some large-scale projects, several companies collaborate from different business culture within European countries working together in the same project.

In general, managing a construction project is quite complex, as also confirmed from the findings of the previous studies. Yet, the construction project management in Italy becomes more complicated under the various pressures of the Italian regulations and the European policies.

5.1.1 Plan

The Italian construction processes can be divided into two main processes. These are construction and building management. In the construction process, the planning phase of the construction project starts when a potential client makes the request and sends a project proposal to the construction company. The first step is the site location selection. In Italy, the site location is very important because it has a great impact on construction activities and the main procedures, which are principally enforced by the Urban Planning Scheme of a municipality and the European directives.

Afterward, an initial plan is developed by a general contractor with the collaboration of architects and designers. This plan should reach mutually agreeable requirements of stakeholders; especially the client specifications and building regulations. According to a plan, architects do their drawings and build the different scale of models in order to provide the real needs of the project site. The drawings and models may be rewritten and/or reshaped for a better match to the actual landscape around the building.

When the building has already been designed, all activities will be defined in details including materials specifications, cost estimation, construction process and waste management. These activities will be managed and scheduled through a project management tool (such as timeline or roadmap). A defined plan with all details will support construction companies to develop the selection criteria in order to find the most suitable suppliers and subcontractors, who perfectly meet the project's requirements and specifications.

With attention to every detail throughout the entire process, it has been found that a process of planning and design normally takes time. In this stage, effective communication and coordination are intensely required because the incorrect information may affect the whole process and a success of the project.

5.1.2 Source

The process of selecting suppliers and subcontractors starts when all details of activities are planned and scheduled. The general contractor normally takes responsibility for performing this process. To select material suppliers, the list of materials with the estimated cost and specifications is provided for carrying out an effective decision-making. Suppliers and subcontractors are usually selected based on price with the goal of maximizing profit/minimizing cost. For this reason, it has been often found that a general contractor still adopts a traditional "Design-Bid-Build" method for selecting his construction partners. When the bid is opened for the new project, the prospective suppliers and subcontractors will submit their proposal and bid independently. General contractor will select the partners who best match to project specifications within the estimated cost.

Moreover, the partners should have the ability to provide the materials and services of the right quality, at the right time according to the architecture of a building and schedule plan. These partners can be selected based on their performance in the previous projects, in which they have worked together in the past. In some cases, it has been found that the general contractor selects the partners based on their own personal relationship. This relationship is a win-win relationship without any long-term collaboration.

After the selection process is finalized, the subcontractors and suppliers will be informed regarding the production plan and production schedule. According to the project schedule, suppliers will manage the inventory at their own warehouses, which can minimize the inventory level at the construction site. Once the construction starts, each subcontractor and supplier will carry out their work package separately and independently, based on the given plan and schedule until a construction project is completed.

In general, an environmental engineer regularly evaluates the intrinsic performance of suppliers and subcontractors through the checklist program. The evaluation result will report with photograph for continuous improvement. In order to get paid, their performance must be satisfied in accordance with the standards and agreement. During the construction stage, the construction company may change the construction partners due to the different situations; such as bankruptcy, poor performance, market change and choice of materials change.

5.1.3 Make

During the construction process, the construction manager, also known as a site manager, is responsible for managing the flow of activities/processes and controlling the overall construction performance. The guideline, which has been developed during the planning stage, will assist the construction actors in better performing of construction works. With this guideline, each department will perform and manage activities independently according to the schedule. Every week there are regular meetings for updating the latest status of the project, resolving the problem, and scheduling the deliveries. If the delayed occurred mainly due to an unexpected situation, they need to catch-up the schedule as soon as possible by hiring more workers (job hunters) on that task to recover the delay. The waste generated during the construction process will be properly sorted and sent for recycling or to landfill. It has been noticed that the waste will also be eliminated, when the work is following the exact schedule and work plan.

Checklist program is also adopted as guidance for construction workers on how to perform their works according to the standards and for monitoring the quality of day-to-day operations. With this checklist program, it has been found that in most case the activities was managed to meet just the requirements on the checklist. There is a lack of understanding the actual standards, which may enhance the improvement of the entire construction process in a long-term perspective. Additionally, most construction companies are following ISO standards for health and safety. The workers are required to wear personal protective equipment at the construction site.

5.1.4 Deliver

The replenishment planning team working together with a project manager develops the materials requirements plan and schedules the delivery of materials. Typically, suppliers are informed about the forecasted delivery schedule at the time that a contractual agreement was made. At the weekly meeting, the current project status will be updated by all departments. With this updated information, delivery schedules are planned for an effective management of material flow. The replenishment team will send at least two-days advance notice of any materials delivery modification to suppliers in order to fulfill the construction plan in a timely manner. A penalty expects to be applied in respect of an unreasonably late delivery because this might have a negative impact on another task and/or on overall construction process at a large-scale. In some cases, the general contractor may be required to pay the penalties if the project is delayed. These penalties are typically much higher than the penalties received from the supplier. As the result, the general contractor may terminate the supplier agreement and select a new supplier.

When materials are delivered, they will be placed over the pallets on a designated storage area of the construction site and should be monitored at all times. The storage area must be clean and dry, which enables to prevent the materials from physical damage due to humidity, excessive moisture, sunlight, water, dust, and uncertain temperature.

5.1.5 SCOR Mapping Of The Construction Supply Chain

Along the beginning lifecycle of a building, construction supply chain in the Italian case involves four main elements to manage its supply chain. These are general contractor, construction site, suppliers and suppliers' warehouses. To visualize the construction supply chains in the Italian case, the SCOR model in level 1, level 2 and level 3 are presented in Figure 5.1, 5.2 and 5.3, respectively. In Figure 5.2, the dotted lines represent the information flows and solid lines represent material flows.

At the planning stage, an initial plan for an overall process of the project is developed including time and budget. In this stage, all stakeholders and construction actors cooperatively work in planning for supply chain process (P1.4) and construction process (P3.4).

At the design stage, the information from an initial plan is used for architectural design. In the architectural design, the materials choices with specifications (P2.1) and the building structural plan in details (M3.1) are provided as a prequalification for selecting the most suitable materials suppliers and subcontractors (P2.4). Through the competitive bidding process, the suppliers and subcontractors are selected (S3.2). In the contract, the suppliers will be acknowledged within production plan, as developed by a general contractor. In accordance with a given production plan, each supplier will prepare its delivery plan before the construction work starts (P4.4). Suppliers will develop their own materials schedule (S1.1) and stock these materials in their warehouses on hand in order to ensure on-time delivery (S1.2, S1.3, S1.4).

At the construction stage, all construction activities are scheduled for an effective materials management (M3.2). Construction workers are also required to perform their jobs according to this plan (M3.4) and the construction waste will send to a recycling plant or landfill (M3.8).

On the supplier side, the materials in stock will be transferred into the construction site (D1.12), when the notification is received about the delivery schedule (S3.3) with date, time and location from a general contractor (D3.6, D3.7). On the agreed delivery date, the materials will be delivered at the construction site (S3.4, S3.5, D3.13).

Figure 5.1: SCOR level 1 model for construction supply chain – the Italian case

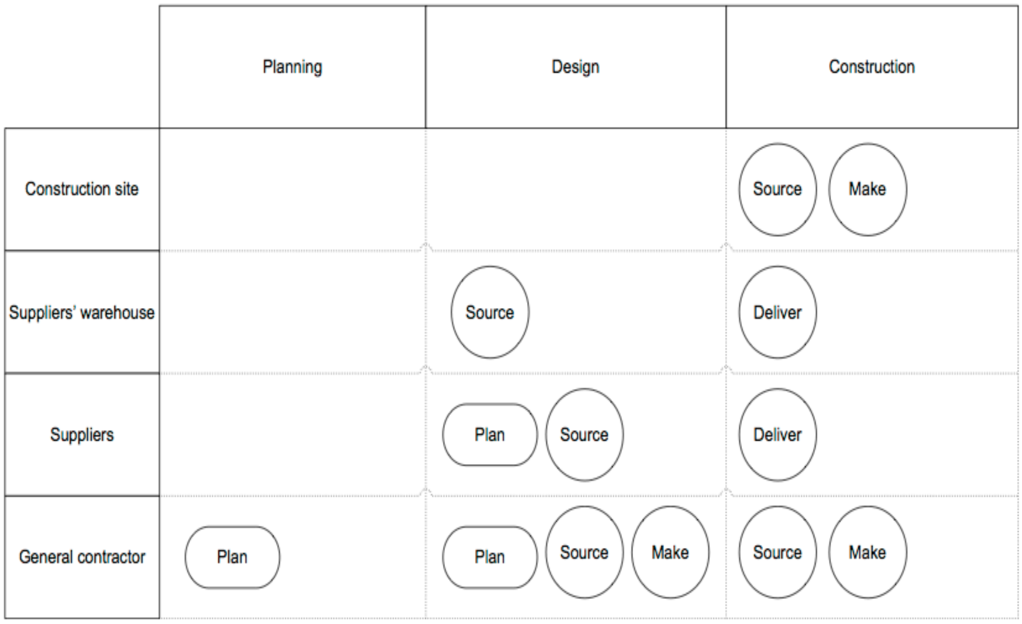
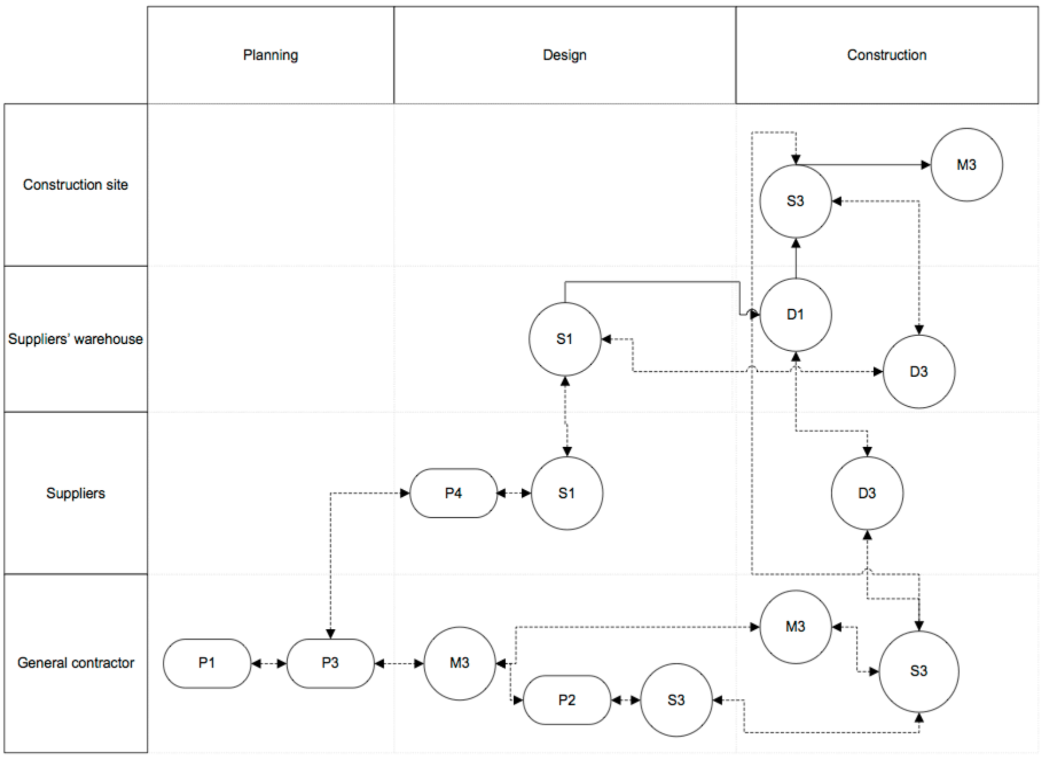
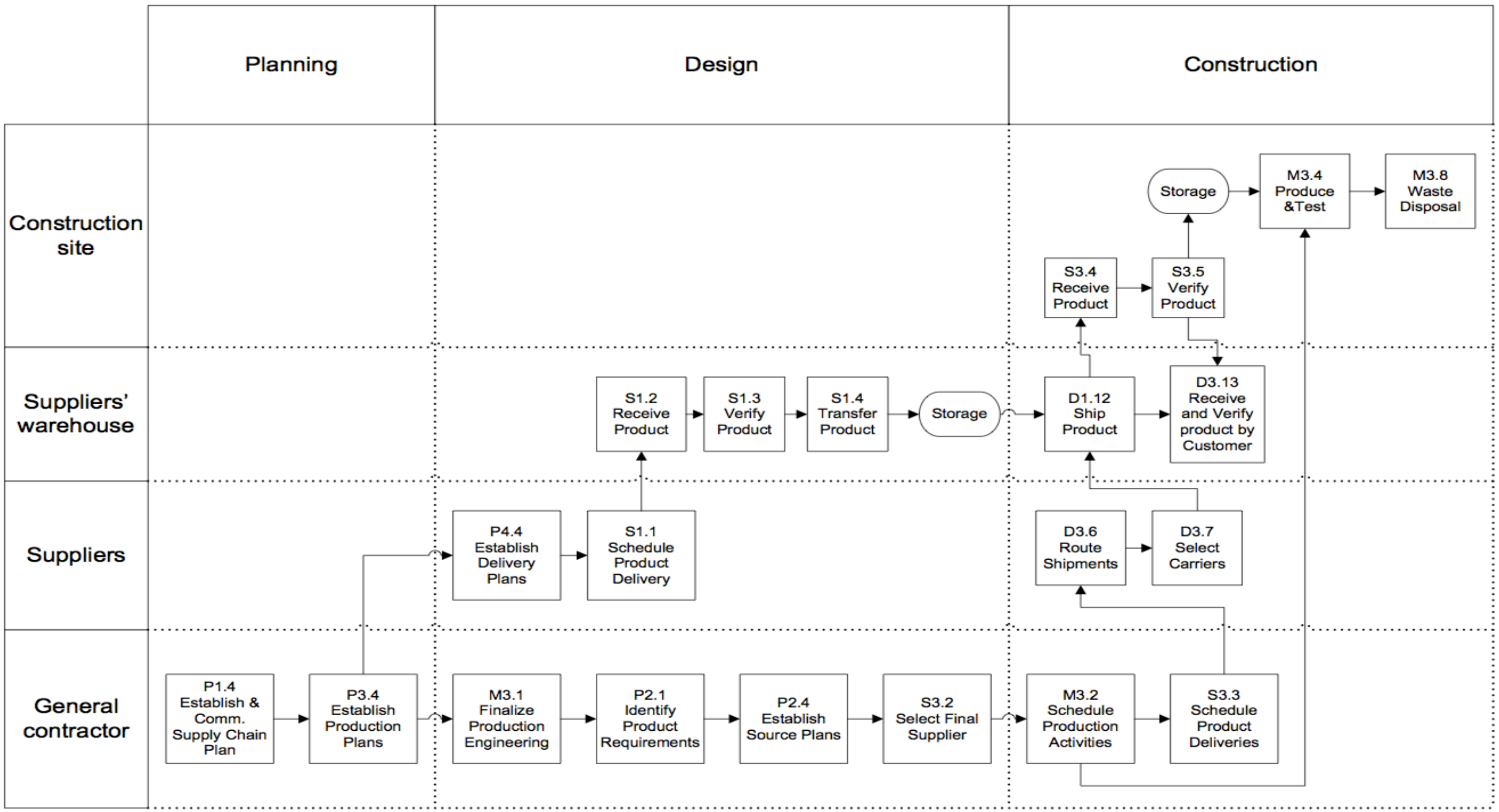


Figure 5.2: SCOR level 2 model for construction supply chain – the Italian case



(P1: Plan Supply Chain, P2: Plan Source, P3: Plan Make, P4: Plan Deliver, S1: Source Stock Product, S3: Source Engineer-to-Order Product, M3: Engineer-to-Order, D1: Deliver Stocked Product, D3: Deliver Engineer-to-Order Product)

Figure 5.3: SCOR level 3 model for construction supply chain – the Italian case



In the Italian case, it has been found that a general contractor plays an important role in managing an overall construction project and its supply chain, with the objective to perform cost minimization/profit maximization. With this objective, it leads to adopt the traditional "Design-Bid-Build" process to select suppliers and subcontractors, based on the specifications defined by architects. This traditional process typically creates a short-term relationship through a project-based contractual agreement. Some projects select the suppliers and subcontractors based on the personal relationship. It can be argued that there is a lack of standard for selection process applied in the construction project.

Moreover, it has been found that the suppliers are responsible for managing the material flows in isolation under the defined conditions of contract and have little involvement in managing the overall construction processes. Materials are not directly supplied from manufacturers. Some materials have extremely long lead time due to a complex manufacturing, which makes difficult to fulfill an order and delivery on time. Besides, the information about product specifications may not be updated, or perhaps some materials are being discontinued. These outdated products would have a limitation on the enhancement of building performance. On the other hand, the collaborative working does not exist in every process along the construction supply chain. It has been found only between a general contractor and subcontractors during a construction process. Table 5.1 summarizes the current construction supply chain practices found in the Italian case and issues on its management.

Table 5.1: Summary of current construction supply chain practices – the Italian case

Supply chain process	Current practices	Issues
Plan	General contractor, architect and designer are involved in project planning; Developing the production plan through a project management tools.	Need the effective of communication and coordination.
Source	Selecting the materials based on price and specifications; Supplier and subcontractor selected by bidding process and based on personal relationship; Supplier and subcontractor working under an agreement and contract; Applied penalty due to the delayed and poor performance; Regularly auditing the supplier performance through the checklist; Monitoring the inventory to prevent materials performance; A minimum inventory level or zero inventory; Acknowledged suppliers about a brief project planning in contractual agreement.	Materials selected according to architectural design; Outdated information of materials and/or discontinued materials; Construction company only focuses on maximizing profit; Only general contractor have decision-making authority concerning supplier/subcontractor selection; Lack of standard for the selection process; Less collaborative working in some processes; Lack of extended collaborative relationship in long-term perspective.

Make	Providing guideline for all construction works; Managing each construction activity independently; Day-to-day auditing performance through a checklist program; Regularly meeting for updating the project status and scheduling delivery.	Lack of understanding regulations or standard.
Deliver	Delivery schedule managed by replenishment team; Supplier informed about an exact delivery date only a couple of days in advance; Yield penalty due to delayed delivery.	The supplier will be subjected to change due to the unsatisfied performance.

5.2 Case Study 2 - Construction Supply Chain Management: The Brazilian Case

A current construction boom in Brazil generates a higher competition among the construction companies in the real estate market. A number of approaches have been applied to increase its ability to gain competitiveness including the adoption of supply chain management approaches.

Along a construction project, at each stage of building lifecycle individual supply chains can be found. Considering the beginning of building lifecycle, there are three main teams who usually manage the construction project. These teams are land development, product development, and engineering. Land development team includes the architects, landowners and investors. Product development team includes the land development team and stakeholders. Engineering team normally consists of a general contractor, subcontractors, suppliers and construction workers.

5.2.1 Plan

Site investigation is the first step of construction project. Land development team will propose the prospective lands with a study of market value and market demand based on neighborhoods attributes. With this data, product development team will analyze the economic feasibility of the land regarding to the type of project and the construction cost estimations. The process of land investigation generally takes approximately one year and product development takes between 9-12 months.

During the planning, construction documents including design plan, construction plan and action plan are prepared. These document provide detailed guidance on how to manage and perform overall construction activities called as "*the operative construction*". Some department may have more than one document that they would need to follow.

With these documents, the engineering team working collaboratively with suppliers develops the strategic plans for the materials delivery and workforce by considering the construction plan coupled with material lead time.

5.2.2 Source

Normally, the engineering team performs the process of selecting manpower suppliers, materials suppliers, and subcontractors. The overall supply process, including selection process, contract administration and order planning, mostly takes up to nine months. The materials are selected based on the overall cost estimation and given materials specifications. New suppliers and subcontractors will be selected through a competitive bidding process. Some subcontractors directly contact the engineering team to be part of the project. In this case, the team has to check their work performance reports from previous projects.

However, it has been found that construction companies attempt to build a collaborative relationship with their suppliers in a long-term perspective. Some suppliers have been working together for over 30 years. Through a collaboration with suppliers, higher quality of materials on the available budget would be offered in order to deliver a better building performance to clients. This collaborative relationship also exists with subcontractors but it is difficult to maintain in a long-term. This is because most subcontractors are small-sized companies, which does not adopt the good management practices.

In general, an engineering team supplies materials and labor for different projects at the same time to increase batch sizes in order to achieve a reduction of overall costs and time. The contractual agreement is made based on agreed quality and quantity without penalty. The engineering team will place an order according to the lead time of materials. The long lead time materials may be ordered in advance. Moreover, these suppliers and subcontractors will be closely monitored and evaluated against their performance at least once every six months through the checklist and ISO system.

5.2.3 Make

Before the construction work begins, the engineering team will carefully review the construction documents and ensure that the complete information is provided for the construction process. They may ask for a revision, if there is any missing information relevant to the construction plan.

With this information, the weekly work plan (WWP) is scheduled through the last planner system. This system is a tool of the Production Planning and Control (PCP) program, which is commonly used for preparing and controlling daily construction activities. The construction workers will be assigned their daily works in each task and evaluated their work performance weekly. They will work according to the given operational guideline (*"Operative construction"*), defined by product development team and their work performance will then be evaluated by the color evaluation system. This color system evaluates the work performance regarding task quality, security and cleanness. At the end of the week, the result from evaluation will be reported as Red-bad, Yellow-fair, and Green-good. The section that performed the best will receive a reward. Every month a meeting will be held with the involvement of all departments; especially from planning team and construction site to report the latest status of the project concerning delivery, expenditure and work performance. They believe that collaborative working as a team is needed for improving construction works more efficiently.

At the construction site, there is a security control staff responsible for health and safety of construction workers by following the ISO standard. He will create a good working environment and provide valuable information to the workers related to the operational standard. According to the local waste management regulations, the construction wastes should be separated into 3 main categories; iron, wood and paper and each category has a specific destination for disposal. The overall construction process approximately takes 24-36 months until the project is complete.

5.2.4 Deliver

Practically, materials and products have an assigned lead time of production and delivery. The engineering team has been informed about the lead time of each material when the contract was stipulated. To ensure smooth operations of the overall construction process, the delivery will be scheduled according to lead time and production plan and the order request must be processed at the right time. This is because it may lead to inability to fulfill the flows of material.

The engineering team works together with suppliers to effectively manage the flow of materials. The objective is for the on time delivery. Since there is a space limitation at the construction site, the stock should be at the minimum level. The inventory space will be reserved for the long lead time materials and materials that will be used in this week and following week.

5.2.5 SCOR Mapping Of The Construction Supply Chain

Construction supply chain for the Brazilian case consists mainly of product development team, engineering team, suppliers, and construction site. The SCOR model in level 1, level 2 and level 3 are adopted to justify the construction supply chain in the Brazilian case as presented in Figure 5.4, 5.5 and 5.6, respectively.

At the planning stage, the product development team analyzes the economic feasibility of the project by considering and identifying the overall supply chain requirements (P1.1). At the design stage, they develop construction documents (P1.4) as the project description; including construction plan (P3.4), design plan (M3.1), and the materials choices with specification (P2.1).

Before the construction process starts, the engineering team creates plan for a strategic sourcing (P2.4) and overall construction process (P3.1) by considering the provided information from construction documents. The qualified suppliers and subcontractors according to the documents will be selected (S3.2). Through the collaboration with suppliers, the delivery schedule is planned coupled with the materials lead time (P4.4, P4.3).

During the construction process, all construction activities are scheduled weekly (M3.2) and construction workers are required to perform their tasks by following this schedule (M3.4). The materials will be placed the order (S3.3) and delivered to the site as per the lead time (S3.4, S3.5, D3.12, D3.13). The details about the time and location will be informed in advance (D3.6, D3.7). Moreover, the waste occurred during construction process will be sent for disposal (M3.8).

Figure 5.4: SCOR level 1 model for construction supply chain – the Brazilian case

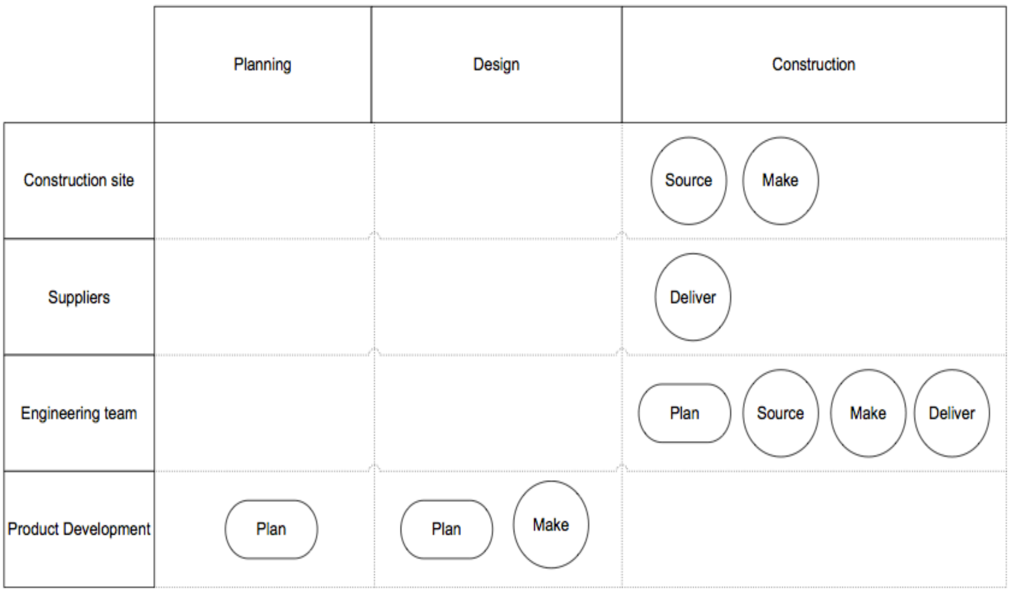
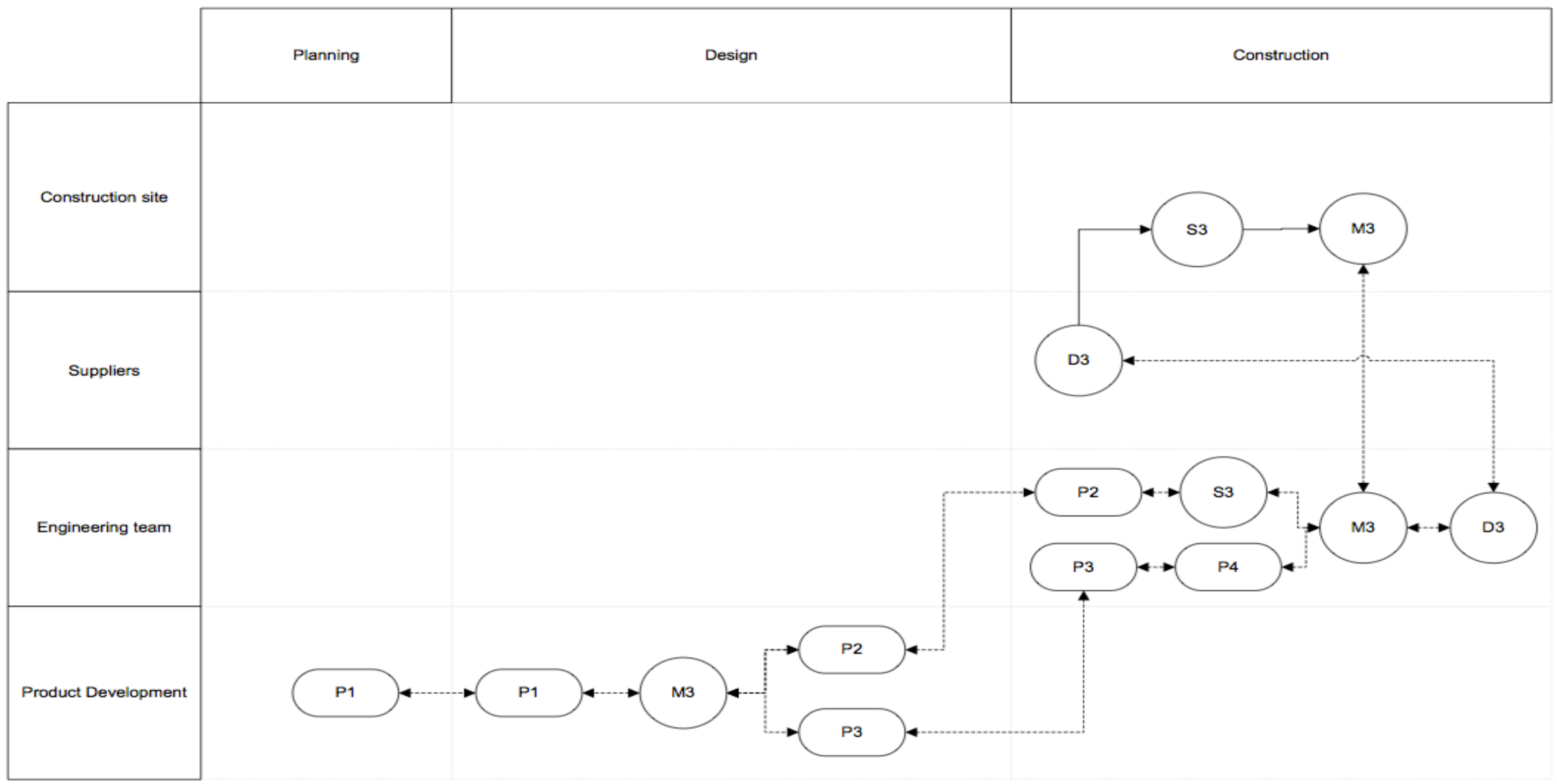
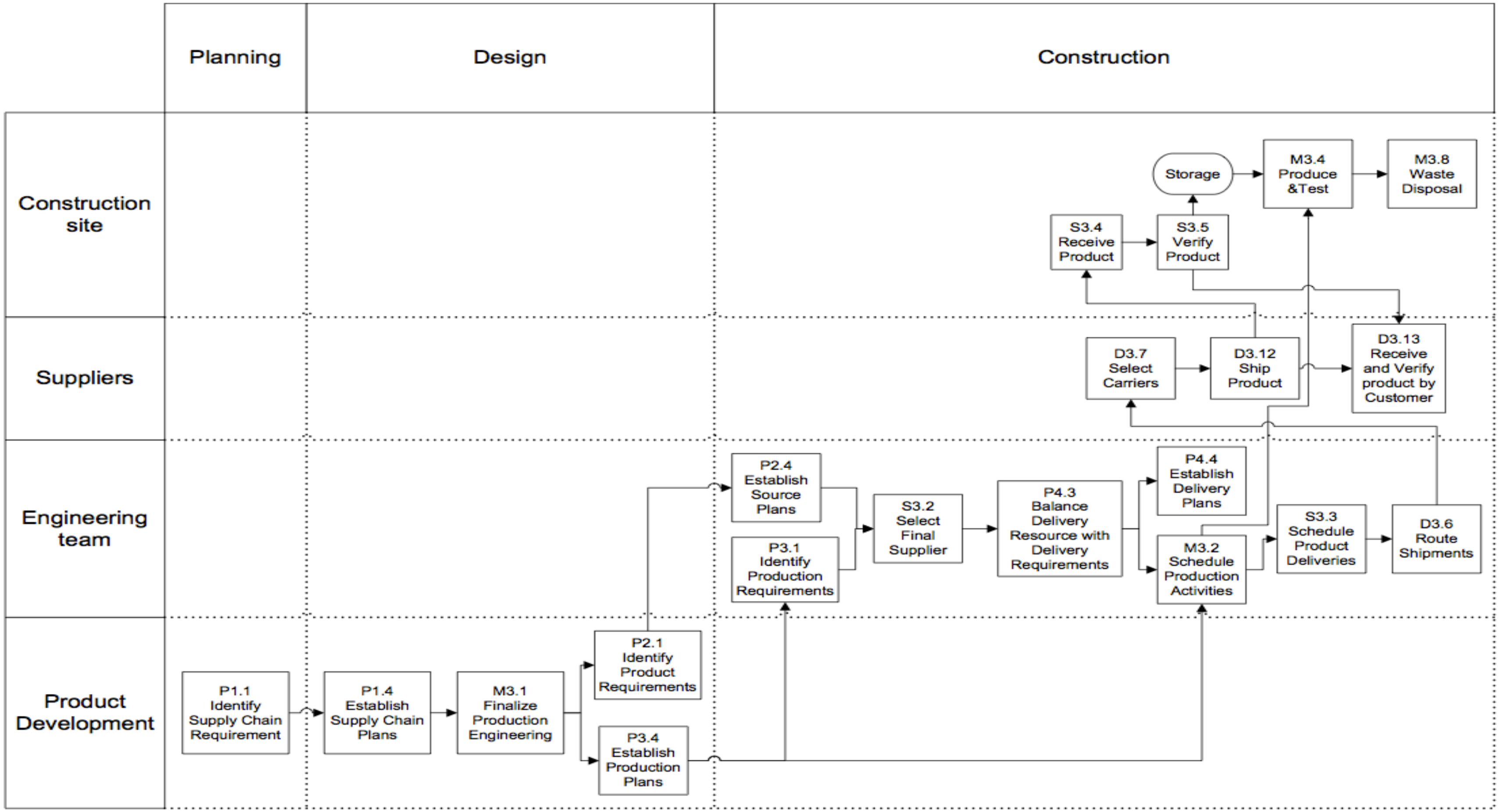


Figure 5.5: SCOR level 2 model for construction supply chain – the Brazilian case



(P1: Plan Supply Chain, P2: Plan Source, P3: Plan Make, P4: Plan Deliver, S3: Source Engineer-to-Order Product, M3: Engineer-to-Order, D3: Deliver Engineer-to-Order Product)

Figure 5.6: SCOR level 3 model for construction supply chain – the Brazilian case



It has been observed that the Brazilian construction industry still performs the project with a traditional procedure known as labour-based methods. Therefore, the efficiency of the overall construction process is based on the productivity of skilled workers. Most construction companies attempts to improve their construction performance towards gaining more efficiency but their construction workers do not detain qualified skills. The construction companies notice that the workers are not willing to perform their work by following the guidelines and standards. For this reason, the color evaluation system with the rewards is adopted to motivate the workers towards a better performance. Through this evaluation program, it leads to a more collaboration working as a team to contribute towards quality works. This collaborative work environment has also been found in every step along the construction project; from planning stage to the construction stage, which ultimately brings more value to the client.

Moreover, it has been found that a long-term relationship with suppliers and subcontractors already existed along the construction supply chain. With a positive relationship, there are still some problems related to delivery. The penalty could also be the adequate solution due to a delay in delivery. However, it is quite difficult to adopt this penalty because it will negatively influence a supplier relationship. Table 5.2 summarizes the current construction supply chain practices found in the Brazilian case and issues on its management.

Table 5.2: Summary of current construction supply chain practices – the Brazilian case

Supply chain process	Current practices	Issues
Plan	Product Development team and stakeholders are involved in project planning; Developing the construction documents as the guideline.	Need a more collaborative working.
Source	Selecting the materials based on price and performance; Enhancing more value of the project with the higher materials performance; Developing a positive relationships with supplier and subcontractor Selecting new supplier and subcontractor through bidding process; Supplying the materials and labor from different project at the same time; Ordering the materials based on the lead time; Regularly auditing the supplier performance through the checklist and ISO system; A minimum inventory level at the construction site.	Materials selected according to architectural design; No penalty applied due to the delayed and poor performance; Most subcontractor lacks of good managerial practice; Unqualified skilled workers.

Make	Providing guidelines for all construction works; Scheduling construction activities through the last planner system; Managing each construction activity independently; Day-to-day auditing the construction performance through checklist program with color evaluation system; Monthly meeting for updating the project status and scheduling delivery; Health and security control following the ISO standard.	Lack of understanding about regulations or standard; Construction workers are not willing to work following the guidelines.
Deliver	Delivery schedule managed by engineering team collaborating with suppliers.	The delayed delivery is often occurred.

5.3 Case Study 3 - Construction Supply Chain Management: The Australian Case

Australian construction industry has been facing an increase competitive pressure level, probably caused by high tendering cost, delays in project and detailed bids. Moreover, many areas in Australia are frequently dealing with the flood situation that may have negative impacts on the construction site and the construction management. For this reason, the government inquires the construction industry about the flooding plan and the risk management before approval is granted. To proceed with the construction project in Australia, it has been noticed that construction companies need an effective management and detailed preparation in planning, design, construction, and delivery.

5.3.1 Plan

In general, the managerial process of construction work is quite similar even in different packages of project specification. Once the project is approved, the design and project plan is developed in detail. A general contractor will receive the construction documents related to all technical specifications, when the architectural design is done. Based on these technical specifications, construction plan and site plan will be prepared.

In some large construction projects, there might be more than four construction companies involved in the project. At the planning stage, it may take time for effective planning to ensure that all the requirements are fulfilled.

5.3.2 Source

According to architectural design, the given materials specifications always provide some alternative options for a general contractor to select the suitable suppliers and subcontractors in the project. They will contact the suppliers and subcontractors based on their particular list and ask them to submit product specification, price list and lead time as a quotation. Normally, these suppliers and subcontractors have experienced with them in different projects and have a positive relationship for a long-term. Therefore, the general contractor knows very well about their ability to provide the products and services according to project specification. The agreement will be made without a written contract, which can be beneficial for both general contractor and suppliers. A general contractor can be eligible to switch a supplier with alternative suppliers, if a particular supplier is unable to provide required material at an agreed delivery time. On the other side, a supplier benefits in terms of no penalty or charge imposed against a failure for non-delivery.

Normally, the peak construction season is in the summer months. During this time, it has been found that the construction companies (who work as a general contractor) will carry out several different projects at the same time. In this case, they will work together with suppliers to effectively manage the flow of materials and schedule the delivery. Since a supplier has a limited number of the available trucks, the general contractor may process the order for large bulks at once and store these materials in their warehouse.

5.3.3 Make

Under the flooding condition, the stormwater may come suddenly without warning and has immediate impact on the construction site. The construction work should be monitored at all time according to the schedule and due to unexpected situation, since everything can happen in Australia. If they fail to complete the project on time, due to the unplanned responses to such a situation, the construction company may pay penalty to the clients. To follow up the work schedule, they need to pay subcontractors for overtime to meet the deadline.

For the waste management, there are two options to manage the construction waste. First option is for the landfills because it is an easiest way to do. Second option is recycling. Most wastes from construction site can actually be recycled. Currently, construction companies have to pay for the recycling plant and manage the truck service for them. Considering this option may increase an overall project cost. Therefore, construction industry tries to minimize the damage and waste occurred from the construction works, since less damage can save them cost.

5.3.4 Deliver

Suppliers will get confirmation of the order with the quantity, product specification, and delivery date in advanced. A couple of days before the delivery date, the supplier will send the notification to construction site about estimated time of delivery. The construction site manager will manage the traffic and access for the delivery trucks. To avoid the traffic caused by the truck sitting, suppliers will send a second truck when the first truck is almost done unloading. Some materials are stocked in general contractor's warehouse for being used in different projects, whilst other material is directly stocked at the construction site based on the construction work schedule.

For the concrete delivery, the supplier may charge the general contractor for the waiting time at the construction site. It is because concrete will start setting up timely after it is mixed for 25 minutes and suppliers may lose their market opportunities due to a limitation of delivery capacity.

5.3.5 SCOR Mapping Of The Construction Supply Chain

From the above discussion, construction supply chain in the Australian case comprises general contractor, suppliers, general contractor' s warehouse, and construction site. It can be explained with the SCOR model Level 1, Level 2 and Level 3 in Figure 5.7, 5.8, and 5.9, respectively.

At the planning stage, the general contractor will develop the project plan for an approval (P1.1). Once the project is approved, they develop project plan in details (P1.4). This plan includes construction plan (P3.4), design plan (M3.1), and the materials specification (P2.1).

Before the construction process starts, a general contractor will plan the overall construction process (P3.1) and contact the qualified suppliers and subcontractors on their list (S3.2) requesting for the quotations. A general contractor will work together with suppliers for scheduling the delivery based on materials lead time (P4.4, P4.3).

Most of the cases, the order will be placed in the large bulks for several projects. Some materials are ordered for stocking at the warehouse (S1.1, S1.2, S1.3, S1.4, D1.12, D1.13) and some materials are ordered for ongoing construction work (S3.3, S3.4, S3.5, D3.12, D3.13). The details about the time and location will be informed in advance (D1.6, D1.7, D3.6, D3.7).

During the construction process, all construction activities are scheduled (M3.2) and construction workers operate according to the schedule (M3.4). The waste occurred during construction will be sent for disposal (M3.8).

Figure 5.7: SCOR level 1 model for construction supply chain – the Australian case

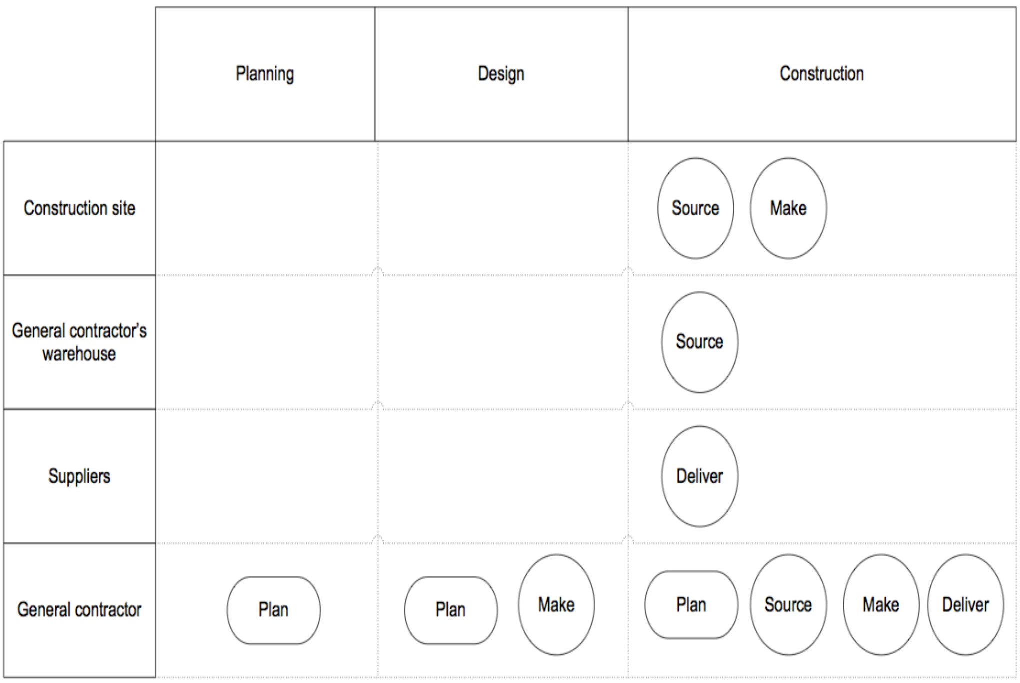
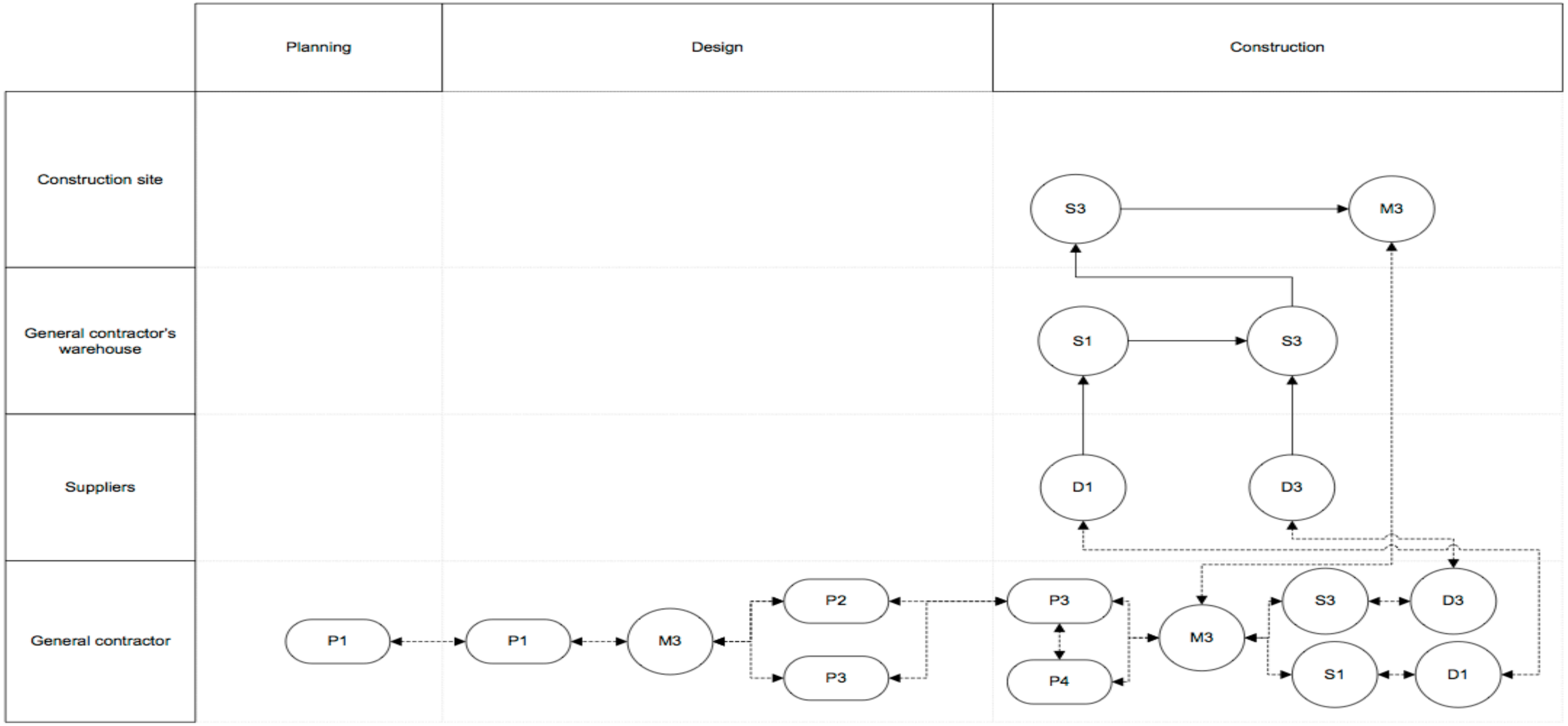
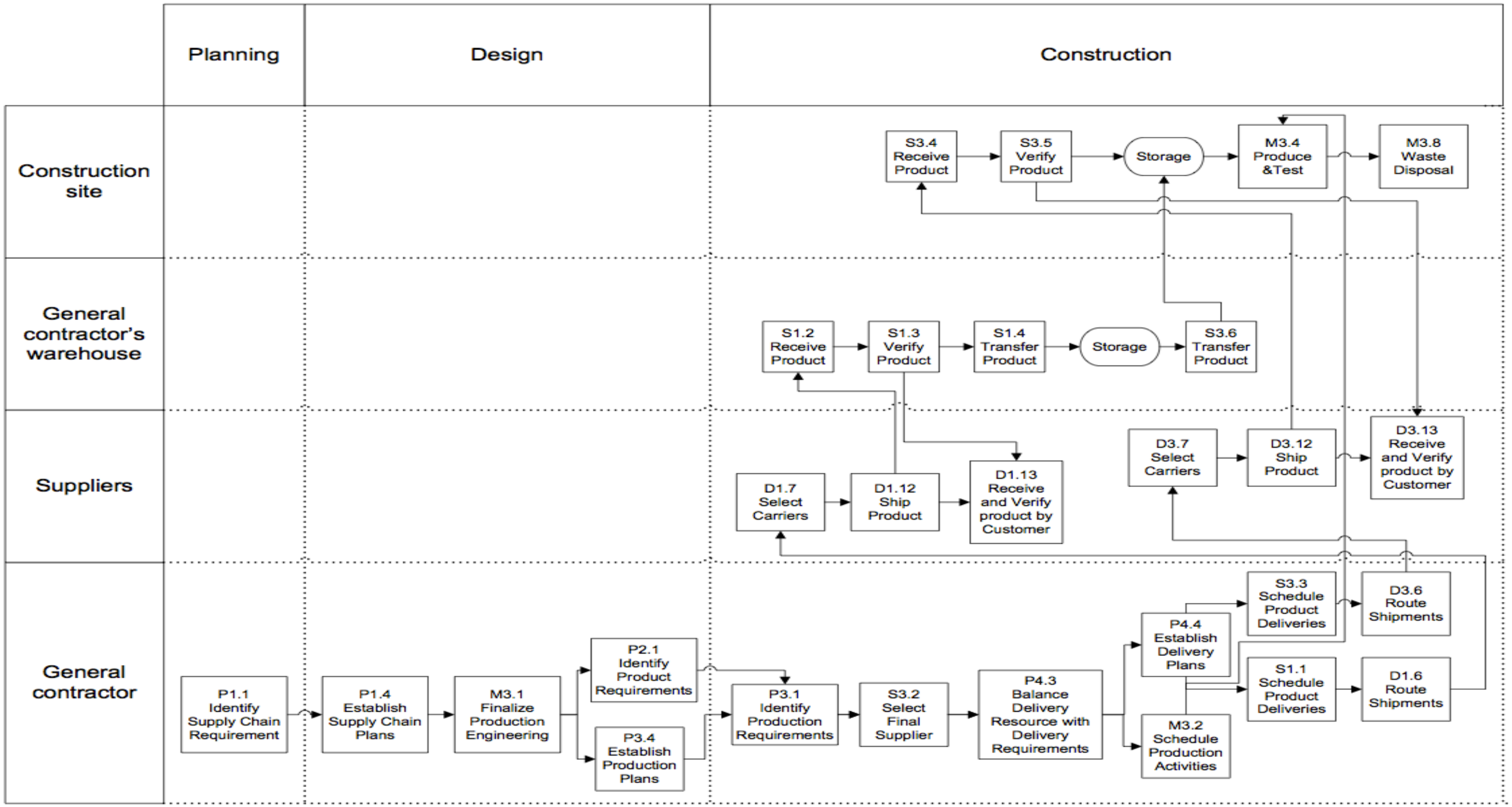


Figure 5.8: SCOR level 2 model for construction supply chain – the Australian case



(P1: Plan Supply Chain, P2: Plan Source, P3: Plan Make, P4: Plan Deliver, S1: Source Stock Product, S3: Source Engineer-to-Order Product, M3: Engineer-to-Order, D1: Deliver Stocked Product, D3: Deliver Engineer-to-Order Product)

Figure 5.9: SCOR level 3 model for construction supply chain – the Australian case



From the Australian case, it has been observed that the construction companies recognized an importance of managing materials flow. They noticed that completion of construction projects would be delayed if they could not supply the materials timely. It is because of the shortage of materials during the peak construction season. Most of suppliers have a limited capacity to supply the materials to the construction projects. Sometimes they could not deliver in time or the lead time of materials is extended due to the excess demand. As the result, the construction companies always stock the material both in their warehouse and at the construction site in order to fulfill construction requirements, depending on the lead time of materials.

Moreover, it is quite difficult to identify the strategic management practices for construction activities. It seem construction workers perform their works independently according to the plan and the evaluation system for controlling the construction performance does not exist.

A collaborative working has been developed between the general contractor and suppliers in order to improve the effective materials management. Therefore, the relationship with suppliers has a significant positive impact in a long-term perspective. Table 5.3 summarizes the current construction supply chain practices found in the Australian case and issues on its management.

Table 5.3: Summary of current construction supply chain practices – the Australian case

Supply chain process	Current practices	Issues
Plan	General contractor manages the overall supply chain according to project specification and regulations.	Only general contractor has decision-making authority in every step of construction process.
Source	Building long-term relationship with supplier and subcontractor. Supplier working without contract; Material order based on the lead time; A minimum inventory level or zero inventory.	Materials selected according to architectural design; Construction company only focuses on the materials flow; Less collaborative working in some processes.
Make	Managing each construction activity independently; Monitoring construction work at all time; Construction waste sent to recycling plant and landfill; Construction companies manage the logistics of waste; Minimize waste to save their cost.	Lack of performance measurement system; The waste management cost is relatively high.
Deliver	Collaborative working with suppliers to manage delivery schedule; Supplier sends the notification about delivery time couple day before delivery date; Construction site manages the traffic and access for delivery; Yield penalty due to truck waiting.	Supplier will be subject to change if they are unable to deliver; The high level of inventory due to the peak construction season.

5.4 Analysis Of The Construction Supply Chain Management: The Italian Case, Brazilian Case, And Australian Case

From three case studies, it is interesting to note that construction industry across the world is principally based on a traditional approach. The selection process for "Design-Bid-Build" still adopted in some construction projects, especially in the large projects. This is because the cost minimization/profit maximization remains the main goal for most construction companies in order to gain competitive advantage in the real estate market.

To achieve success in the completion of construction project, the construction companies in the Italian case pay more attention on the planning and design stage. To improve a construction performance, the project should be well defined in every activity. That is why the planning stage spends more time than other stages.

In the Brazilian case, the companies tend to improve their construction process management and its performance by adopting advanced managerial practices (such as the last planner system and color evaluation system). It is because the construction process in Brazil is labor-based method. Labor cost is still relatively cheap in the Brazilian labor market comparing to investing on the high technology. However, such low-cost labor (or unskilled workers) may lead to disruption in the overall performance of construction project.

In the Australian case, most companies have recognized an important role of suppliers in achieving their project successfully. It is because suppliers could support the construction companies in managing materials flow effectively. With the supplier proactive support, materials management can be flexible and adaptable due to the unexpected situation (such as flooding condition).

Moreover, it has been found that the construction companies in these three case studies attempt to develop a positive long-term relationship with suppliers and subcontractors.

The strong relationship with suppliers has been maintained over the long time, while the relationship with subcontractors does not exist in the construction network due to their poor performance. These suppliers will provide the materials for several projects and work together with construction companies in managing the material flow.

Additionally, it has been found that the construction activities along the project path are completely independent. The general contractor holds full decision-making authority in response to the overall construction process. The collaborative working has been established in some processes, which focuses more on collaborative problem solving. Therefore, a more effective communication and coordination are constantly required towards a greater successful management of construction project and its supply chain.

5.5 Conclusion

From three case studies, it has been found that there are various managerial practices adopted for managing the construction projects and its supply chain management.

In the Italian case, construction companies have recognized the importance of project planning. The success of construction project is that the construction actors perform their works according to the defined plan and materials are scheduled with the supplier support. The suppliers will manage the materials flow and fulfill the construction activities in a timely manner.

In the Brazilian case, construction companies have implemented the advance planning approach and evaluation system in order to improve the overall construction performance. However, unskilled and/or unmotivated workers remains as the major problem resulting in unsatisfied work performance.

In the Australian case, construction companies are facing a shortage of materials during the peak construction season. They jointly work with their suppliers and adopt the suitable practices for efficiently managing the materials flow and the level of inventory.

Based on an available source and market pressure in different business cultures, there are different ways to manage the construction process and construction supply chain. However, it has been found that similar issues have occurred in managing the construction project from these three case studies. To improve a better construction performance, it requires a more collaborative working along the path, an effective communication and a positive long-term relationship with suppliers and subcontractors.

Chapter 6 Supply Chain Management And Its Practices Towards Sustainable Performance

In this chapter, the third research question will be responded:

What is construction industry lacking in managing its supply chain? And how can construction supply chain management be improved towards the achievement of sustainability?

This chapter presents the sustainable construction policies and building legislation in Italy, Brazil and Australia, which particularly influence on managing the construction project and its supply chain. Then the construction supply chain management for sustainability and its practices are described. This chapter concludes with the analysis of construction supply chain practices towards sustainable performance associated to the ISCAB framework.

6.1 Sustainable Construction Supply Chain Management: The Italian Case

The move towards sustainability improvement has been an important issue in construction industry nowadays. At the European level, the European Commission (EC) includes construction industry in the context of the *Smart Growth Agenda 2020*. This agenda is a future strategic plan aiming at "smart, sustainable, inclusive growth", referring in particular to three mutually reinforcing priorities: Smart growth (knowledge and innovation), Sustainable growth (more efficiency, more greenness and more competitiveness), and Inclusive growth (social and territorial cohesion) (Ecorys, 2011). According to this context, the Italian construction industry is enforced by various building codes and policies both at regional and national level.

6.1.1 Building Regulation And Sustainable Policy In Italy

Recently, the construction regulatory system in Italy has been designed for quality building control in sustainability aspects, especially for environmental matters. From twenty regions across Italy, five autonomous regions (namely; Sardinia, Sicily, Trentino-Alto Adige/Südtirol, Vale de Aosta and Friuli-Venezia Giulia) implement their own construction and building regulations, based on the climate zone and development planning needs. The regions are divided into 109 provinces and subdivided into numerous municipalities. Each municipality applies building regulations with its own standards for sustainable building (called in Italian as *Norme per l'edilizia sostenibile*) following the Regional and National Building Code.

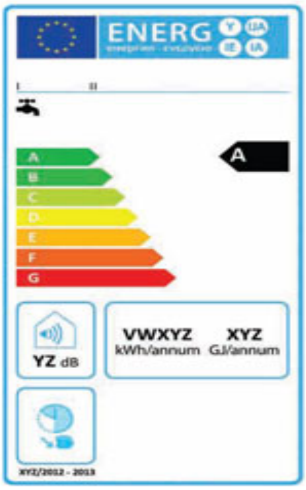
In accordance with the Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings (EC, 2003), energy performance certificates (EPCs) have been introduced and been forced by law since 2006 for promoting the 'Zero Energy Buildings 2020' policies. These certificates provide reliable information to consumers regarding energy performance in order to compare the cost-effective building (Mudgal *et al.*, 2013).

In Italy, the '*Norme*' has implemented the Energy Performance Building Certificate in term of efficiency scales based on primary energy use, as show in Figure 6.1. These labels currently apply to all buildings including non-residential and residential buildings.

Figure 6.1: Energy performance building certificate

Class	
A+	≤0.25 EPiL+9kWh/m2 year
A	≤0.5 EPiL+9kWh/m2 year
B	≤0.75 EPiL+12kWh/m2 year
C	≤1.0 EPiL+18kWh/m2 year
D	≤1.25 EPiL+21kWh/m2 year
E	≤1.75 EPiL+24kWh/m2 year
F	≤2.5 EPiL+30kWh/m2 year
G	>2.5 EPiL+30kWh/m2 year

(End-uses considered : Heating, Hot water, Light)



Source: IEA (2013)

In 2004, the first sustainable building certification called as '*Protocol for evaluation of environmental sustainability*' or the National ITACA Protocol was developed by ITACA (Innovazione e Trasparenza degli Appalti e Compatibilità Ambientale) in collaboration with iiSBE Italia (International Initiative for Sustainable Built Environment), based on the Sustainable Building Method; known as SBTool. The ITACA Protocol is a multi-criteria tool for evaluating sustainability of the building through all phases of the building lifecycle (Violano and Verde, 2013).

From the first version to the most recent version of the protocol (The ITACA Protocol 2004, 2007, 2009, 2011), the criteria of evaluation system have been continuously modified according to updated regulations. These criteria mainly address the social and environmental concerns including location quality, resource consumption, environmental loads, indoor comfort, and service quality (Violano and Verde, 2013).

Nowadays, the National ITACA protocol is used as a regional and communal evaluation system for controlling the construction work (e.g. in Basilicata, Campania, Lazio, Toscana, and Veneto). Moreover, it has become a valuable communication instrument among all stakeholders in order to develop an effective strategic management that enables to contribute positively towards a better sustainable building performance (Violano and Verde, 2013).

In 2009, the Italian Green Building Council (GBC Italy), a member of world GBC and a partnership with U.S. Green Building Council (USGBC), was established to encourage a sustainable building and green construction practices through the adoption of the LEED® certification system. GBC Italy is the first in Europe adopting this rating system. The LEED® is a voluntary sustainable buildings certification that assesses the building performance into five categories; (1) sustainable sites, (2) water efficiency, (3) energy and atmosphere, (4) materials and resources, and (5) indoor environmental quality. Currently, 165 projects have been registered for the LEED® certification and 26 projects have been certified (EC, 2011) .

As described above, there are numerous regulatory and policy instruments applied to promote the sustainable buildings in Italy. By building regulations, the buildings are required to present their energy performance to customers as mandatory. Other sustainable building tools are adopted as voluntary programs. Additionally, awareness-raising among end users about sustainability issues has stimulated the demand of sustainable buildings in the Italian real estate market. Therefore, sustainability-related performance of the buildings has become a key marketing strategy of most construction companies to seek the new opportunities in gaining competitiveness.

6.1.2 Construction Supply Chain Management Towards Sustainable Performance

Regarding the interviews, the benefit of sustainable construction is not just for the marketing purposes, but also for a long-term value regarding a better quality of life. In general, the overall construction process of sustainable projects is similar to traditional projects. However, performing the construction process in a sustainable way requires an integrated consideration of architectural approach, environmental impacts and economic aspect.

Regarding the architectural approach, the large quantity of information received from clients is important for the planning and design. The designers will create comfortable, relaxing and pleasant spaces with the flexible and functional layout. It is important to provide uniform illumination by increasing the use of natural light. Moreover, the building should include a green space in order to enhance health and wellbeing minimizing maintenance costs. Accessibility of public transportation networks and alternative means of transportation (e.g. bicycle paths) should also be considered in the architectural approach.

The environmental impacts include water, energy, light, materials, and indoor air quality. Resource usage and energy saving are the main fundamental aspects of the sustainable project. It is about how buildings can gain benefits with less resource used. With this aspect, construction activities are planned to use soils on construction site. Rainwater harvesting system with underground tank is designed to collect rainwater for garden irrigation and for the sanitary system. Moreover, the adoption of technologies can increase the efficiency in terms of reducing harmful emissions and resource consumption.

During the construction process, waste requires an adequate management. The quality of air and water are monitored. Also all chemical materials (such as glues, sealants, primers, varnishes, and glazes) need to be controlled with the limited of volatile organic compound (VOC) emission. With these practices, it will protect the health and safety of construction workers and also create a positive relationship with the neighborhood and community.

Economic aspects refer to overall cost of facilities; utility and maintenance cost. Most buildings currently install the photovoltaic systems for self-consumption. For the heating system, the district heating power plant distributes heat for heating and hot water to the buildings in the same area. This heating power plant can provide a higher efficiency and generate less pollution. The cooling system uses the cool underground water for air-conditioner. Through photovoltaic system and district heating, a building can optimize its consumption and can reduce operating costs.

Improving the construction performance towards sustainability should start from planning. Generally, the sustainability of building is strongly influenced by the choice of materials. The selection criteria should consider the sustainable aspect.

Construction companies select materials that are made from wholly or partly recycled materials and are possible to reuse in the future. The local materials are also considered in reducing the transportation cost and in contributing the benefits to the society. In the future, materials may need the certification in order to guarantee their sustainable performance. Therefore, the supplier must provide the complete information of each material in all aspects. At the moment, construction companies find it difficult to find the sustainable material in the local market.

6.2 Sustainable Construction Supply Chain Management: The Brazilian Case

The development of construction industry towards sustainability has been growing in Brazil. More recently, it is having a faster growth with the government policies pressures influenced by the Brazilian Agenda at Rio+20 Conference. This conference is the United Nations Conference on Sustainable Development (UNCSD); took place in Rio de Janeiro, in 2012. Brazilian Agenda has focused on the sustainable development in mainly nine areas; including greenhouse gas emission, solid waste management, water management, energy, transportation, sustainable construction, sustainable public sector procurements, sustainable tourism, and sustainable food (Gusmão, 2012). Responding to the agenda, the different kinds of national/federal policies have been created to enforce the construction companies in order to implement desirable actions.

6.2.1 Building Regulation And Sustainable Policy In Brazil

In 2010, the Ministry of Planning first regulated the sustainable-related legislations for construction industry under the norm 001/2010. This norm is related to the adoption of sustainable criteria for public purchasing and construction contracting(EY and GBC, 2013). The criteria include:

- Promote the use of natural ventilation and avoid the use of air conditioning systems
- Automated the light system through lighting control and load control
- Use the photovoltaic and renewable source for water heating

- Use of individual water meters and electricity meters
- Use of recycled water or reuse of rainwater
- Used of recycled and reused materials
- Use of certified wood
- Use of labor and materials in local market
- Adopt the waste management program

Resulting from Rio+20, the sustainable criteria are also implemented in the auction of government projects under the publication of Presidential Executive Order 7.746/2012. The law stated that the government auction must be awarded to the contractor, who promotes the use of construction materials with recycled components and non-hazardous materials. Moreover, the project must be operated and maintained at lower costs and have a low environmental impact (EY and GBC, 2013).

At the municipal level, the local government fosters the sustainable construction policy through tax incentive; called GREEN IPTU (property tax). This tax aims to promote the adoption of sustainable construction practices according to sustainable urban planning. The total amount of tax possibly is reduced up to 20% during the period of five years when the construction companies adopt at least two practices below (EY and GBC, 2013):

- Rain water storage
- Recycle and reuse water
- Installing photovoltaic system for water heating
- Green roof
- Use of materials with a low environmental impact
- Use of renewable energy source
- Waste management program
- Green area in the property

On the other hand, the move toward sustainable construction is also related to the certification schemes. Currently, there are four main voluntary sustainable building rating systems used in Brazil. These are LEED®, the AQUA process, PROCEL, and CASA AZUL.

The Green Building Council Brasil (GBC) was established in 2007 and has disseminated the LEED® sustainable certification in Brazil. The LEED® certifies the all types of construction projects across all regions of Brazil (e.g. residential buildings, industrial plants, laboratories, supermarkets, restaurants, hotels, and stadiums). The number of buildings certified by LEED® has been cumulatively increasing year by year. Over 900 projects have been now registered for the LEED® with 120 projects certified. Among these projects, it includes the 2014 World Cup stadiums and the Olympic Park for Rio 2016 (EY and GBC, 2013).

In 2008, the AQUA (Alta Qualidade Ambiental) process is developed based on the HQE (Haute Qualité Environnementale) approach, which is the French certification scheme. The AQUA assesses the quality of building into four mains areas; eco-construction, eco-management, comfort, and health. Along the building lifecycle, there are four types of the AQUA certificates. These are (1) building program for goal definition, (2) building concept for design phase, (3) building realization for construction phase, and (4) building operation for operation phase. (Vanzolini, 2013)

Nowadays the electricity consumption in Brazil has greatly increased every year especially in residential and commercial building. As the result, the National Politics on Conservation and Electricity program (PROCEL Edifica) for building was established for promoting energy efficiency. This labeling program classifies the level of energy-efficiency by the evaluation in scale, based on the energy demand of the building; from “A” (more efficient) to “E” (less efficient) (Tubelo *et al.*, 2013).

CAIXA sustainable program has been developed by the Caixa Econômica Federal along the collaboration with the Ministry of Cities (Ministério das Cidades). CAIXA operates in banking and insurance, which holds a great share of housing financial market and urban infrastructure in Brazil. This program aims at fostering the adoption of sustainable building practices regarding energy efficiency, legal wood action, and blue house label (Selo Casa Azul). Through the blue house label program, the sustainable performance of housing projects will be evaluated according to six categories; urban quality, thermal comfort, energy efficiency, materials and resources conservation, water efficiency, and practices in social aspect. The certificate will be granted at three levels; gold, silver and bronze, according to the evaluated scores (Castro and Benevides, 2007).

From the above review, it has not been found a strict building code toward sustainable development exists in the Brazilian regulation system. Most policies are voluntary programs for stipulating the construction practices in sustainable manner. However, it has been evidenced that the number of buildings registered for the sustainable building has been increasing year by year. This is because the construction companies have recognized the sustainable building value, which attracts the customers in the real estate market and allows the development in the future.

6.2.2 Construction Supply Chain Management Towards Sustainable Performance

From the interviews, sustainability of construction is widely used as a marketing strategy. Since the national building regulation for sustainability does not exist, most construction companies register for sustainable buildings label in order to certify their high building performance.

Nowadays there are an abundance of renewable energy sources available in Brazil (including solar power and wind power). Most construction companies target to promote the use of renewable energy but the equipment is still relatively expensive. Therefore, the generation system is already implemented in the new buildings, the equipment (photovoltaic panel and wind turbine) need to be installed by clients. Moreover, the green roof has been considered in many buildings in order to reduce the heat loss and improve the energy performance.

During the construction process, sustainable performance can be improved through the use of industrial materials and the waste reduction. The industrial materials include drywalls and plaster. According to the traditional process, brick lanes, concrete, gypsum and painting have contributed to a high level of pollution. Air and noise pollution are from activities related to these materials. Improving their traditional process with high technological machines may be an alternative solution but the cost of machinery is too expensive compared to labor cost. Accordingly, it will be more appropriate to improve the process efficiency with labor-related activities. In general, construction companies provide the sustainable guideline for all construction activities. With unmotivated and unqualified workers, it becomes more difficult to perform their works towards sustainability. Therefore, training is required to become a qualified worker.

In addition, construction companies try to build a good relationship with their neighbors and treat their neighbors as same as their client. During the construction phase, the construction workers are asked to avoid the disturbance and any potential impact on environment around construction site.

Regarding to the waste, construction wastes are sorted into four main categories: iron, wood, paper, hazardous waste (paint and chemical). Each type of waste has its own specific destination and requires proof of actual destination. Currently, there are the companies, which are responsible for waste management; including construction waste, household waste and industrial waste. As the construction wastes are large and heavy items, there is a limited place for disposal. With the problem of disposal destination, construction companies try to reduce their waste through lean construction techniques.

Currently the practices adopted in managing construction processes are limited to solving the problem in the short term. The choice of material and technology are not the best solutions for the achievement of sustainable performance but construction companies need to improve their processes in the long-term perspective along the building lifecycle. Thus, construction companies need to ensure the sustainable performance according to the planning. Nowadays the sustainable performance is not further monitored after the building is completed.

The sustainable value creation in construction industry necessitates sustainability thinking as well as its demand from clients to be successful. Construction companies need to be constantly updated for the new kind of materials and new construction techniques. In Brazil, sustainable construction community is under development. It needs the support of government in terms of the building regulations towards sustainable development.

6.3 Sustainable Construction Supply Chain Management: The Australian Case

Typically, sustainability of buildings in Australian needs to be driven by building regulation. The Australian Building Codes Board (ABCB) develops broader government policies and forms the Building Code of Australia (BCA) for all capital cities across Australia based on a goal of sustainability. The implementation of BCA will be flexible in each state and territory depending on its geographic location. The additional mandatory requirements may also apply beyond the BCA (ABCB, 2014).

6.3.1 Building Regulation And Sustainable Policy In Australia

Currently the BCA standard provides the energy efficiency provisions depending on climate zone. This standard determines the amount of energy used for heating and cooling system in a building through star rating. The star rating system ranges from 0 to 10 stars. The 0 star rating indicates the building inefficiency to minimize the discomfort of hot or cold weather. The 5 star rating reflects the building with good thermal performance. The 10 star building may not need any of cooling and heating. In the future, the BCA (Part 3.12 Energy Efficiency) expectedly requires the new building with the equivalent of a 6 star energy rating (ABCB, 2014).

Additionally, the Department of Environment, Climate Change and Water, the New South Wales Government has developed the National Australian Built Environment Rating System (NABERS) to assess the sustainability of existing building during the operations phase without a consideration of construction, maintenance and end-of-life phase of the building. This system is a voluntary assessment tool for measuring the operational efficiency of the building in four areas; NABERS Energy, NABERS Water, NABERS Waste, and NABERS Indoor Environment. With the commencement of the Building Energy Efficiency Disclosure Act 2010, the NABERS Energy has become mandatory for the commercial office space over 2,000 square meters (ABCB, 2014).

In Australia, it has been evidenced that each state and territory requires the different mandatory provisions towards water and energy efficiency. In Victoria, 5 star building fabric rating system was created based on the national BCA provisions. This rating system requires water saving fixtures, a rainwater tank for all sanitary flushing system and solar water heating system. In Queensland, all new residential buildings must fulfill the minimum water saving targets. These targets can be achieved by installing household rainwater tanks, reusing stormwater, and adopting a greywater treatment program. In South Australia, rainwater tanks and rainwater harvesting must be designed in the new homes and renovated homes with roof area spanning greater than 50 square meters. Lastly, in West Australia, the new homes must increase their energy efficiency of water heating system by using a solar system or a gas system rated at least 5-star (ABCB, 2014).

Furthermore, the Green Building Council of Australia (GBCA) developed a Green Star as a national voluntary rating system in order to encourage environmental efficiencies of individual building and communities. Green Star certification for individual building assesses the construction projects along the building lifecycle from design, construction and operation into nine areas. These assessment areas are including: management, indoor environment quality, energy, transport, water, materials, land use and ecology, emissions, and innovation. Green Star for communities assesses communities regarding governance, design, livability, economic prosperity, environment, and innovation. The rating ranges from 1 to 6 star; 1 star for minimum practice, 2 star for average practice, 3 star for good practice, 4 star for best practice, 5 star for Australian excellence, and 6 star for world leadership (GBCA, 2013).

According to the strategic planning actions of local government, there are various national provisions developed for continually improving the sustainability. However, it has been found that the mandatory requirements for building give rise to issues of energy and water efficiency. This is because the increasing water and energy demand is now a priority of government. Therefore, these issues have become the focus of the Building Code of Australia under green building principals and currently influence designers and builders to develop advanced methods to meet the standards.

6.3.2 Construction Supply Chain Management Towards Sustainable Performance

From the practitioner points of view, sustainable construction should be efficient and cost-effective with less environmental impact in a long-term perspective. In term of energy efficiency, the construction companies have not yet focused on this aspect, since the building code towards energy efficiency is now voluntary. The current practice is to select energy-efficient appliances and equipment with a high star rating. On the other hand, solar power system is still costly in Australia and might not be feasible for everyone. This is because installing the solar system may take almost 20 years to reach a break-even point. Therefore, the design can be the alternative option to achieve the energy efficiency. For example, in building structure careful attention should be given towards window placement along with heating and cooling system.

Regarding water efficiency, most new buildings are designed with the rainwater harvesting systems under the building, as regulatory requirements by the building code. This system will collect rainwater into a storage tank through a drainage technique. The water will be used for sanitary flushing system, garden irrigation and other external water uses. This water efficiency practice directly lower the water bills, conserves potable water, helps to save the environment and indirectly reduces the flood damage.

In addition, waste is the main problem in Australia. Municipal solid waste always ends up in landfills because there is an abundance of vacant land. This waste will generate the methane emissions, which have negative impacts on the construction site and its environment. As a result, the existing wastes are covered with construction wastes (timber, steel, and roof tires) in order to reduce the hazard and then construct the building on the top. In general, construction companies hire a skip to manage their wastes that are heavy items. The skip will be responsible for collection, transportation and sorting all waste before sending to recycling plant. Since disposal fees are based on weight, the disposal cost for construction waste is sufficiently high. Therefore, construction companies need adequate cost-effective planning to manage their waste and ensure that overall waste is minimized.

The choice of materials can play a significant role to improve the sustainability of construction process. Material that can be continuously used for multiple times is selected. For example, timber can be again used for new building as structural frame and can be brought back to industrial production being the key component of other materials. Therefore, materials can be considered as "sustainable" material when that material either is not waste, or can be recovered by recycling. In the planning stage, the sustainable performance of materials will be considered with the project specification. Fortunately, most materials used in the construction project can be recycled materials. The steel and concrete are from recycling plant. Timbers are from demolition site.

However, the sustainable issue has been rising regarding the production process of sustainable materials. Most materials are declared their performance as the sustainable materials but it does not mean that their production process is completely sustainable. Consequently material should be also identified in terms of its sustainable performance along the entire lifecycle through the LCA methodology.

At the moment, there are not many construction companies interested in these kinds of materials. This is because of the cost of sustainable materials is usually high comparing to normal product. Actually, the recycled materials should be less expensive since they are of lower quality than virgin materials. Only construction companies, aiming to promote the green environment for their clients or registered for the sustainable construction certification, will select the certified products with the sustainable label. Regarding to the Green Star rating system, the choice of materials is just a small part of a sustainable building. The overall sustainable performance is highly dependent on the implementation of sustainable practice for their process.

Indeed, most construction companies constantly improve their performance towards sustainability but construction companies and clients think about "sustainability" with different perspectives. Therefore, it is becoming a government role to provide a common understanding about sustainability in all aspects; not only to the construction companies, but also to the supplier and the supplier of supplier. This is because there are numerous actors involved in one project, which will support an achievement of sustainable performance in a long-term perspective.

The process improvement towards achieving a more sustainable performance, necessitates construction companies to plan ahead their construction activities and properly go along with the defined plan. In some cases, they require financial assistance from the government (including tax incentive) to invest for innovative processes. However, it has been found that the most difficult step is to control and maintain the sustainable performance along the building lifecycle.

6.4 Overall Discussion From The Three Cases

From the above discussion, there are numerous practices adopted for improving the construction sustainable performance, some of which are straightforwardly influenced by the building regulations and policies. However, construction companies currently pay less attention on the long-term perspective. The sustainable performance has usually been considered until the building is completed. Therefore, the improvement of construction supply chain management is required for ensuring the sustainable performance along the entire building lifecycle.

Regarding to the ISCAB framework presented and discussed in Chapter 4, the construction actors should have a clear and mutual understanding of the possible impacts on the overall building lifecycle, when adopting the appropriate practices. These practices require the collaboration among all relevant construction actors with a consideration of building lifecycle perspective at the beginning stage of the project in order to achieve the long-term sustainability.

Based on the integrated analysis of practices from the three cases and the practices from the literature review coupled with the consideration of building lifecycle, the five main supply chain management practices are defined to support the achievement of a high sustainability. These practices include (1) adopting sustainable criteria, (2) considering the sustainable source availability, (3) collaborative working for planning and design, (4) building a positive relationship with all stakeholders, and (5) implementing the adequate management techniques.

6.4.1 Adopting Sustainable Criteria

To improve sustainability, the procurement strategy has been proposed with the adoption of sustainable criteria (Hartmann and Caerteling, 2010; Palaneeswaran *et al.*, 2003). The sustainable criteria could be adopted both in the materials supplier selection process and in the subcontractor selection process through an integrated consideration of materials performance, management performance, and operations performance.

Practically, energy efficiency can be improved through the sustainable selection criteria. In the Italian case, the heat is supplied from the district heating power plant, which can provide a higher efficiency and generate less pollution. On the other hand, the construction companies in the Australian case energy efficiency are improved by selecting the materials based on the energy efficiency-rating label.

From the three cases, environmentally friendly materials should be selected and all hazardous materials should be avoided for protecting the health and safety of construction workers and occupants. Other sustainable performance aspects (such as recycle materials or high content of recycled materials, reused materials and local materials) should also be considered in order to reduce the use of resource.

To select these kinds of materials, the construction companies need the complete information from suppliers. In the future, these materials may require the certification or label to certify their sustainable performance, and supplier and subcontractors may be required to obtain the certification of environmental management systems.

6.4.2 Considering The Sustainable Source Availability

According to the findings from literature, selecting an appropriate construction site can increase a better sustainable performance. This is because the sustainable source that is available on the construction site could support resource saving (Sev, 2009).

Based on the practitioner's point of view, the planning and design should consider the sustainable source availability on the construction site.

In the Italian case, the building with the support of architectural design should encourage the use of natural light, which can reduce the energy consumption through the placement of windows and doors. Some buildings have installed the photovoltaic systems for energy self-consumption and used the cool underground water for the cooling system. During the construction process, some construction activities are using soils available on the construction site and using the rainwater during rainy season.

In the Brazilian case, most new buildings promote the use of renewable energy. Some buildings have installed the photovoltaic systems, while some buildings have installed the wind power systems. The adoption of these systems is based on the location of construction site and the availability of renewable source. Moreover, the green roof is an alternative design option to reduce heat loads in the building.

In the Australian case, most buildings are designed with the rainwater harvesting systems. Rainwater is used for garden irrigation and sanitary flushing system, which would support the improvement of water efficiency.

6.4.3 Collaborative Working For Planning And Design

From the literature review, the collaboration among the construction actors in planning and design can improve the overall construction processes for being more effective and efficient including delivery, production and purchasing management (Cao and Zhang, 2010; Edum-Fotwe *et al.*, 2001; London and Kenley, 2001). However, the level of collaboration usually relies on the effective communication with the timely and accurate information sharing for a detailed planning.

According to the Italian case and the Brazilian case, a large quantity of information is provided for planning and design the project. Therefore, the effective collaboration and communication among construction companies are required for efficiency managing the construction project.

During the design stage, the architectural design team should work collaboratively with all stakeholders to increase a high degree of service quality through the flexible and functional layout. The building should provide the good environmental conditions both inside the building and outside the building.

During the planning stage, the well-defined production and delivery plan through the collaborative working with suppliers can improve the overall construction performance regarding the construction waste management, traffic management, transportation route, and delivery schedule.

6.4.4 Building A Positive Relationship With All Stakeholders

In the theoretical point of view, a positive long-term relationship with all stakeholders can be developed for continuous improvement, which may promote innovation in construction processes for a higher degree of sustainability (Cao and Zhang, 2011; Eriksson, 2010).

In the Brazilian case, construction companies are attempting to build a good relationship with their neighbors and the communities, and give careful attention regarding the disturbance and any potential impacts on the environment.

In the Australian case, construction companies have built a positive long-term relationship with their suppliers and subcontractors to support the improvement of the overall construction process, ultimately construction performance. Moreover, the positive long-term relationship with subcontractors and suppliers can also enhance the innovation opportunities towards sustainable performance.

6.4.5 Implementing The Adequate Management Techniques

The management techniques such as Lean Construction are extensively adopted for improving the production processes, optimizing the timely materials flow, and controlling the quality of the overall performance (Bankvall *et al*., 2010; Koskela *et* *al*., 2010; Sacks *et al*., 2009). Through the implementation of Lean Construction approach, the construction waste and resource consumption would be minimized as well as pollution would be prevented.

From the Italian case, the quality of air and water should be monitored during the construction process in order to limit the amount of pollution and potable water consumption. To achieve the sustainable performance, the building must be continuously monitored throughout the building lifecycle, from the perspective of design and construction to the operation and maintenance.

In the three cases, construction companies require an adequate waste management for efficiently managing the construction waste. In the Italian case, the construction waste is sent to the recycling plant. In the Australian case, the construction companies hire a skip to manage their waste. In the Brazilian case, the Lean Construction techniques are adopted to solve the construction waste issue. High technology machinery for the construction processes can also help construction companies to reduce the pollution but this machinery should adopt maintenance programs to ensure continuous productivity.

To improve the construction process towards sustainability, the practitioners in all three cases mentioned that construction companies should keep updating the information related to appropriate approach, which can fulfill the sustainable requirements based on the national sustainable policies and the building regulations.

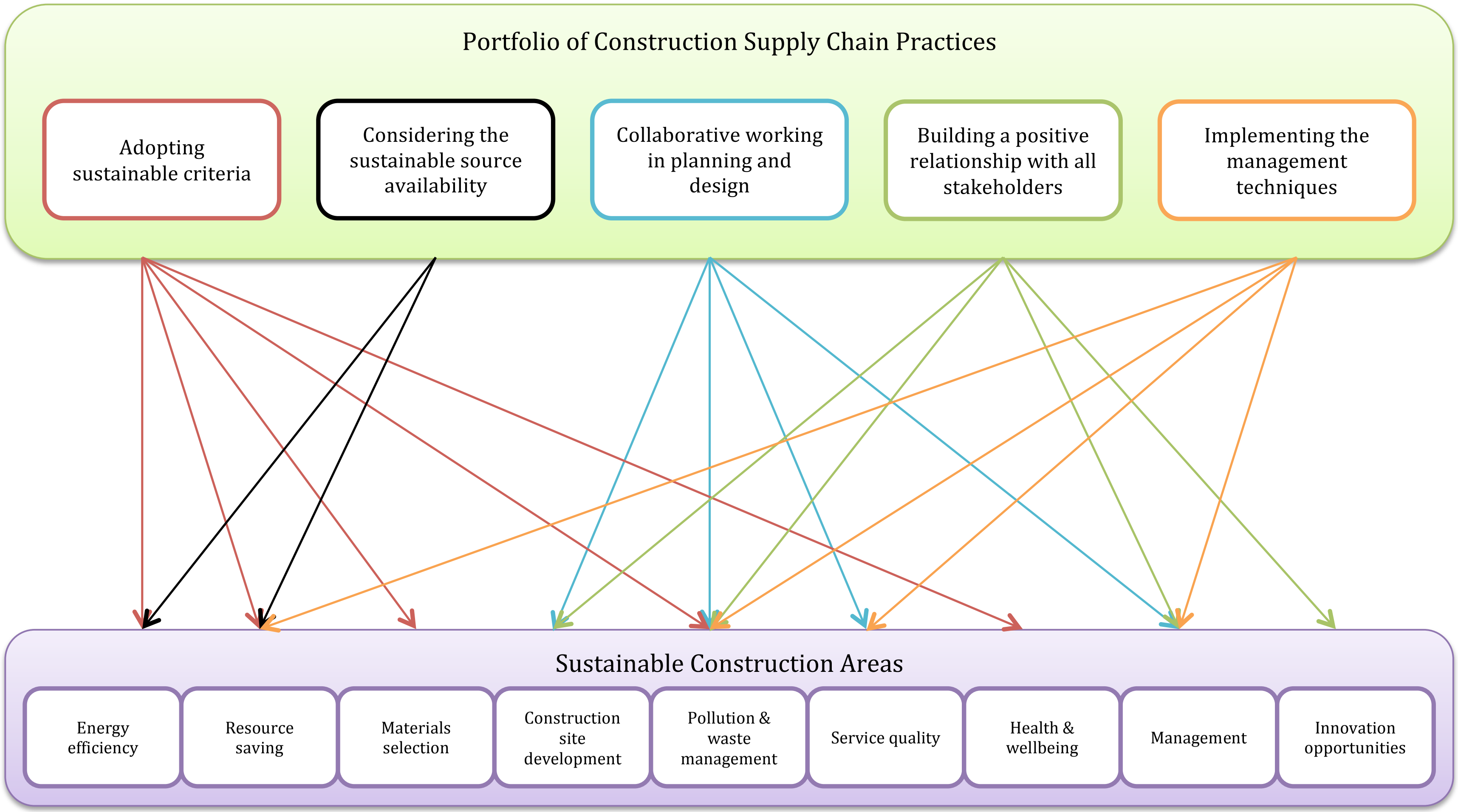
According to the above discussion, these five main practices are proposed for a portfolio of construction supply chain management practices. Table 6.1 summarizes the contributions of these practices based on the nine characteristics of sustainable construction (discussed in chapter 1). Figure 6.2 presents a portfolio of construction supply chain management practices according to the ISCAB framework.

Table 6.1: Summary of the appropriate practices for the construction supply chain management (IT: The Italian case, BR: The Brazilian case and AU: The Australian case)

Practices	Findings from literature review	Findings from case studies
Adopting sustainable criteria	Materials selection (Hartmann and Caerteling, 2010; Palaneeswaran *et al.*, 2003)	Energy efficiency (IT, BR, AU) Resource saving (IT, BR, AU) Pollution and waste management (IT, BR, AU) Health and wellbeing (IT, BR, AU)
Considering the sustainable source availability	Resource saving (Sev, 2009)	Energy efficiency (IT, BR) Resource saving (IT, BR, AU)
Collaborative working in planning and design	Management (Cao and Zhang, 2010; Edum-Fotwe *et al.*, 2001; London and Kenley, 2001)	Construction site development (IT, BR) Pollution and waste management (IT, BR) Service quality (IT, BR) Management (IT, BR)
Building a positive relationship with all stakeholders	Management (Cao and Zhang, 2011; Eriksson, 2010)	Construction site development (BR) Pollution and waste management (BR) Management (AU) Innovation opportunities (AU)

Implementing the management techniques	Resource saving Pollution and waste management Management (Bankvall *et al.*, 2010; Koskela *et al.*, 2010; Sacks *et al.*, 2009)	Resource saving (IT) Pollution and waste management (IT, BR, AU) Service quality (IT) Management (IT, BR, AU)

Figure 6.2: A portfolio of construction supply chain management practices



Regarding the five main practices in the portfolio, each practice can respond to two or more sustainable areas but none of them can achieve all sustainable construction areas. With the validity of each practice, a set of complementary practices would be required in order to respond to a multi-dimensional sustainable area, depending on the project specification requirements.

For example, the construction company is attempting to improve its sustainable performance in term of energy efficiency, resource saving, pollution and waste management, and service quality, simultaneously. A set of practices, including adopting sustainable criteria (for energy efficiency, resource saving, and pollution and waste management) and implementing the management techniques (for resource saving, pollution and waste management, and service quality), would be required.

Moreover, the set of appropriate practices to be adopted may be dynamically modified during the building lifecycle according to any change in the project specification, or to the need to upgrade a specific sustainable area due to exogenous pressures (e.g. assimilation of new directives, availability of new best technologies). Implementing the practices from the portfolio would reduce the risk of myopic decisions, though locally and in the short-term deemed optimal, from an overall sustainable perspective along the building lifecycle.

6.5 Difficulties Towards The Improvement Of Sustainability

According to the construction supply chain management processes and their practices in the three different business cultures, some difficulties have also been found. These difficulties may have impacts on managing the construction project towards sustainable performance as following:

- The construction companies still lack of understanding about construction supply chain and lack of experience to improve the construction supply chain towards sustainability.

- Materials with sustainable performance are not available in the local market and the price of these materials is relatively high comparing to the virgin materials.
- Suppliers do not have a suitable knowledge of their products regarding to sustainable performance and specification factor.
- The use of recycled water is not suitable in some construction activities.
- Construction workers are not motivated to perform their works in sustainable manner.
- Some sustainable materials are not completely sustainable along their lifecycle.
- To improve a better sustainable performance, the construction companies may need to change the whole process, which may require a huge investment.
- Most construction companies pay more attention on the architectural design and the choice of materials rather than improving their construction process.

From these difficulties, it can be concluded that the improvement of construction supply chain management needs the efforts of construction actors and the support of government to enhance a better contribution towards sustainability in the long-term perspective. It will take time to build a mutual understanding of sustainable construction between relevant stakeholders and create common practices to accomplish the sustainable target.

Therefore, the practices from portfolio would be used as guidance in order to provide a valuable contribution on reducing the level of fragmentation between the lifecycle phases and on enhancing the overall construction sustainability performance.

6.6 Conclusion

Sustainable construction performance is currently a marketing strategy for most construction companies. From the practitioner viewpoints, it has been found that there are different managerial practices adopted for achieving the sustainable construction performance. Most practices are directly forced by the building regulations and national sustainable policies.

In the Italian case, the building regulations and policy towards sustainability have given attention to the energy efficiency in the building that can be seen from the mandatory requirement for energy performance certificate. Since the energy performance certificate measures the energy consumption of buildings, most construction companies attempt to achieve the high rating energy performance with the architectural design.

In the Brazilian case, there is no compulsory minimum standard regarding sustainable building to control the building performance. Nowadays, it has been found that most new buildings have started installing a photovoltaic system and/or have been covered with green roof. On the other hand, the final destination of construction waste disposal is currently a major problem of construction companies. To overcome this problem, most construction companies have adopted the management approaches and techniques (such as "Lean Construction") to eliminate the waste occurred during the construction process.

In the Australian case, the mandatory requirements for building performance give rise to issues of energy and water efficiency. For energy efficiency, construction companies consider the choice of materials with a high star energy efficiency rating and the architectural design of the building. For water efficiency, the rainwater harvesting system with storage tank has been installed in the new building to reduce the use of portable water.

To achieve a better sustainable performance, a set of practices is proposed for a portfolio. These practices are defined with the integrated analysis of the findings from literature and the findings from three cases coupled with the consideration of the building lifecycle. The five main practices are (1) adopting sustainable criteria, (2) considering the sustainable source availability, (3) collaborative working for planning and design, (4) building a positive relationship with all stakeholders, and (5) implementing the adequate management techniques.

According to the findings, each practice can contribute to two or more construction sustainable areas. Therefore a set of practices may be adopted to enhance a better sustainable performance at the large scale based on the project specification and the regulation requirements.

Chapter 7 Conclusion And Future Research

The notion of sustainable development has a particularly influence on the construction industry. Consequently, the construction actors and stakeholders are enforced to perform their activities towards sustainability throughout the entire building lifecycle. From the literature, it has been found that construction companies need a systematic view for a successful management of their construction activities in a long-term perspective.

In practical, construction actors as practitioners are still inexperienced and have a lack of understanding on increasing the sustainability.

With this issue, the research aimed to fill this gap by providing a systematic perspective for managing a construction supply chain and highlighting its practices towards a more sustainable performance.

The objective of this research is to investigate how to improve the construction supply chain management, which may support the design, realization and operation of sustainable buildings.

7.1 Research Questions And Its Findings

With this objective, the a set of interrelated research questions is addressed and this research has been performed to answer these research questions adequately as:

Research question 1: **How can supply chain management support the sustainability in construction industry? And, what are the main elements to be considered to manage the construction supply chains, which will ensure the sustainable performance along the entire lifecycle of a building?**

Traditionally, the performance-related problem is a major issue of the construction industry. With the consideration of the sustainable performance areas of construction industry, it has been found that most of them rely on supply chain activities.

To effectively improve the construction performance towards sustainability, the adoption of supply chain management would greatly benefit construction companies in order to provide a systematic view for the successful management throughout the building lifecycle phases.

From the literature review, two main elements have been discussed for managing the project successfully: role of construction actors with collaborative relationship and the lifecycle perspective. The idea on collaborative working derives the most efficient way of making decisions openly and resolving problems adequately, based on mutual benefits and risk sharing. With the consideration of lifecycle perspective, the actual sustainable performance would be optimized over the long lifecycle of a building in terms of quality specifications of construction products and the value of construction project.

With these elements, the ISCAB framework has been proposed to provide a systematic view on how to manage the construction activities with an integrated consideration of all the elements in a construction supply chain for achieving a more sustainable performance, according to the sustainable construction characteristics.

According to the ISCAB framework, the sustainable impacts along the complete building lifecycle would be fully explained through collaborative working among construction actors within supply chains. The high sustainable benefits would be provided when the lifecycle thinking applied at an early stage of the project (planning phase).

Research question 2: **How does construction industry manage its supply chain? What are the existing practices adopted in managing the construction supply chain?**

Three case studies were conducted in different business culture (Italian case, Brazilian case, and Australian case). Based on the case studies, the construction supply chain processes and their practices have been mapped and explained by the SCOR model.

In Italian case, a general contractor plays an important role in managing an overall construction project and its supply chain. The suppliers are responsible for managing the material flows in isolation under the defined conditions of contract and have little involvement in managing the overall construction processes. Therefore, the success of construction project is that the construction actors perform their works according to the defined plan and the materials flow are managed with the supplier support.

On the other hand, the Brazilian construction industry still performs the project with a traditional procedure; known as labour-based methods. The efficiency of overall construction process depends on productivity of skilled workers. Consequently, construction companies have implemented the advance planning approach and evaluation system in order to improve the overall construction performance.

In Australian case, the construction companies have recognized an importance of managing materials flow for the successful completion of construction projects. Therefore, collaborative working with their supplier is necessary for the adoption of suitable practices for efficiently managing the materials flow.

Research question 3: What is construction industry lacking in managing its supply chain? And how can construction supply chain management be improved towards the achievement of sustainability?

According to the case studies, it has been found that similar performance-related issues have occurred in managing the construction project. To improve a better construction performance, it requires a more collaborative working along the path, an effective communication, and a positive long-term relationship with suppliers and subcontractors. Through the integrated analysis of practices from the literature review and practices from the case studies, the five main supply chain management practices have been defined to support the achievement of sustainability. These five main practices have been proposed for a portfolio of construction supply chain management practices as presented below in Table 7.1.

Table 7.1: Supply chain practices and their contributions for the construction sustainable areas

Practices	Sustainable areas contribution
Adopting sustainable criteria	Energy efficiency Materials selection Resource saving Pollution and waste management Health and wellbeing
Considering the sustainable source availability	Energy efficiency Resource saving
Collaborative working in planning and design	Construction site development Pollution and waste management Service quality Management
Building a positive relationship with all stakeholders	Construction site development Pollution and waste management Management Innovation opportunities
Implementing the management techniques	Resource saving Pollution and waste management Service quality Management

A portfolio of construction supply chain management practices has been developed as a guidance to enhance the overall construction sustainability performance in a long-term perspective. Since each practice has a valid response to some sustainable areas, a set of complementary practices may be required to achieve the sustainability at a large scale. Moreover, these practices can be modified to fulfill the specific project specifications or the new regulation requirements.

7.2 Scientific Implications Of The Thesis

Regarding the scientific implications, this research extends the implementation of supply chain management approach into the construction industry, which is relatively a new focus area of the supply chain management research. In particular, this research is addressed to study how supply chain management can support the sustainability in construction industry.

Firstly, this research defines the ISCAB framework with the main elements that need to be considered in managing the construction supply chains for the sustainable performance along the entire lifecycle of building. These main elements are the role of construction actors and the building lifecycle perspective. An integrated consideration of these main elements provides a systematic management of the whole process of building lifecycle phases through the collaboration among different construction actors and all stakeholders.

Secondly, this research defines the unique characteristics of construction industry, which make the construction supply chain management more complex. These characteristics are described in terms of structural characteristics and managerial characteristics. The structural characteristics include a project-based industry, high fragmentation, and interdependency of all tasks. The managerial characteristics include collaboration between several construction actors, customer-centricity, and high need of information and communication technologies.

Lastly, this research explores the construction supply chain management practices towards sustainable performance, as the supply chain practices related to construction industry have not been defined yet. Through the multiple case studies, a set of appropriate construction supply chain practices is explored in accordance with the main areas of sustainable construction and these practices are considered for developing a portfolio of construction supply chain practices towards sustainability.

7.3 Managerial Implication Of The Thesis

Regarding the managerial implications, this research aims to providing the practical guideline to help construction companies in managing their supply chain towards sustainability in a long-term perspective.

Firstly, this research builds a better understanding on the construction supply chain management. This is because the supply chain management concept is relatively new in the field of construction and practitioners are still inexperienced. Therefore, this research adopts the SCOR model level 1, 2 and 3 to describe the construction supply chain process.

Secondly, this research extends the sustainable thinking throughout the building lifecycle. Currently the purpose of adopting supply chain management practice in construction industry is limited for solving specific performance problems in a short-term perspective, which may not respond to an overall building performance. Based on the lifecycle point of view, highly sustainable construction practices are considered for achieving the complete building performance.

Lastly, this research develops a portfolio of construction supply chain practices towards sustainability based on the ISCAB framework. A set of appropriate construction supply chain practices is explored in accordance with the main areas of sustainable construction and proposed to develop a portfolio of construction supply chain management practices towards sustainability. The portfolio would be used as a guideline to help construction companies in managing their supply chain in a long-term perspective.

The portfolio, developed from the findings of this research, may apply to other construction companies, which have been forced to improve their sustainable performance by the marketing pressure and/or by mandatory requirements of building regulation. The main construction supply chain practices are proposed for a portfolio including adopting sustainable criteria, considering the sustainable source availability, collaborative working for planning and design, building a positive relationship with all stakeholders, and implementing the adequate management techniques. However, each practice can provide a valid response to several sustainable areas. Therefore, a set of complementary practices would be needed in order to gain different areas of sustainable performance.

7.4 Limitations Of The Research Work

This research considers the improvement of construction supply chain management at the beginning phase of building lifecycle towards a long-term sustainable building performance.

The case studies were conducted in specific regional areas of each country: Bergamo in Italy, Porto Alegre in Brazil and Adelaide in Australia. These specific areas may perform construction supply chain management, which is forced by its regional building regulations. Moreover, data and information from interviews are mostly based on the opinions and experiences of the respondents.

7.5 Future Research Directions

Regarding the future research, this topic can be carried out to evaluate each practice in the portfolio in order to seek the most suitable construction supply chain management practices towards each sustainable construction area. The multiple case studies methodology is still the most suitable to conduct this topic.

However, further investigation can separately focus on each type of construction projects including residential buildings, commercial buildings, and infrastructures.

References

ABCB. 2014. National Construction Code: Australian Building Codes Board.

Akbiyikli, R., Eaton, D., & Dikmen, S. U. 2012. Achieving sustainable construction within private finance initiative (PFI) road projects in the UK. ***Technological and Economic Development of Economy***, 18(2): 207-229.

Akintoye, A., McIntosh, G., & Fitzgerald, E. 2000. A survey of supply chain collaboration and management in the UK construction industry. ***European Journal of Purchasing and Supply Management***, 6: 159-168.

Alyami, S. H., & Rezgui, Y. 2012. Sustainable building assessment tool development approach. ***Sustainable Cities and Society***, 5: 52-62.

Bankvall, L., Bygballe, L. E., Dubois, A., & Jahre, M. 2010. Interdependence in supply chains and projects in construction. ***International Journal of Supply Chain Management***, 15(5): 385-393.

Berardi, U. 2012. Sustainability Assessment in the Construction Sector: Rating Systems and Rated Building. ***Sustainable Development***, 20: 411-424.

Bolstorff, P., & Rosenbaum, R. 2003. ***Supply Chain Excellence: A Handbook for Dramatic Improvement Using the SCOR Model***. New York: AMACON.

BPIE. 2011. Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings: Building Performance Institute Europe.

BRE. 2011. BREEAM New Construction: Non-Domestic Building, ***Technical Manual: Version: SD5073***, Vol. 3.0.

Bribián, I. Z., Uson, A. A., & Scarpellini, S. 2009. Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. ***Building and Environment***, 44(12): 2510-2520.

Cao, M., & Zhang, Q. 2010. Supply chain collaborative advantage: A firm's perspective. ***International Journal Production Economics***, 128: 358-367.

Cao, M., & Zhang, Q. 2011. Supply chain collaboration: Impact on collaborative advantage and firm performance. ***Journal of Operations Management***, 29(3): 163-180.

Castro, A. L. d. S., & Benevides, J. R. 2007. ***CAIXA ECONÔMICA FEDERAL – the Brazilian Federal Loan and Saving Bank Promoting Sustainable Urban Development***. Paper presented at the 2nd International Conference on Managing Urban Land, Stuttgart, Germany.

Cavalieri, S., Ierace, S., Pedrali, N., & Teodori, D. 2012. ***Fourth Party Energy Provider for the Building Value Chain***. Paper presented at the Competitive Manufacturing for Innovative Products and Services, Rhodes, Greece.

CIB. 1999. Agenda 21 on sustainable construction. Rotterdam, The Netherlands.

CIB, & UNEP-IETC. 2002. Agenda 21 for Sustainable Construction in Developing Countries. In WSSD (Ed.).

EC. 2003. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. ***Official Journal L1***: 65-71.

EC. 2011. The regulatory system in Italy, avalable at: http://ec.europa.eu/enterprise/sectors/construction/files/compet/national-building-regulations/prc-it_en.pdf (accessed: 20th October 2013).

EC. 2012. Construction sector should seize excellent opportunities of low energy building. Brussels: European Commission.

Ecorys. 2011. FWC Sector Competitiveness Studies N° B1/ENTR/06/054 – Sustainable Competitiveness of the Construction Sector. Rotterdam: European Comission.

Edum-Fotwe, F. T., Thorpe, A., & McCaffer, R. 2001. Information procurement practices of key actors in construction supply chains. ***European Journal of Purchasing and Supply Management***, 7: 155-164.

Eriksson, P. E. 2010. Improving construction supply chain collaboration and performance: a lean constructon pilot project. ***International Journal of Supply Chain Management***, 15(5): 394-403.

EU. 2007. Accelerating the Development of the Sustainable Construction Market in Europe: the Taskforce on Sustainable Construction. Brussels: European Union.

EY, & GBC. 2013. Sustainable Building in Brazil.

GBCA. 2013. Introducing Green Star: Inspiring innovation, Encouraging environmental leadership and Building a sustainable future.

Giang, D. T. H., & Pheng, L. S. 2011. Role of construction in economic development: Review of key concepts in the past 40 years. ***Habitat International***, 35(1): 118-125.

Gusmão, F. a. o. A. d. 2012. RIO+ Report the Brazilian Model: Sustainability Report of the Organization of the United Nations Conference on Sustainable Development. Brasilia.

Haake, H., & Seuring, S. 2009. Sustainable Procurement of Minor Items-Exploring Limits to Sustainability. ***Sustainable Development***, 17(5): 284-294.

Hadaya, P., & Pellerin, R. 2010. Determinants of construction companies' use of web-based interorganizational informantion systems. ***International Journal of Supply Chain Management***, 15(5): 371-384.

Halldórsson, Á., Kotzab, H., & Skjøtt-Larsen, T. 2009. Supply chain management on the crossroad to sustainability: a blessing or a curse. ***Logistics Research***, 1: 83-94.

Hartmann, A., & Caerteling, J. 2010. Subcontractor procurement in construction: the interplay of price and trust. ***International Journal of Supply Chain Management***, 15(5): 354-362.

IEA. 2013. Sustainable Buildings Centre, available at: http://www.sustainablebuildingscentre.org/buildings/labels/Italy/National/non-residential/existing/Energy_Performance_Building_Certificate (accessed: 4th November 2013).

JaGBC/JSBC. 2011. Comprehensive Assessment System for Built Environment Efficiency: CASBEE® ***CASBEE Technical Manuals***. Tokyo, Japan.

Koskela, L. 1992. Application of the new production philosophy to construction. Stanford: Center for Integrated Facility Engineering.

Koskela, L., Owen, B., & Dave, B. 2010. Lean construction, Building information modelling and Sustainability, ***ERACOBUILD WORKSHOP***. Malmo, Sweden.

Krause, D. R., Vachon, S., & Klassen, R. D. 2009. Special topic forum on sustainable supply chain management: Introduction and reflections on the role of purchasing management. ***Journal of Supply Chain Management***, 45(4): 18-25.

Krigsvoll, G., Fumo, M., & Mordiducci, R. 2010. National and International Standardization (International Organization for Standardization and European Committee for Standardization) Relevant for Sustainability in Construction. ***Sustainability***, 2: 3777-3791.

Larsson, N. 2012. User Guide to the SBTool assessment framework: iiSBE.

Linton, J. D., Klassen, R., & Jayaraman, V. 2007. Sustainable supply chains: An introduction. ***Journal of Operations Management***, 25(6): 1075-1082.

London, K. A., & Kenley, R. 2001. An industrial organization economic supply chain approach for the construction industry: a review. ***Construction Management and Economics***, 19: 777-788.

Lönngren, H.-M., Rosenkranz, C., & Kolbe, H. 2010. Aggregated construction supply chains: success factors in implementation of strategic partnerships. ***International Journal of Supply Chain Management***, 15(5): 404-411.

Love, P. E. D., Irani, Z., & Edwards, D. J. 2004. A seamless supply chain management model for construction. ***International Journal of Supply Chain Management***, 9(1): 43-56.

Mao, X., & Zhang, X. 2008. Construction Process Reengineering by Integrating Lean Principles and Computer Simulation Techniques. ***Journal of Construction Engineering and Management***, 134(5): 371-381.

McGraw-Hill. 2006. ***Green builidng smart market report: Design & construction intelligence***. New York.

Mudgal, S., Lyons, L., & Cohen, F. 2013. Energy performance certificates in building and their impact on transaction prices and rents in selected EU countries.

Nwokoro, I., & Onukwube, H. 2011. Sustainable or Green Construction in Lagos, Nigeria: Principles, Attributes and Framework. ***Journal of Sustainable Development***, 4(4): 166-174.

Ofori, G. 2000. Greening the construction supply chain in Singapore. ***European Journal of Purchasing and Supply Management***, 6(3-4): 195-206.

Ortiz, O., Castells, F., & Sonnemann, G. 2009. Sustainability in the construction industry: A review of recent developments based on LCA. ***Construction and Building Materials***, 23(1): 28-39.

Palaneeswaran, E., Kumaraswamy, M., Rahman, M., & Ng, T. 2003. Curing congenital construction industry disorders through relationally integrated supply chains. ***Building and Environment***, 38(4): 571-582.

Pan, N.-H., Lin, Y.-Y., & Pan, N.-F. 2010. Enhancing construction project supply chains and performance evaluation methods: a case study of a bridge construction project. ***Canadian Journal of Civil Engineering***, 37: 1094-1106.

Rademaekers, K., Zaki, S. S., & Smith, M. 2011. Sustainable Industry: Going for Growth and Resource Efficiency: European Commission: Enterprise and Industry.

Reed, R., Bilos, A., Wilkinson, S., & Schulte, K.-W. 2009. International Comparison of Sustainable Rating Tools. ***Journal of Sustainable Real Estate***, 1(1): 1-22.

Robichaud, L. B., & Anantatmula, V. S. 2011. Greening Project Management Practices for Sustainable Construction. ***Journal of Management In Engineering***, 27(1): 48-57.

Saad, M., Jones, M., & James, P. 2002. A review of the progress towards the adoption of supply chain management (SCM) relationships in construction. ***European Journal of Purchasing and Supply Management*** 8(3): 173-183.

Sacks, R., Koskela, L., Dave, B. A., & Owen, R. 2010. Interaction of Lean and Building Information Modeling in Construction. ***Journal of Construction Engineering and Management***, 136(9): 968-980.

Sacks, R., Treckmann, M., & Rozenfeld, O. 2009. Visualization of Work Flow to Support Lean Construction. ***Journal of Construction Engineering and Management***, 135(12): 1307-1315.

Salem, O., Solomon, J., Genaidy, A., & Minkarah, I. 2006. Lean Construction: From Theory to Implementation. ***Journal of Management In Engineering***, 22(4): 168-175.

SCC. 2010. Supply Chain Operations Reference (SCOR) model Overview - Version 10.0. Cypress, TX: Supply Chain Concil.

Segerstedt, A., & Olofsson, T. 2010. Supply chains in the construction industry. ***International Journal of Supply Chain Management***, 15(5): 347-353.

Seuring, S., & Muller, M. 2008. From a literature review to a conceptual framework for sustainable supply chain management. ***Journal of Cleaner Production***, 16(15): 1699-1710.

Sev, A. 2009. How can the construction industry contribute to sustainable development? A conceptual Framework. ***Sustainable Development***, 17: 161-173.

So, S., Parker, D., & Xu, H. 2012. ***A conceptual framework for adopting sustainability in the supply chain***. Paper presented at the the 10th ANZAM Operations, Supply Chain and Services Management Symposium, Melbourne, VIC, Australia.

Störmer, E. 2008. Greening as strategic development in industrial change - Why companies participate in eco-network. ***Geoforum***, 39: 32-47.

Thunberg, M., & Persson, F. 2013. Using the SCOR model's performance measurements to improve construction logistics. ***Production Planning and Control***: 1-14.

Tubelo, R. C. S., Rodrigues, L., & Gillott, M. 2013. ***A Parallel between the Brazilian Energy Labelling System and the Passivhaus Standard for Housing***. Paper presented at the PLEA2013 - 29th Conference, Sustainable Architecture for a Renewable Future, Munich, Germany.

UN. 1987. Our Common Future, From One Earth to One World. Oslo: the World Commission on Environment and Development.

UN. 2007. Industrial Development for the 21st Century: Sustainable Development Perspectives. New York: Department of Economic and Social Affairs.

UN. 2011. UNIDO Green Industry Initiative for Sustainable Industrial Development: United Nations Industrial Development Organization.

UN. 2013. World Population Prospecs: The 2012 Revision, Vol. 1. New York.

UN-HABITAT. 2003. The Habitat Agenda Goals and Principles, Commitments and the Global Plan of Action.

UNDP. 2012. Triple wins for sustainable development: Case studies of sustainable development in practice. New York: United Nations Development Programme.

UNEP. 1992. Promoting Sustainable Human Settlement Development, ***Human Settlement***: United Nations Environment Programme: environment for development.

UNEP. 2009. Buildings and Climate Change : Summary for Decision-Makers. Paris: Sustainable Building & Climate Initiative.

USGBC. 2002. Green Building Rating System For New Construction and Major Renovations (LEED-NC) Version 2.1, ***LEED: Leadership in Energy & Environment Design***: U.S. Green Building Council.

USGBC. 2003. Building momentum: National trends and prospects for high-performance green buildings. Washington D.C.: the U.S. Senate Committee on Environment and Public Works.

Vanzolini. 2013. Processo AQUA: Alta Qualidade Ambiental, available at: http://www.vanzolini.org.br/conteudo_104.asp?cod_site=104&id_menu=758 (accesses: 25th January 2014).

Verbeeck, G., & Hens, H. 2010. Life cycle inventory of buildings: A contribution analysis. ***Building and Environment***, 45: 964-967.

Vidalakis, C., Tookey, J. E., & Sommerville, J. 2011. Logistics simulation modelling across construction supply chains. ***Construction Innovation***, 11(2): 212-228.

Violano, A., & Verde, F. 2013. Protocol ITACA: A Decision Tool for an Energetically Efficient Building Management. ***Multicriteria and Multiagent Decision Making with Applications to Economics and Social Sciences Studies in Fuzziness and Soft Computing***, 305: 289-299.

Vrijhoef, R., & Koskela, L. 1999. ***Roles of supply chain management in construction***. Paper presented at the IGLC-7, Berkeley, CA, USA.

Vrijhoef, R., & Koskela, L. 2000. The four roles of supply chain management in construction. ***European Journal of Purchasing and Supply Management***, 6(3-4): 169-178.

Warnock, A. C. 2007. An overview of integrating instruments to achieve sustainable construction and buildings. ***International Journal of Management of Environmental Quality***, 18(4): 427-441.

Watermeyer, R. 2002. Sustainable construction: Looking ahead to the World Summit on Sustainable Development, ***Civil Engineering: Magazine of the South African Institution of Civil Engineering***, Vol. 10: 5-9.

Xue, X., Li, X., Shen, Q., & Wang, Y. 2005. An agent-based framework for supply chain coordination in construction. ***Automation in Construction***, 14: 413-430.

Yin, R. K. 2003. ***Case Study Research: Design and Methods*** (3 rd ed.). Thousand Oaks, CA: Sage Publications.

Zhou, H., Benton, W. C., Schilling, D. A., & W.Milligan, G. 2011. Supply Chain Integration and the SCOR Model. ***Journal of Business Logistics***, 32(4): 332-344.

Annexure

This research has been presented in several events including the doctoral workshops, research seminars, summer schools and international scientific conference as:

Date	Descriptions
December 10-13, 2013	IEEE International Conference on Industry Engineering and Engineering Management (Bangkok, Thailand)
December 4, 2013	Research seminar at School of Management, University of South Australia (Adelaide, Australia)
November 18, 2013	Research seminars at NORIE, Federal University of Rio Grande do Sul (Porto Alegre, Brazil)
July 29-30, 2013	The IGLC Industry Day about Lean Construction implementation to industry practitioners (Fortaleza, Brazil)
July 31- August 2, 2013	IGLC21: the 21st International Group for Lean Construction (Fortaleza, Brazil)
June 9-12, 2013	20th EurOMA Conference: Operations Management at the Heart of the Recovery (Dublin, Ireland)
June 8, 2013	6th EurOMA workshop on Journal Publishing in Operations Management (Dublin, Ireland)
September 24-26, 2012	International Conference on Advances in Production: APMS 2012 (Rhodes, Greece)
September 22-23, 2012	PhD Doctoral Workshop: APMS 2012 (Rhodes, Greece)
September 12-14, 2012	PhD Summer School - XVII Summer School "Francesco Turco"Ed (Venice, Italy)
June-July 2011	PhD Summer Academy at MIT-Zaragoza Logistics Center (Zaragoza, Spain)

Visiting academic period:

Date	Description
July 2011-January 2013	MIT-Zaragoza Logistics Centre, Spain
November 11-20, 2013	NORIE research centre, Universidade Federal do Rio Grande do Sul, Brazil
November 25-December 10, 2013	School of Business, University of South Australia, Australia

The list of publications

Jaenglom, K., Cavalieri, S., Pinto, R. & Ierace, S. (2013), "*An Overview of Supply Chain Management Practices for Sustainable Construction*", Proceedings of the 20th EurOMA 2013 Conference, Dublin, Ireland

Jaenglom, K. and Tariq, Z. (2013), "*The Role of Purchasing Management Towards Sustainable Supply Chain: A Life Cycle Perspective*", Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bangkok, Thailand