Exploring pathways for improving the Supply Chain Integration of Infrastructure Projects

by

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Thesis submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy in Engineering

University of Warwick, Warwick Manufacturing Group

September 2022

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Acknowledgements

First, I am deeply grateful to my supervisors, Professor Janet Godsell and Professor Naomi Brookes. Without your involvement in providing not only guidance, but also kindness, this research project would not have been completed. I would like to acknowledge that I am exceptionally grateful to Professor Janet Godsell for recognising my potential and standing by me even if my behaviour has been odd at times.

Second, I would like to express my gratitude to several members of the department for providing opportunities to be part of the larger WMG team and mentoring me. In particular, to Dr. Adrian Watt for providing the opportunity to be a seminar demonstrator on the module Operations Strategy; I am grateful for this valuable teaching experience. Also to Katy Angliss, who I collaborated with in developing a chapter for a textbook.

I would also like to thank the members of the supply chain research group in WMG. Our discussions have been of great benefit to my project and to me personally. Some fellow PhD students started their journey a few years ahead of me and have been highly supportive with their research insight. At the same time, I have played a similar role in supporting students that started after me. I will miss our monthly meetings and the collaborative spirit.

Furthermore, I am very grateful to the anonymous participants of this study. Their participation involved a lot of time and effort and was integral to the completion of this research project.

Finally, this work would not have been possible without the understanding and support of my family. Thank you for your care, patience and support in going through the ups and downs over the past few years. I am thankful for the upbringing that provided me with the values of discipline, courage and pioneering spirit, invaluable on this journey.

Declaration

I confirm that this thesis is my own work. The book chapter declared under the heading ‘Publications’ has been wholly written by myself. Co-authors of these publications acted in advisory or assisting roles.

While insights published in the following book chapter informed sections of this thesis, any specific material contained in the thesis is published prior to the publication of the following book chapter:

Aleksandar Nikolov and Pete Harpum (2023) Chapter 21: Supply Chain Integration and Portfolio Management in Kate Angliss and Pete Harpum *“Strategic Portfolio Management in the Multi-Project and Program Organisation”*, Oxon, Routledge.

I confirm that this thesis has not been submitted for a degree at another university.

Publications

Aspects of this research project have previously been published. In chronological order, the rationale underpinning the introductory chapter was synthesised from:

Aleksandar Nikolov and Pete Harpum (2023) Chapter 21: Supply Chain Integration and Portfolio Management in Kate Angliss and Pete Harpum '*Strategic Portfolio Management in the Multi-Project and Program Organisation*', Oxon, Routledge.

Parts of the literature review chapter and the purpose of this study, have benefitted from:

Nikolov, A. (2019) Improving the efficiency and effectiveness of infrastructure projects: towards a new frontier. Published in Proceedings of the 26th Annual EurOMA Doctoral Seminar, Helsinki, Finland, 15-19 June 2019.

Finally, a journal article based on the research of this thesis has been submitted to the journal of Construction Management and Economics by Aleksandar Nikolov, Jan Godsell and Donato Masi in January 2021. Since May 2021, the article is under the status of 'major revisions'.

Abstract

Supply chain integration (SCI) has been proposed as one mechanism through which customer, main contractor and suppliers' interests may be aligned in construction. This study aims at depicting how SCI can be improved in construction. Specifically, the study explores the practices underpinning SCI, the pathways that focus integration efforts and the expected outcomes from SCI, positioning SCI as a key enabler towards value realisation in construction supply chains (SCs).

Achieving integration is particularly challenging for a construction SC, characterised by non-repetitive projects. In the light of this challenge, several studies suggest specific practices and pathways for the achievement of higher levels of integration in construction. A comprehensive framework creating a synthesis of the different practices and pathways towards improving SCI in the construction sector has yet to be developed and validated. The lack of a systematic view in the application of SCI in construction has impeded the diffusion of a value-driven approach in construction projects and delayed the transition to an integrated SC. The study explores the effects of four integration pathways (actors, flows, processes and technologies) to identify the pathways of actors and flows as value-driving to improved SCI in construction. These pathways are supplemented by practices focused primarily on improving the relational integration between SC actors. In addition, the study identifies the role of the pathway of integrating processes and activities in various construction projects towards a set of outcomes realising value in construction projects.

This thesis adopts a two-phase research design. Phase 1 applies a Systematic Literature Review (SLR) method towards synthesis in a conceptual framework for improving SCI in construction. Phase 2 applies a Delphi method towards building a systematic empirical investigation of the conceptual framework using qualitative and quantitative enquiry. This choice of methodology is suitable both for theory conceptualisation in a nascent stage, as is the case for this study, and theory building and testing. The Delphi method leads to a more complete and comprehensive understanding of the phenomenon investigated and its practical adoption in industry.

The study extends current knowledge by developing a conceptual framework for improving SCI in construction. Knowledge from the quantitative Delphi investigation reveals the relationships between practices, pathways and the resultant outcomes. The novelty of this study is in demonstrating SCI as key enabler to value realisation. Several avenues for future research emerge from these contributions.

Keywords: supply chain integration; construction; systematic literature review; Delphi study

List of Abbreviations

ABS	Association of Business Schools
AMP	Asset management period
APMO	Average percent of majority opinions
B	Behaviour of SC actors
BIM	Building Information Modelling
C	Communication
CAGR	Compound annual growth rate
CDM	Coordinated Decision Making
CE	Construction excellence contract
CF	Conceptual Framework
CI	Customer involvement
CM	Commitment
CMC	Construction management contract
CR	Critical realism
CSB	Configuration of supply base
CSCMP	Council of supply chain management professionals
CTSV	Compete through superior underlying value
CV	Coefficient of variation
DA	Developmental activities

DB	Design and build contract
DCV	Defining client values
DCI	Develop continuous improvement
EI	Early Contractor Involvement
ESR	Establish supplier relationships
FA	Framework agreement
FEL	Front-end loading
GDP	Gross domestic product
ICC	Intraclass correlation coefficient
IDN	Interdependent networks
IPA	Integrated project activities
IPD	Integrated project delivery
IQR	Interquartile range
IS	Information Systems
IT	Information technology
JOP	Joint operational planning
JSP	Joint strategic planning
JWP	Joint work processes
LR	Length of relationship over series of projects
LTO	Long-term orientation

MCC	Manage costs collaboratively
MDP	Mobilise and develop people
MEICA	Mechanical Electrical Instrumentation Control and Automation
O&SCM	Operations and supply chain management
PIL	Participant information leaflet
PP	Power position of firm in the SC
PRISM	Preferred reporting items for systematic reviews and meta-analyses
RQ	Research question
RS	Resource sharing
SC	Supply chain
SCI	Supply chain integration
SCM	Supply chain management
SJR	Scimago journal ranking
SLR	Systematic literature review
SME	Small and medium-sized enterprise
ST	Use of supporting technology
T	Trust
TI	Timing of involvement in a single project
TMC	Top management commitment
TSI	Types of SC interdependencies

Chapter 1 : Introduction

1.1 Chapter Introduction

Following this introductory section, this chapter is divided into two subsections: 1.2 'Background of the Study' providing the background knowledge to position the study and 1.3 'Thesis Route Map' outlying the steps that frame this thesis. Finally, Section 1.4 concludes and presents a summary of the chapter. The structure of this chapter is illustrated in Figure 1.1.

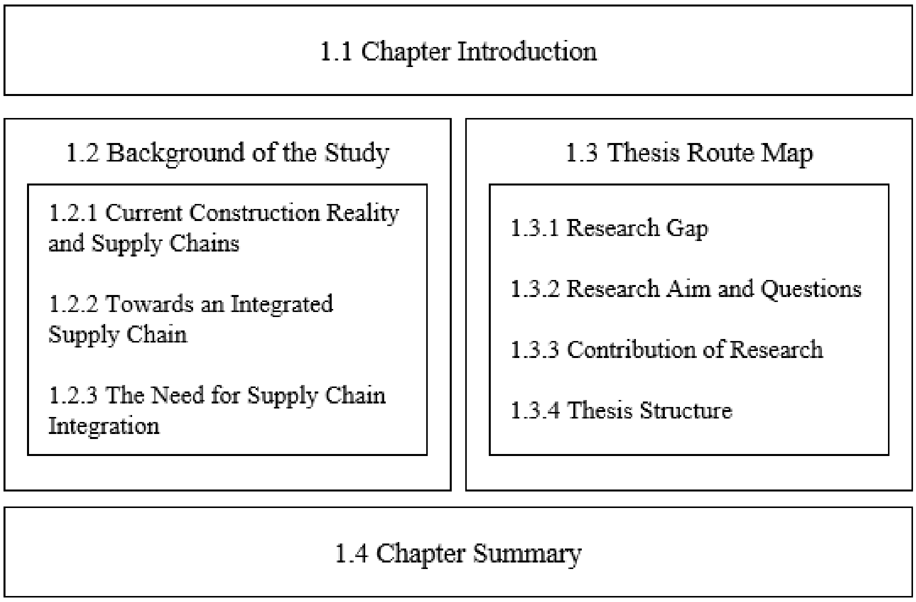

Figure 1-1: Structure of Chapter 1

1.2 Background of the Study

This section presents the background and context of this study. It starts with a backdrop to the study, depicting current construction reality and approaches in supply chain management (SCM) (see Section 1.2.1). Section 1.2.2 presents a practical approach to improved value in construction, setting the stage for improving supply chain integration (SCI). This is followed by Section 1.2.3 focusing in further detail on the need for SCI in construction.

1.2.1 Current Construction Reality and SCs

The construction industry encompasses the planning, design, manufacture, regulation, construction and maintenance of buildings and infrastructure (Cox and Ireland, 2002). On a global scale, construction output in 2020 was 10.7 trillion USD with projection for growth by 42% or 4.5 trillion USD between 2020 and 2030 (Oxford Economics, 2021). Putting this data into perspective, spending on construction accounted for 13% of global gross domestic product (GDP) in 2020 and is expected to reach over 13.5% in 2030. The global construction industry is set to be one of the engines for economic growth and recovery following COVID-19.

Out of the different types of construction, infrastructure is forecasted to be the fastest growth sector over the period to 2030. An annual average growth of 5.1% is expected globally for infrastructure construction output during the period from 2020 to 2025. The major drivers of this growth are unprecedented levels of government stimulus and the acceleration of pipelines of global mega infrastructure projects. Readiness of existing pipelines of infrastructure projects is a key condition enabling this acceleration. As highlighted in the ‘Future of construction’ 2021 report, the UK and Australia are well positioned to accelerate infrastructure development amongst the top 10 global construction markets (see Figure 1-2).

Focusing on the UK infrastructure sector, between 2016 and 2021, the UK government committed to investing £100 billion in the refurbishment of roads, airports, railways, and utilities infrastructure (HM Infrastructure and Projects Authority, 2016). Overall, the pipeline for construction of public infrastructure projects is strong and the industry is projected to grow by 70% by 2025 (HM Government, 2013). Given that there is strong pipeline of demand for construction projects, large infrastructure clients (e.g., roads, water, electricity, and other utility companies) can shape their strategic planning processes in order to unlock better effectiveness and efficiency in projects’ delivery.

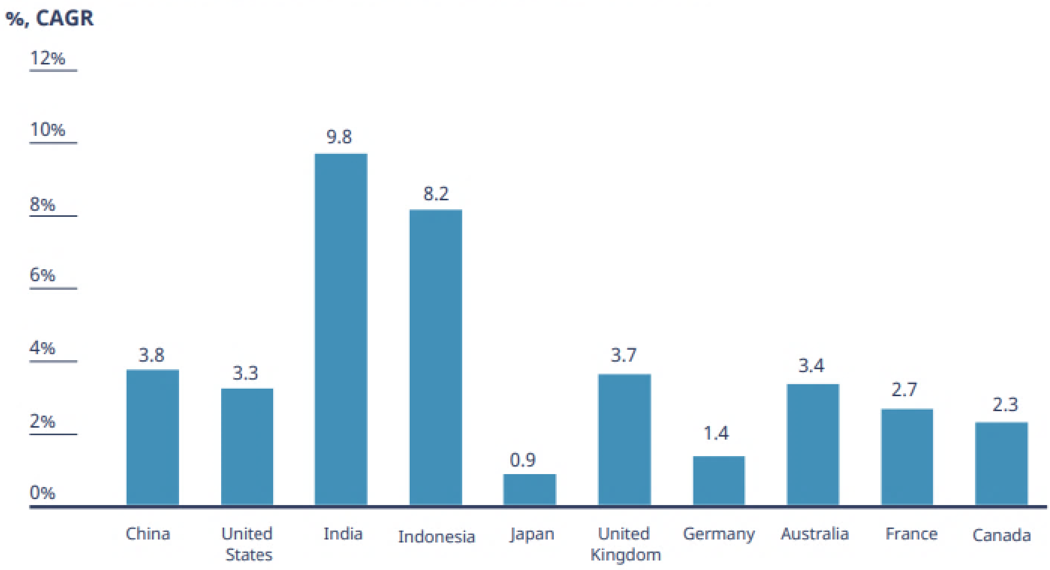

Figure 1-2: Growth in infrastructure construction by country (2020-2030) (Source: Oxford Economics, 2021)

In reality, the demand for construction work can show considerable variation due to both the frequency (intermittence) and size (lumpiness) of projects in a pipeline (Godsell et al., 2018). This creates a ‘project-uniqueness bias’, making projects appear both unpredictable and non-repeatable while high commonality in requirements may exist between them. For example, a study of a portfolio of projects in a large water utility company in the UK, found that 49 projects in a 5-year AMP (Asset Management Period) of 110 projects are both predictable and repeatable (Godsell et al., 2018). In other words, a considerable share of projects can be planned with a high degree of certainty ahead of the start date and generally follow the same design, use the same (or similar) materials, resources and equipment, and are implemented according to a similar plan. In this context, some main contractors are developing a strategic orientation towards establishing long-term partnerships with their customers with the intention of growing their revenue and improving productivity (Dainty et al., 2001b; Humphreys et al., 2003; Bygballe et al., 2010; Hartmann and Caerteling, 2010; Tang et al., 2010; Gottlieb et al., 2020). However, such partnerships often neglect subcontractors (Miller et al., 2002; Bygballe et al., 2010) and do not ‘consider the structural, economic and organisational nature of the industry’s supply chains (SCs) in order to develop a better appreciation of the role of subcontractors’ (Ross, 2011, p.6). Not accounting for the possible efficiencies locked in SCM and adopting a 'project-uniqueness bias', main contractors often create a new SC for each project, predominantly focused on low-cost delivery. Despite the efforts of cost minimisation, infrastructure projects consistently overrun in terms of cost and time (Olawale and Sun, 2010). This thesis investigates this phenomenon in more detail, as this suggests that there are large losses of value in construction SCs.

The inter-organisational issues with construction SCs are not new. Since the end of the 1980s, the industry has gone through the launch of a number of 'scattered and partial' SCM initiatives (Vrijhoef and Koskela, 2000). Contributing factors to unsatisfactory performance in projects include lack of demand visibility, late involvement of contractors and suppliers, design changes, risk transfer upstream, adversarial relationships, lack of trust, and reliance on a large, fragmented supply base of Small- and Medium-Sized Enterprises (SMEs) (Ireland, 2004; Bankvall et al., 2010; Hartmann and Caerteling, 2010; Polat et al., 2014). Such factors lead to disjointed efforts and the creation of a new SC for each project, which in turn results in short-term, discontinuous inter-firm relationships (Dainty et al., 2001a; Briscoe and Dainty, 2005).

Currently the construction pipeline of infrastructure projects in the UK is strong. In this context, the necessary conditions for developing improved effectiveness and efficiency in delivery start with the customer's strategic planning processes. Some main contractors focus on establishing long-term partnerships downstream with the customer; however, relationships upstream with subcontractors and suppliers are short-term and discontinuous. Main contractors often assemble a new SC for each project based predominantly on low-cost criteria, nevertheless construction projects consistently overrun in cost and time. This points to large losses of value in the construction sector and calls for introducing alternative approaches to SCM.

Considering the bigger picture, the construction industry appears as a prime example of an industry suffering from misalignment between the different SC actors involved. Following a 'value chain' paradigm, the sector exhibits poor value identification and realisation. The value chain paradigm is essentially a stylised synopsis that borrows terminology from the discipline of 'systems thinking' (Checkland, 1981). 'A value system comprises people making judgements about best value and value for money. A value system is a complex, organised whole existing in an environment, and is delineated from other value systems by boundary. It is structured hierarchically and has a common purpose and objectives that can, at times, be in conflict when judging best value and value for money' (Male, 2002, p.13). In a more general sense, a value chain is often viewed as a set of activities that firms operating in a specific industry perform, in order to deliver a valuable product to the end customer. To focus this study further, given its construction context, value is practically defined here as 'how well owners' objectives are met' in projects, programmes or sub-portfolios.

To summarise, construction output in the UK is more than £110 billion per annum and contributes 7% of GDP. Between 2016 and 2021, the UK government committed to investing £100 billion in public infrastructure, in the refurbishment of roads, airports, railways, and utilities infrastructure (HM Infrastructure and Projects Authority, 2016). Construction of public infrastructure is a high-profile sector that can benefit from new approaches to SCM, aimed at better value identification and realisation.

1.2.2 Towards an Integrated SC

The perception of the construction industry's large-scale inefficiencies has long been recognised (Latham, 1994; Egan, 1998; Murray and Langford, 2003). The need for change in the industry has been addressed in various ways and by a multitude of agents, including policy-makers (Egan, 1998; Fairclough, 2002; Wolstenholme et al., 2009; Innovation Growth Team, 2010; UK Cabinet Office, 2011), research funding bodies, industry change agents and academic research. Despite the various change agents, the literature highlights the disparity between stakeholders with institutional power to fund, promote and explore change, and stakeholders with power to introduce widespread sustainable change. Nevertheless, the prevailing perception is that SCM is a robust, relevant and reliable approach to deliver widespread efficiencies in construction, but to this point remains not fully embraced and underexplored (Fernie and Tennant, 2013).

Taking a closer view of the different approaches to improved effectiveness and efficiency in construction, many studies diverge in how this is addressed. Such has been investigated from a variety of angles including lean construction (Lönngren et al., 2010) and integrated project delivery (IPD) models (Mesa et al., 2016). Typical SCM activities and approaches applied through several layers of the supply chain, include formal partnering arrangements, information and risk sharing, sharing of specialist expertise in production and manufacturing with less technically advanced members of the SC, implementing total quality management (TQM) philosophies, and the now ubiquitous just-in-time logistical delivery approach to eliminate inventory standing in stock (Nikolov and Harpum, 2022). The effect of SCI on performance through the lens of achieved outcomes has been continuously recognised in the literature (Wheelwright and Clark, 1992; O'Leary-Kelly and Flores, 2002; Flynn et al., 2010; Stock et al., 2010; Terjesen et al., 2012; Huang et al., 2014; Mackelprang et al., 2014; White and Marasini, 2014; Broft et al., 2016; Keung and Shen, 2017). As pointed out by Huang *et al.* (2014, p.65) 'The analysis of the outcome of an integrated supply chain constitutes a significant research opportunity in supply chain and organisational management'. Overall, while there are numerous approaches available in the literature and in practice to improved efficiency and effectiveness in construction project delivery, such are often viewed in isolation. There is a lack of a critical view of the different project characteristics and what such could mean for taking a differentiated approach when applying SCI. As recognised by Nikolov and Harpum (2022) demand profiling allows SCI to be carried out more effectively, with specific approaches applied to the different demand profiles of projects.

As outlined in the first section, improved effectiveness and efficiency in construction requires a value-driven approach across all involved stakeholders in the SC (customer, main contractor and subcontractors, and suppliers). This approach can be simply described through taking an end-to-end SC view focusing on two perspectives, value identification and value realisation.

Starting with the customer and given the strong construction pipeline, the strategic planning process can utilise value identification techniques in the portfolio of infrastructure projects. This involves identifying the type of projects in a portfolio (routine or innovative) and their SC characteristics (predictability, repeatability, and budget size). This can result in formulating demand profiles (of projects) that enable ‘economies of repetition’ through execution of routine, highly repeatable projects. The supplying organisations (i.e., main contractor and subcontractors) can deliver a series of similar projects at lower cost and more effectively, taking advantage of the learning opportunities that this offers (Davies and Brady, 2000). Furthermore, the strategic planning process is based on the notion that ‘innovative’ projects are not entirely unique in their scope. Instead, they utilise elements of familiar projects, including engineering design and planning expertise, equipment, labour and raw material or prefabricated components. Utilising the strategic planning process further, ‘economies of repetition’ developed through routine projects can be leveraged in order to foster greater efficiency in delivery of innovative projects through ‘economies of recombination’ (Grabher, 2004). The supplying organisations can recombine familiar elements for work packages of both large and non-repeatable, ‘innovative’ projects. This perspective exemplifies that value improvement starts with value identification from the client organisation through to strategic planning. The strategic planning process establishes the necessary conditions for the main contractor and supplying organisations to improve the effectiveness and efficiency of project delivery.

With the necessary conditions in place for achieving higher levels of effectiveness and efficiency, the supplying organisations require an SC approach that enables realisation of this potential value. A salient approach suggested by researchers and practitioners, that stands out from the rest, is upgrading SCM in construction by borrowing practices from manufacturing (e.g. Egan, 1998; Vrijhoef and Koskela, 2000; Changali et al., 2016; Kim and Nguyen, 2018). Among these practices, SCI is emerging as one of the most promising approaches (Dainty et al., 2001a; Briscoe and Dainty, 2005; Vrijhoef, 2011; Godsell et al., 2018), due to its focus on the creation of systemic production channels (Power, 2005; Bankvall et al., 2010) and the continuous involvement of the different actors in the construction processes (Briscoe et al., 2004). SCI is formally defined as ‘the extent to which an organization manages its intra- and inter-organizational processes to achieve effective and efficient flows of products, services, information, money and decisions with the objective of providing maximum value to its customers’ (Frohlich and Westbrook, 2001; Bowersox et al., 2002; Bakker et al., 2012, p.2). In practice, instead of creating a new SC for individual projects, SCI aims at developing systematic production channels of integrated construction organisations best able to realise the value from demand profiles (of projects) as identified through the strategic planning process. Demand profiling in its core is the ability to recognise and cluster the different demand characteristics of individual stock keeping units (Godsell et al., 2011). Applied to project-based context, demand profiling aims at clustering projects according to project characteristics of predictability, repeatability and budget size. These three characteristics are explained as follows following Godesell et al., 2018, p.1439. Repeatability is 'a measure of whether the project of a specific type generally follow the same design, use the same (or similar) materials, resources and equipment, and are implemented according to a similar plan'. Predictability is a 'measure of whether the projects are planned well in advance with high degree of certainty, vs being scheduled on ad hoc basis'. Lastly, budget is a measure of 'the budget allocated to the project, and cut-off points should be based on the individual history and context of the particular origanisation'. This forms strategic planning based on clusters of projects, which in turn results in the necessary conditions for improved effectiveness and efficiency in execution. SCI in turn, as demonstrated in this thesis through practices, pathways and outcomes, is a key enabler for realising the potential value from demand profiling towards achieving the desired effectiveness and efficiency in execution. For example, clustering highly repeatable and predictable projects into programmes of repeatable projects can facilitate an integrated unit of SC actors to develop continuous recurring flows of information, materials and finance. As presented in this thesis, actors and flows are key pathways of SCI, enabling improved efficiency and effectiveness in project delivery.

1.2.3 The Need for Supply Chain Integration

Traditional SCM focuses on its supporting functional role in delivering construction projects, driven by their individual requirements. This approach is reactive in nature to the stream of projects coming out of the portfolio pipeline. Taking account of the need to realise effectiveness and efficiency from a project portfolio (e.g., AMP), SCM requires a different approach, one that is proactive in pursuing the client's strategic objectives. In the UK, infrastructure projects are planned through 5-year periods, comprising portfolios of projects. For example, in the water sector these 5-year periods are called the AMP (Asset Management Plan) periods. In this context, the role of SCI is not to create a number of supply chains for each project thus increasing complexity, but instead to integrate these supply chains towards value realisation. Instead of individual project requirements, SCI uses demand profiling to integrate requirements, setting up the necessary conditions for improved effectiveness and efficiency of delivery. The strategic planning process of the client organisation develops patterns in the project portfolio (i.e. based on predictability and repeatability) and SCI enables the embedded efficiency and effectiveness in realising value from such patterns. Taking an SCI approach allows pursuing the strategic objectives of the client organisation proactively, as SC partners are already positioned in production channels, to realise value continuously as demand comes through. The role of SCI as an overarching goal of SCM (e.g. Broft et al., 2016; Pillay and Mafini, 2017) in construction is suggested as a way of improving alignment between clients' strategic objectives and the supplying organisations. In addition, as SC actors integrate, they develop objectives between themselves resulting in outcomes such as, but not limited to, increased production volume, secure and stable demand for future project work and development of new project competencies. In this way, partners can collectively develop improved value realisation for the client organisation as well as generate profit based on their individual specialisation and value drivers. This approach enables the role of SCI as an antidote to fragmentation (e.g. Papadonikolaki and Wamelink, 2017) as partners develop an active interest in both individual commercial and joint performance aspects. Developing joint practical understanding of the interdependence actors share in project performance is critical for the success of SCI. Inability to meet performance criteria on projects in a demand profile can lead to missed strategic objectives for the client organisation. This in turn results in a strategic planning process unable to aggregate value based on 'economies of repetition' and 'economies of recombination'. Underperformance inhibits creation of value from strategic planning, detaches SC actors from the overriding strategic planning process and creates demand for small in size, dispersed work packages suitable for execution by a limited number of individual SC actors. In such instances, actors are unable to aggregate demand and develop production flows, and instead bid on multiple criteria associated with individual work packages that may not necessarily be aligned with their value drivers. The outcome is disintegration of actors from the strategic planning process and loss of commercial position. It is thus in the best interest of involved SC organisations to develop SCI.

Overall, the construction industry exhibits symptoms of a disjointed end-to-end value chain with various types of construction organisations acting in isolation from one another. Against this backdrop, large construction customers desire a 'value for money' approach, given the presence of strong pipelines of projects and responsibility towards the spending of public money. Nevertheless, main contractors find aggregating value challenging, as they often assemble a new SC for individual projects with a predominantly low-cost focus. In addition, main contractors often apply commercial pressure, regardless of suppliers' and subcontractors' good performance. This limits productivity, as relationships with subcontractors and suppliers are short-term and discontinuous, leading to numerous SCs not capable of maximising value realisation. Against these realities, SCI emerges as an alternative approach to construction SCM, aimed at continuous involvement of the different construction actors and creation of systemic production channels. This thesis connects to the emerging developments of industrial practice in applying SCI in construction and specifically how SCI can be improved in construction.

1.3 Thesis Route Map

This section presents the main steps taken in developing this thesis. The first step comprises positioning the research in light of the research gap identified (see Section 1.3.1). This is followed by a second step, Section 1.3.2 'Research aim' which outlines the aim and overarching research questions (RQs) of the thesis. As a third step, Section 1.3.3 'Contribution of research' presents the ways in which this thesis is set to make contributions to academia and practice. Finally, as the last step Section 1.3.4 'Thesis structure' presents the overall structure of the thesis.

1.3.1 Research Gap

SCI has been recognised since 1989 (Stevens, 1989), but its potential has not been fully realised in construction (Lönngren et al., 2010; Tang et al., 2010; Mesa et al., 2016; Costa et al., 2019). Many studies explore the term generally, or through comparison with other industries, but few investigate how it applies to the construction sector (Bankvall et al., 2010; Cheng et al., 2010). In addition, there are conceptual imprecisions in SCM research regarding constructs such as coordination, cooperation, collaboration and integration. The differences between these terms are clarified by Autry et al. (2014), indicating SCI as encompassing the other terms and possessing the highest value-creation potential. With its encompassing nature, SCI involves considerable complexity in its conceptualisation. This highlights the need for developing a higher level of reliability in this study, through an in-depth systematic review and synthesis of how SCI is operationalised in a project-based construction context.

Recent research on SCI in construction is in a relatively nascent stage and divergent. Studies explore SCI as part of collaboration efforts (London and Pablo, 2017), cooperation (Fu et al., 2015) or as the focus of partnership arrangements (Venselaar and Gruis, 2016; Gottlieb et al., 2020; Le et al., 2021). In addition, what constitutes integration is primarily addressed through informational integration (Khan et al., 2016; Pala et al., 2016; Robson et al., 2016), and relational integration and outcomes enabled by the integrated network of actors (Keung and Shen, 2017; Pryke et al., 2017; Loosemore et al., 2020). The formation of identity and the role actors play in integration has also gained significant momentum in recent research (Hietajärvi and Aaltonen, 2018; Kabiri and Hughes, 2018). Lastly, the concept of flows in construction continues to be investigated (Sacks, 2016; Andalib et al., 2018), as illustrated by Carillion’s recent example of how mismanagement of such can lead to catastrophic outcomes (Hajikazemi et al., 2020).

This study identifies a knowledge gap in exploring project-based SCI in construction and addresses this by synthesising and building onto what is currently known in the literature through a systematic literature review (SLR). Following Harty and Leiringer (2017) this study addresses the need for convergence in construction management research to arrive at a holistic SCI framework.

SCI is an established concept in a manufacturing context, and several studies analysed it both theoretically and empirically, with a focus on the definition and measurement of SCI (Frohlich and Westbrook, 2001; Childerhouse and Towill, 2003; Kim, 2013). However, the concept has not been reviewed in depth, systematically and holistically in terms of its application in the construction context. A detailed review of the concept is conducted in this study through three emerging crucial areas: the pathways leading to improved SCI, the practices that frame SCI efforts and the outcomes that can be achieved in construction, as a result of improved SCI. These three areas of SCI are reviewed in turn in relation to how they are positioned as a knowledge gap in existing research.

First, as a transitive verb, integration requires a clear focus on what is being integrated. Fabbe-Costes and Jahre (2007) define SCI based on the layers that managers can consider for higher levels of SCI, and they identify four layers of integration: integration of flows (physical, informational, financial), actors (structures and organisations), processes and activities, and technologies and systems. These four layers can also characterise four different integration pathways, each leveraging the integrated construction organisations to improved SCI. Previous studies (e.g. Vrijhoef and Ridder, 2005; Poirier et al., 2016; Kesidou and Sovacool, 2019) as well as the direct experience of the author suggest that when improving SCI different companies follow different integration pathways. The different pathways' effectiveness in improving SCI represents a gap in the existing literature characterised as 'confusion spotting' regarding the competing explanations of the four integration pathways.

Second, the four different integration pathways leverage a different set of managerial practices for improved SCI. The studies on the managerial practices promoting higher levels of integration of flows, actors, processes and technologies, however, are fragmented, since they generally focus on a specific practice related to one among the four possible pathways of integration. Developing an encompassing structure of the different SCI practices from a systemic perspective, is reviewed through four integration dimensions. These are the strength, scope, duration, and depth of SCI (Leuschner et al., 2013; Eriksson, 2015). These dimensions serve as a valuable starting point in conceptualising SCI and operationalising it with different SCI practices. The existing gap in research in this area is characterised as ‘neglect spotting’ with practices that have been overlooked, under-researched or lack empirical support.

Lastly, the role of improved SCI towards better value realisation in construction is viewed through a set of construction-specific outcomes. As different construction actors develop higher levels in realising their integration potential, they can develop outcomes that enable reaching better effectiveness and efficiency in each, or across different projects. This area in existing research can be characterised as ‘application spotting’ with a new application of the existing literature.

The research on SCI in construction is in a nascent stage and the knowledge base is fragmented across studies and journals. Moreover, little is known on how SCI in construction can be practically improved. The oversights in current research amount to knowledge gaps identifying the lack of an encompassing SCI framework. This presents the most pressing challenge to the adoption of an SCI approach to construction management, mirrored by the sparsity of such approaches and offers in practice.

1.3.2 Research Aim and Questions

As outlined in Section 1.3.1, the current perspective of the emerging concept of improving SCI in construction focuses on the pathways, practices and outcomes of SCI. There are gaps in the knowledge in these three areas and specifically in how they can collectively constitute improvement in SCI in the construction sector.

Therefore, positioning this study through practices, pathways and outcomes, in the context of improving SCI in construction, the aim of this thesis is:

‘To explore how construction organisations can improve SCI through applying relevant practices, pathways and outcomes to value realisation.’

This thesis aims to address the identified research oversights explicated as a research gap ‘by answering research question(s) posed by the researcher’ (Ahlström, 2016, p.68). This approach broadly corresponds to the established logic of ‘gap spotting’. Nevertheless, Sandberg and Alvesson’s (2010) critique of this approach is addressed through ‘problematization’, by conducting the research in a practical context as SCI has been shown to encounter problems in how it is understood, adopted and consecutively improved in construction.

The following research questions underpin this study in order to achieve the research aim.

RQ1: What is the current understanding of SCI in construction?

RQ2: What are the most significant SCI practices to improve SCI?

RQ3: What is the relative importance of each pathway in improving SCI in construction?

RQ4: What are the major outcomes that SCI delivers?

RQ5: What pathways lead to the achievement of SCI outcomes?

In order to answer these RQs, two phases of research design are adopted. The first phase focuses on developing a conceptual framework through applying the method of an SLR and the second phase consists of a Delphi investigation for empirical validation of the developed framework. Both phases are specifically carried out in the construction context.

This research started with exploring how the previously described emerging SCI approach to construction SCM has been researched in scholarship. Several oversights in the understanding of how SCI is applied in the construction context have emerged, which threaten its potentially transformative power to the sector. In addition, research to date on applying SCI in a project-based construction context is largely fragmented across disciplines and subject areas, with considerable imprecision in its conceptual development. At the first stage, the oversights and conceptual imprecisions call for adopting a systematic approach in reviewing the literature on the topic. This defines the set of RQs and translates into a conceptual framework. At the second stage, a Delphi investigation was conducted aimed at empirical validation and responding to the set of RQs. Responding to these RQs will enable the thesis to make a trifold contribution to the domain of SCI applied in a project-based, construction context: at large with a view of the public benefit, to practice, and to academia.

1.3.3 Contribution of Research

Addressing these RQs will allow the study to make three types of contribution.

First, the thesis contributes to scholarship. The development of an encompassing SCI framework and assessment of which practices are impactful in improving SCI in construction will allow other researchers to focus their future efforts on developing SCI mechanisms and models that may be expected to be relevant. This allows the field to study facets of SCI adoption and improvement in greater detail and in a structured fashion, as ineffective practices may be disregarded while impactful practices are further explored. This assessment is facilitated by the thesis' introduction and application of theory that has not previously been utilised in SCI improvement in construction research. The generic framework resulting from the application of theory may be adopted by other researchers to quantify which practices drive improved SCI in given construction SCM contexts. Furthermore, studies can explore how interventions through the four pathways of integrating actors, flows, processes and technologies may improve adoption propensities. In addition, this thesis refines the understanding of the relationship between improved SCI and value realisation in construction, explicated through sets of expected outcomes, indicating that there are more distinct features to this relationship than have previously been assumed.

Second, the thesis makes a practical contribution, as it enables construction companies seeking to introduce SCI in the future to make better decisions, which ties in with taking an outcome-based approach, as cited in construction management literature. Knowing which SCI configurations of pathways and practices can leverage better value to the client organisation and how SC actors' interest may be increased is critical to integration. SCI, in turn, is presented as a prerequisite to achieving greater productivity in construction on the one hand, but also to developing a better commercial position through guaranteed construction demand on the other hand. Furthermore, the role of the different pathways to SCI are explored, which is of interest to established construction companies seeking to exploit the potential of SCI, through a closer customer-orientation and better SC alignment with supplying organisations.

Third, on a macro-level, this thesis contributes to solving the problem of responsible spend of public money, as performance on UK government-funded infrastructure projects have shown to incur large losses of value in delivery. Utilising an SCI approach to construction can have considerable benefits through improving the productivity potential in public projects and hence a better spend of taxpayers' money. This is an incremental contribution, but also validates the significance of the research topic overall and as a step in the right direction.

These contributions will be achieved in the context of a hypothetical construction SCI state, containing characteristics that diverge significantly from current construction reality to promise gains in realising value from infrastructure projects' delivery.

1.4 Thesis Structure

This thesis is divided into eight chapters following a classic structure. Each chapter contains multiple sections that are presented in a chapter introduction and conclude with a chapter summary. The structure of this thesis is presented in Figure 1.3.

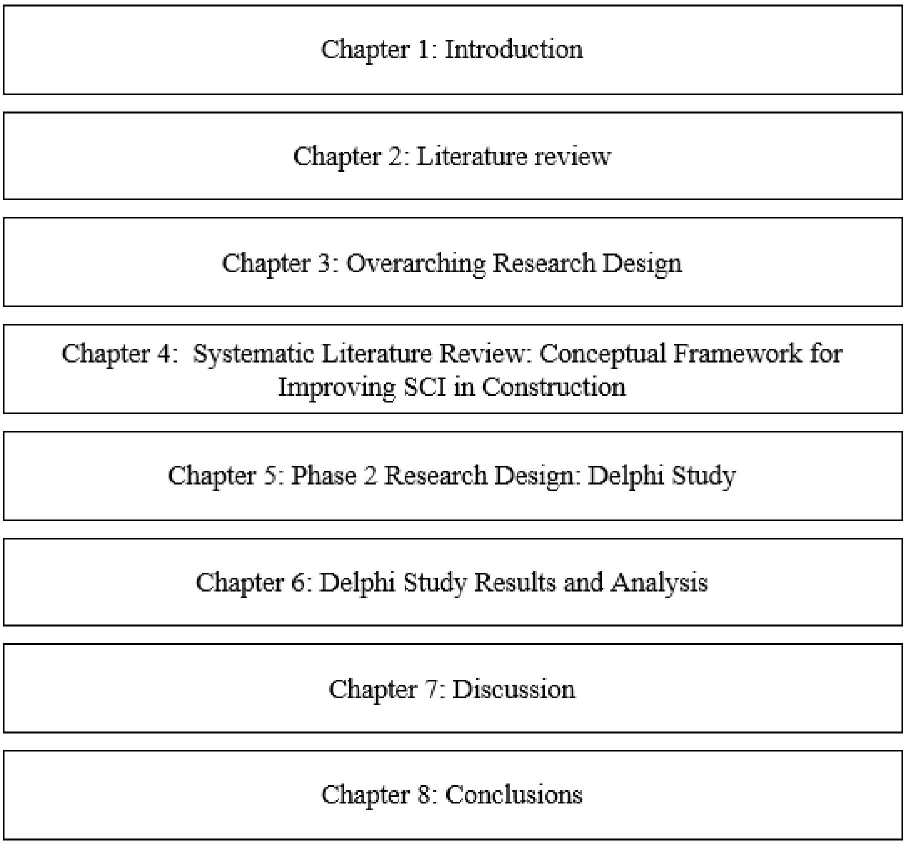

Figure 1-3: Thesis structure

Following this introductory chapter, Chapter 2 introduces the concept of SCI and relevant terminology in greater detail in relation to some conceptual imprecisions and the four pathways underpinning SCI improvement. This section also sheds more light on the transformation potential of the concept, presented as opposite sides of the current construction SCM state and a future improved SCI state.

Chapter 3 provides an overview of the research design applied in this study by reviewing in turn the philosophical standpoint of this research and the epistemology consisting of two stages of the research design. This is followed by a more detailed review of the applied methods in this study as Phase 1, SLR and Phase 2, Delphi investigation. The section also reviews the ‘Research quality’ of the study in terms of reliability, validity and generalisability.

Chapter 4 follows the SLR method as Phase 1 of the research design in reviewing the literature to arrive at a conceptual framework for improving SCI in construction.

Chapter 5 follows the Delphi method as Phase 2 of the research design, to conduct an empirical investigation of the conceptual framework derived from the literature.

Chapter 6 presents the empirical results and analysis of the Delphi study.

Chapter 7 discusses the findings of this research with reference to the existing literature. This chapter serves as a synthesis of the literature and the emerging findings which reflect the conceptual framework; it also provides the foundations for academic and practical contributions.

Chapter 8 summarises the key findings of this research in line with the set of RQs set for the study. Contributions to knowledge and practice are presented. This chapter also describes the study limitations and how these, as well as the results of this study, open avenues for future research.

1.5 Chapter Summary

This chapter has served as an introduction to the thesis, and has generated the following findings:

- The construction infrastructure is a high growth sector both globally and in the UK. In the UK, the sector is supported by readiness for delivery of strong pipelines of projects.
- The construction infrastructure is a high-profile sector responsible for spending UK taxpayer funds; however, there are indications of low levels of value realisation.
- Taking an SCI approach to construction develops both active interest in the collective performance of integrated organisations and their commercial position, with stable demand for projects established through the client's strategic planning process.

- The sector is exhibiting symptoms of SC misalignment between the strategic planning of projects in the pipeline and their execution through a multitude of disjointed supplying organisations.
- SCI emerges as a valuable approach to construction SCs; however, it requires further exploration and tailoring to the construction context.
- The applicability of SCI can be reviewed through a collection of SCI practices characterising SCI, pathways to improvement and the resultant, value-based outcomes of SCI.
- In academic literature, gaps have emerged relating to the matter of exploring the interactions between practices, pathways, and outcomes of SCI.
- This thesis seeks to answer five RQs to enable construction organisations to improve their SCI and enable researchers to study SCI with increased accuracy and robustness.

Chapter 2 : Literature Review

2.1 Chapter Introduction

This literature review is divided into three sections after this introductory section. Section 2.2 ‘SCI Background and Terminology’, looks at the main knowledge developments in SCI research in a project-based context and their applicability to construction. In Section 2.3, ‘Factors Inhibiting Adoption of SCI in Construction’ six thematic areas are presented, supplemented by inhibiting factors, that pose both a challenge and an opportunity for the adoption of SCI in construction. This is followed by Section 2.4 ‘The need for a Systematic Literature Review’, which summarises the main areas of this chapter and the need for their further development through applying an SLR methodology. Finally, Section 2.5 ‘Chapter Summary’ summarises the main points of this chapter. The structure of this chapter is illustrated in Figure 2.1.

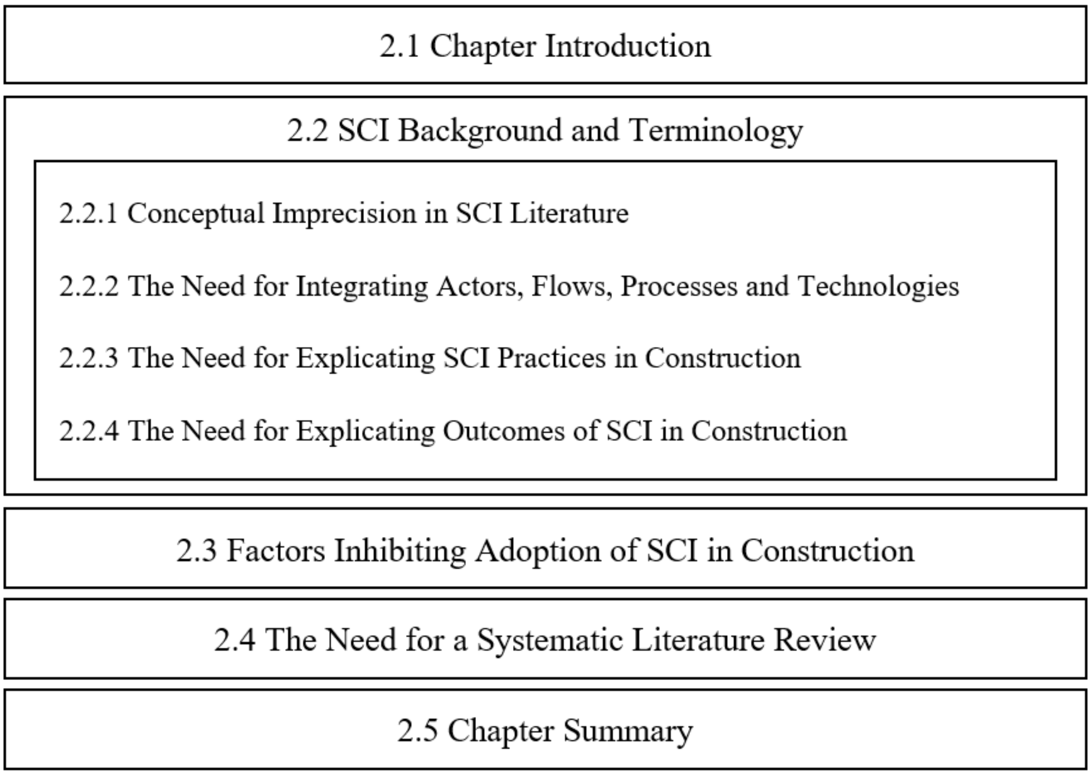

Figure 2-1: Structure of Chapter 2

2.2 Background and Terminology

This section comprises four subsections. Subsection 2.2.1 reviews the most prevalent concepts in SCM related to SCI, highlighting some imprecisions that currently exist in the broader literature on the topic. Subsection 2.2.2 positions the context of this research through the need for further investigation of the pathways that frame integration efforts. In Subsection 2.2.3, the study identifies the need for in-depth investigation and operationalisation of the underpinning practices to SCI in construction. Lastly, in Subsection 2.2.4, the study is further focused through the development of value-based outcomes towards realising value from improved SCI. As outlined in the 'Research aim and questions' section of this thesis, apart from identifying a 'research gap' this study takes on a 'problematization' perspective that can benefit of an initial scoping study. Unlike a full SLR, scoping studies are not aimed at addressing specific research questions, nor assess the quality of included studies. Instead, they are suitable for identifying the issues and alternatives to a problem in line with the 'problematization' perspective taken in a practical SCI context. As such, the subsections within this section reveal some of the insights of the conducted initial scoping study.2.2.1 Conceptual Imprecision in SCI Literature

Recent research on SCI in construction is divergent. Studies explore SCI as part of collaboration efforts (Walker and Lloyd-Walker, 2015; London and Pablo, 2017), coordination (Walker and Lloyd-Walker, 2015), cooperation (Fu et al., 2015) or as the focus of partnership arrangements (Venselaar and Gruis, 2016; Gottlieb et al., 2020; Le et al., 2021). Despite these concepts playing a central role in construction reality, they present partial views to the adoption of SCI, causing disjointed streams of research. As highlighted by Fernie and Tennant (2013) there is an absence of a 'unified theory' (Halldorsson et al., 2007) in construction SCM, and emerging perspectives to shape this holistic management are problematic and unwieldy. Furthermore, contemporary views regarding SCM theory point at a lack of clear and consistent definitions across studies (Mentzer et al., 2001), present limited relevance across contexts and are problematic in delivering generalisable findings and solid theoretical foundations (Ketchen and Hult, 2011). Nevertheless, there are many studies on construction discussing SCM 'issues' (Chima, 2007; Thomas et al., 2011), 'practices' (Prajogo et al., 2012; Wiengarten et al., 2012), 'research' (Manuj and

Pohlen, 2012) and 'knowledge' (Borgstrom, 2012). Observing this academic reality, Kotzab et al. (2011) and Fernie and Tennant (2013) outline the absence of contextually sensitive models for the development and diffusion of SCM in construction.

The first observable stream of research in construction related to SCI is within the domain of SC coordination. The most commonly accepted definition of SC coordination in the literature is: 'The act of managing dependencies between entities and the joint effort of entities working together towards mutually defined goals' (Malone and Crowston, 1994, p.90). In essence, improving SC coordination in construction SCM presents itself as a valuable approach; however, in practice, the concept is relatively limited in its adoption to construction reality. SC coordination does not account for the high demand uncertainty existing in construction SCs, the lack of trust and adversarial relationships, or the high level of design changes common in some construction projects. The concept can be characterised as wishful thinking, not recognising the context it needs to be applied to and, importantly, does not offer the necessary detail of how it can be operationalised and adopted in practice. Furthermore, unlike SCI, coordination does not suggest that SCM of activities and resources can exceed the sum of their parts (Autry et al., 2014).

The second concept related to SCI is collaboration. SC collaboration is a relatively well represented stream of research, but poorly defined concept in SCM with multitude ways of defining it. For example, Fawcett et al. (2008, p.93) define collaboration as 'the ability to work across organizational boundaries to build and manage unique value-added processes to better meet customer needs', while Cao and Zhang (2011, p.161) define it as 'a partnership process where two or more autonomous firms work closely to plan and execute supply chain operations toward common goals and mutual benefits'. What stands out in these definitions is the lack of reliability in how the concept is defined and consecutively measured. Although the concept is predetermined on the ability of SCM to maintain value (Kramer,1991), applying collaboration in construction SCM reality appears inappropriate in an industry known for its cost opportunism, transfer of risk upstream and reliance on a large supply base of fragmented SMEs.

Third, cooperation in the context of SCM emphasises mainly the alignment towards a common goal and a shared purpose. It has been argued that the term does not suggest a close operational working relationship, but simply a positive attitude towards other SC members (Moharana et al., 2012). It is thus argued that cooperation is simply a pre-existing attribute of SCM that can facilitate integration (Cao et al., 2015). In the SCM context, cooperation often appears in a cross-functional setting, mainly in dyadic types of transactions and has a culture-related focus (Chen et al., 2009; Cao et al., 2015).

In summary, the literature on coordination, cooperation and collaboration is inconclusive on how these terms are defined in SCM. Through conducting in-depth analyses of these terms Thomas et al. (2015) and Wankmüller and Reiner (2019) conclude that academia does not fully agree on unique definitions regarding these terms.

A notable area of research in construction SCM is in the domain of partnerships. It is argued that in the construction industry the notion of partnering appears to convey a different meaning from that of traditional views, based on continuous relationships and repeated long-term relational exchanges (Moller and Wilson, 1995; Gadde and Håkansson, 2001). In the SCM literature, a partnership is defined as 'a long-term relational mechanism between an industrial supplier and its customer, which replaces open-market mechanism and provides financial and operational incentive for partnering entities to pursue performances individually and jointly' (Cheng and Carrillo, 2012, p.291; Chang, 2008; Zhang, 2009; Whipple and Roh, 2010). Evidence of the partial adoption of partnering in construction can be attributed to cost opportunistic behaviour and the broad use of the term 'partners'. In fact, there are three levels of partnering that can relate to SCI. The most integrative type has joint development activities (Jap and Anderson, 2003). Members of this type of partnership together create a new entity or mutually exchange ownerships. A lesser form of integration is strategic alliance, where partners implement contractual agreements to achieve operational effectiveness (Gulati and Higgins, 2003). Each partnering entity remains autonomous, but the business exchanges are cooperative and collaborative. Finally, the most flexible format is the ‘de facto’ partnership that may not have a tangible contractual form (Johnstone et al., 2009). More recent research on partnering in construction highlights a high diversity in partnering definitions, supplemented by high variety in partnering elements applied to actual partnerships (Hosseini et al., 2018). Research on construction partnerships demonstrates large discrepancy between what constitutes partnering in theory and the actual practice of only applying a few desired elements in partnerships. Furthermore, examples of partnering, such as framework agreements, are common in construction; however, these often fail to reap the desired benefits. This is often due to the high demand uncertainty of construction work, opportunistic behaviour or applying commercial pressure through contracts won on low-cost criteria in the first place. Such examples develop attitudes of mistrust and adversarial relationships in SC partners and inhibit the desired effectiveness of partnering arrangements. Generally, partnership arrangements are justified by ‘the enduring desire to maintain a valued relationship’ over a long period (Moorman et al., 1992, p.316), which in practice is not predominantly common in construction.

Looking at the bigger picture calls for taking a practical approach to the problematisation of the construction industry’s SCM reality. According to the Council of Supply Chain Management Professionals (CSCMP, 2022), SCM is: ‘an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model’. This definition clearly delineates the integrative focus needed for effective and efficient management of SCs. Moreover, according to Pagell (2004, p.460) SCM and integration are intertwined to the extent that ‘the entire concept of SCM is really predicated on integration’. Taking this notion further, Bankvall et al. (2010) regard the term ‘integrate’, as being defined ‘to form, coordinate, or blend into a functioning or unified whole’. In SCM, this involves the inter-organisational integration of actors, flows, processes and technologies (Power, 2005; Fabbe-Costes and Jahre, 2006). This characterises four integration pathways to be taken forward across construction companies as bases for developing SCI in construction.

2.2.1 The Need for Integration of Actors, Flows, Processes and Technologies

Taking the problematisation perspective further, through exploring some of the current issues in construction supply chains, reaffirms the notion of applying SCI as a viable approach. This subsection draws on the findings of the initial scoping study, to present some insights to the issues contextual to integration of the four pathways. These issues are highlighted in the following section considering the four pathways of integration: actors, flows, processes and technologies.

First, the need for integrating different actors in construction is highlighted by problems in translating client demand across the SC (Elliman and Orange, 2003; Titus and Bröchner, 2005; Xue et al., 2007; Forgues and Koskela, 2009; Eriksson, 2015; Broft et al., 2016). Such problems can be associated with the complexity of processes, but fundamentally come to disagreements in asset strategic choices (Van Lith et al., 2015; Godsell et al., 2018). Causes for disagreements can include diffusing competencies, contradictory estimations and inconsistent aggregation needs of actors (Dainty et al., 2001a). Furthermore, actors in construction SCs can exhibit unrealistic or false expectations towards other actors (Dainty et al., 2001b; Xue et al., 2007) and misunderstand what partnering entails (Gosling et al., 2015; Broft et al., 2016; Kim and Nguyen, 2018). In addition, construction SCs on larger projects typically involve hundreds of different companies supplying components, materials and a wide range of services (Dainty et al., 2001a; Briscoe and Dainty, 2005). The high number of SC actors with several tiers of subcontractors suggests low visibility across the SC echelons and increases the probability of disagreements (Godsell et al., 2018). These inhibiting factors highlight the need for integration of actors as one of the four pathways to improved SCI.

Following a cost-driven agenda is negatively associated with achieving recurring flows (of information, material and finance) in the construction SC (e.g Wood and Ellis, 2005). Such negative effects can be explained by exacerbating a tendering culture in partners (Godsell et al., 2018), leading to forming a new SC for every project and developing a reactive nature with little traction between partners' workflows (Titus and Bröchner, 2005; Xue et al., 2005; Näslund and Hulthen, 2012). Another critical factor is the irregular nature of demand patterns in the construction sector. This can affect negatively the SC flows in construction, as irregularity causes discontinuous SCs and limited productivity (Costa et al., 2019). Lastly, compartmentalisation of disciplines and subcontractors in construction also contributes to irregularity of flows (Xue et al., 2007; Bankvall et al., 2010, Van Lith et al., 2015). This factor inhibits flow through lack of cooperation during execution (Broft et al., 2016) and alienates SC actors from integrated design processes (e.g. Front End Loading), aimed at engaging a multi-disciplinary team in the whole project lifecycle (Forgues and Koskela, 2009). These realities in construction highlight the need for integrating flows in construction SCs.

Both setting mutual objectives and effective problem resolution are factors that can enable, or lack thereof inhibit, the integration of processes and activities. High level of objectives' alignment drives integration in this pathway, provided the objectives maximise mutual interests and benefit all actors in the long term. In principle, successfully pursuing mutual objectives requires well-developed pain/gain sharing mechanisms, repeated customer engagements in a series of projects and guaranteed future work for suppliers over a long period of time (Meng et al., 2011). A high level of problem resolution effectiveness is achieved through establishing early warning mechanisms throughout the SC, allowing partners to anticipate potential problems and solve them before they become difficult to resolve. Problems are thus not blocking the integration of processes and activities. Importantly, this approach limits functional fragmentation (Costa et al., 2019) and problems from occurring later in the project (Eriksson, 2015), facilitating the integration of processes and activities. A significant benefit from the integration of processes and activities is the integration of suppliers into value-creation activities. Such activities aim at collaboration in creating innovative and market-oriented products and at continuous enhancement of production processes in projects (Forgues and Koskela, 2009; Davis and Love, 2011; Van Lith et al., 2015; Costa et al., 2019). Moreover, projects of a large size can offer 'innovation windows', where well developed process and activity integration can leverage value (Davies et al., 2015) in accordance with changing customer needs and market dynamics (Pillay and Mafini, 2017). In contrast, exclusion from the early involvement (EI) phase is an inhibiting factor that obstructs innovation and coordination, leading to disjointed process and activities (Xue et al., 2007). These factors indicate the need for developing a pathway of integration of processes and activities to construction industry's reality.

The construction industry exhibits adoption of various types of technologies to manage its intrinsic complexities (Papadonikolaki et al., 2017). As pointed out by Papadonikolaki et al. (2017), diffusion of technologies and systems across the SC can be enriched by an understanding of SCM philosophy. In this context, integration of technologies is seen both as an innovation by itself and as a means to stimulate other innovations (Wamelink and Heintz, 2015), pertaining to either management or technological means. A critical factor in the integration of technologies and systems is developing a continuous improvement mindset, which serves as the basis for consolidation and standardisation of various technologies and systems available between SC actors. Furthermore, assessing the extent of the integration of different technologies and systems, creates the necessity for regular and objective monitoring and benchmarking of the existing partnerships against developments in the wider industry. The successful integration of different technologies and systems may require significant investment from partners, which could be off limits for SMEs. To resolve such investment concerns, partners require a high degree of certainty through guaranteed long-term future work. As such, this pathway can benefit from a secure demand profile of work, which in turn requires a greater degree of client leadership (Broft et al., 2016). Accordingly, aligning partnering arrangements and incentives between suppliers, main contractor and client is an enabling factor that can stimulate the integration of technologies and systems. This highlights the importance of investing in technologies accepted and established as standard in the industry. The current construction reality is missing the required level of alignment between different SC actors and the continuous demand for construction work, which can provide the underlying security for investments. Nevertheless, these factors highlight the need for developing a pathway of integration of technologies and systems in construction, so that the collective of organisations can capture opportunities for innovation and efficiency.

In this section the four pathways of SCI in construction were reviewed in a construction context, highlighting their practical relevance to managerial issues that are complex and strategic. Taking this practical perspective further and following Fabbe-Costes and Jahre (2007), an SCI pathway is defined here as a 'distinct strategic synergy area of converging integration efforts'.

2.2.2 The Need for Exploring SCI Practices in Construction

Furthermore, addressing the need for linking business functions and business processes in a construction context, requires operationalising SCI to construction reality. This involves a set of SCI practices depicting such linkages into a unified whole from a systematic perspective. Through an initial scoping study of how the concept of SCI translates into a project-based context, it became evident that the actual construction practices can be delineated through four dimensions of SC integration (Eriksson, 2015). This involves the strength of integration, focusing on the linkages between integrated organisations through the extent of their informational, operational and relational integration; second, the scope of integration, associated with the number, nature and the SC interdependencies shared between SC partners; third, the duration of integration focusing on the continuity of relationships over series of projects and the right timing of involvement of different construction organisations; and lastly, the depth of SC integration, concerning the practices that establish commitment to integrative activities across the various SC organisations. These dimensions offer structure in reviewing SCI in construction; however, they do not present in sufficient detail the actual practices that can guide impactful actions to be taken towards improving SCI. Following Van der Vaart and van Donk (2008, p.47) SCI practices are here defined as 'tangible activities or technologies that play an important role in the integration of a focal firm with its suppliers and/or customers'.

2.2.3 The Need for Exploring Outcomes of SCI in Construction

Apart from how SCI is operationalised and what is integrated, research is required on the relationship between integration and value realisation. The literature points to this relationship as currently divergent. Such a relationship has been investigated from a variety of angles including lean construction (Lönngren et al., 2010) and Integrated Project Delivery (IPD) models (Mesa et al., 2016). With regard to the application of lean principles to production, many of the types of waste are recognised as present in construction SCs (i.e. Babalola et al., 2019; Bajjou and Chafi, 2019). However, applying lean to improving the value of construction delivery has its critics. Some experts point to a lack of universal applicability of lean on individual structures in the construction SC. Others, such as O'Brien (1995) note the difficulty of applying lean in one-time construction projects, because the effort required for implementation is out of proportion to the benefit in this approach. On the other hand, proponents of applying a lean philosophy to eliminate waste and increase workflow in construction SCs, such as Arbulu et al. (2003) and Ibrahim et al. (2010), advocate a shift in thinking should take place. Such potential change relies on simplification in the configuration of construction supply systems, reduction in their embedded variability and improved visibility. Developing these conditions relates to applying the concept of SCI, suggesting it has an enabling effect on the success of lean initiatives (Eriksson, 2010; Taggart et al., 2014).

In this thesis, the notion of developing SCI as a key enabler to value realisation in construction is reviewed from an 'outcomes' perspective, asserting that improving SCI in construction can lead to sets of outcomes not achievable by any single organisation. It is thus suggested that taking an outcome-based approach can enhance value realisation that represents more than the sum of actors' individual contribution. The perspective of outcomes as a result of improved SCI focuses on the practical benefits of integration. The broader literature suggests that there is a link between improved SCI and achieving value-based outcomes (e.g., Broft et al., 2016; Keung and Shen, 2017). However, in reality, such studies are generally missing in academia and specifically in the construction context. The link between practices and focused integration efforts through the four pathways, as the basis for developing mechanisms that can leverage SCI towards achieving sets of outcomes, has been underexplored up to now. The causes of such linkage to be underexplored can be traced to two main aspects for consideration. First, there is a missing link in the SCI outcomes that drive specific performance improvements in or across various construction projects, rather than general business performance. This points to the notion that SCI can be first focused towards developing a value-based outcome approach shared between different actors and projects, rather than at individual firm performance level. Second, SCI requires an end-to-end view through a set of outcomes that span all involved construction actors (customer, main contractor and subcontractors). These considerations call for further investigation of this linkage in this thesis and specifically, identifying what outcomes can be expected from improved SCI. In the context of this research, the outcome of SCI is articulated as a 'collection of processes or efforts by which integrated organisations can proactively pursue project value objectives'.

2.3 Factors Inhibiting the Adoption of SCI in Construction

In the previous section, some of the factors that inhibit integration were reviewed in the context of integrating actors, flows, processes and technologies. This highlighted the need for investigating SCI in the nexus of these four integration pathways. In light of SCI investigated in this study, as a transformational approach to the current construction sector reality, a pressing question that emerges is why SCI has not yet taken place. In accordance with the problematisation perspective set in this research, SCI has been shown to encounter problems in its adoption and consecutively improvement in construction. It is unclear how improving SCI in construction can lead to transformative and sustainable change in the industry, rather than sporadic initiatives, and what the inhibiting factors that have prevented such change are. This section aims at using the SCI in construction literature, in particular the scoping study, to summarise some of the main problematic areas faced in construction SCs in light of the potential transformation SCI can bring to construction. The areas highlighted serve as bases for further empirical investigation through the qualitative, 'assess' stage of the applied Delphi method, drawing on respondents' experience and insight. The issues are classified into six thematic areas:

- Short-term relationships
- Inappropriate organisational structure
- Functional siloes

- Decentralised planning
- Discrete work packages
- Ad hoc SC scope for individual projects

Each thematic area is supported with relevant literature, bringing together insight into the potential of taking an SCI approach to SCM in construction.

Short-term Relationships

A notable area of SC issues is attributed to short-term, discontinuous relationships in construction. There is a range of related issues that characterise the short-term relationships in construction, but fundamentally construction partners exhibit low levels of mutual trust (Dainty et al., 2001b; Meng et al., 2011; Eriksson and Pesämaa, 2013), low or uneven commitment by different partners (e.g., Wood and Ellis, 2005) and fear of uncertainty translated into opportunistic ways of thinking (Van Lith et al., 2015; Liu et al., 2017). These issues prevent the formation of long-lasting relationships in construction over a series of projects, further exacerbated by often limited top management and leadership commitment to SCI. Additional factors include unfair risk allocation practices (Broft et al., 2016; Manu et al., 2015; Davis and Love, 2011), limited use of collaborative procurement (Briscoe and Dainty, 2005; Eriksson and Pesämaa, 2013) and low financial security in partners to invest in long-term relationships (Pan et al., 2010; Pillay and Mafini, 2017). Overall, relationships in construction are often characterised by poor cultural fit between partners (e.g. Meng, 2012) and do not support win-win attitudes (Meng, 2012; Broft et al., 2016). Against this backdrop, it is suggested that improving SCI can transform this construction reality towards forming long-term, lasting relationships.

Inappropriate Organisational Structure

SCI in the construction literature highlights the improper organisational structure as currently inhibiting SCI from taking place (Dainty et al., 2001b; Meng et al., 2011; Van Lith et al., 2015; Mesa et al., 2016). This current construction reality is exacerbated by lack of formalisation of and complexity in processes, policies and plans (e.g., Xue et al., 2005; Eom et al., 2008). This in turn, can result in ineffective communication between construction partners (Dainty et al., 2001b; Dainty and Brooke, 2004; Pryke, 2004). Furthermore, a notable inhibiting factor to SCI is the disjointed performance measurement between organisations and the lack of benchmarking as collective of organisations, which is instead often at a functional or department level (Elliman and Orange, 2003; Briscoe and Dainty, 2005; Eom et al., 2008; Broft et al., 2016). Overall, the literature points to large compartmentalisation of disciplines and subcontractors in construction (e.g. Xue et al., 2007; Cheng et al., 2010; Pero et al., 2015), which outlines the current reality of an organisational structure inappropriate for SCI in construction, instead of a structure based on SC flows.

Functional Siloes

Another area illuminated by the range of issues in construction relates to functional siloes that construction companies operate under, instead of jointly pursuing SC outcomes that can deliver better value in or across projects. The literature highlights contributing factors to include lack of an inter-organisational approach to value (Dainty et al., 2001b; Briscoe and Dainty, 2005; Khalfan et al., 2010), misunderstanding of what partnering entails (Van Lith et al., 2015; Broft et al., 2016), ineffectiveness of problem resolution in projects (Xue et al., 2005; Gosling et al., 2015) and poor integration of suppliers into value creation (Pryke, 2004; Davis and Love, 2011; Meng, 2012). These inhibiting factors suggest that SCI can be applied towards bringing down functional barriers and adopting a cross-functional and collaborative approach to value realisation, focused on sets of SCI outcomes.

Decentralised Planning

The literature on the issues related to SCM in construction highlights the area of decentralised SC planning. This area relates to the nature and regularity of demand patterns (Dainty et al., 2001a; Godsell et al., 2018), which causes problems associated with understanding and translating clients' demands across the SC (e.g. Wood and Ellis, 2005; Davies et al., 2015). Such issues are further exacerbated by the perceived cost complexity associated with many tiers of suppliers and lack of cost calculation transparency of the main contractor (Meng et al., 2011; Broft et al., 2016). In addition, the construction sector operates with uniqueness-bias towards project-based planning, focusing on projects' customisation, rather than planning requirements at SC level (e.g., Pryke, 2004; Bankvall et al., 2010). These issues suggest that SCI can serve as a valuable approach in transforming the current reality of decentralised planning towards integrated SC planning.

Discrete Work Packages

A category of issues faced in the construction sector relates to the sporadic engagement of construction organisations on individual work packages, rather than continuous involvement in repeated work packages. The literature on SCI in construction highlights the lack of strategic approach to SCI (e.g. Pillay and Mafini, 2017) and lack in length of commitment between construction partners (Kim and Nguyen, 2018; Manu et al., 2015) as major contributing factors. In addition, the literature points to the discontinuous work in construction as impacted negatively by unrealistic expectations (e.g., Xue et al., 2007) and limited partnering experience in some construction organisations (e.g., Kim and Nguyen, 2018). Another considerable factor attributed to this area is the lack of training and education in SC (Eriksson, 2015; Kim and Nguyen, 2018). This issue characterises the lack of understanding in how SCI can leverage the integrated construction organisations as a unit and position them for improved efficiency from continuous repeated work, instead of disbanding at end of projects or work packages. Additional issue includes the exclusion of suppliers and subcontractors from early involvement (EI) phase in projects (e.g., Xue et al., 2005) Lastly, the literature highlights that construction organisations seldom develop mutual SC objectives which inhibits the continuously working on repetitive work packages (Eriksson and Pesämaa, 2013; Mesa et al., 2016; Meng et al., 2011).

Ad hoc SC Scope for Each Individual Project

Following on with the different inhibitors the construction sector is exhibiting, the literature points to predominantly following a cost-driven agenda (e.g. Xue et al., 2005; Kim and Nguyen, 2018) when assembling an SC for each individual project. This often translates into attitudes of uncertainty and opportunistic ways of thinking in individual projects (Wood and Ellis, 2005; Broft et al., 2016; Costa et al., 2019), limited learning and innovation (Dainty et al., 2001a; Saad et al., 2002; Godsell et al., 2018) and low flexibility to change in different projects (e.g. Kim and Nguyen, 2018). In addition, as a new SC is formed at the start of individual projects, this limits the effectiveness of coordination between different partners and the possibilities of resource sharing as part of SCI scope that includes the same actors continuously serving different projects (Saad et al., 2002; Mesa et al., 2016). Furthermore, a considerable inhibiting factor is the lack of consistency in SC scope which leads to the inability to develop partnering agreements that achieve alignment between the different SC organisations (Dainty et al., 2001b; Eriksson, 2015; Kim and Nguyen, 2018). Instead of a new SC scope formed for each project, it is suggested that by improving SCI actors can develop an encompassing SCI scope, enabling them to continuously serve projects with varying degrees of complexity.

Overall, this section examined the literature on the most pronounced inhibitors to value realisation in construction and thematically positioned them in light of what transformation SCI can bring about to the industry. It appears that there are many inhibiting factors to adoption of an SCI approach to construction SCs, presenting both a challenge and an opportunity. The analysis of the main inhibiting factors led to developing insights, categorised into six potential transformational areas. These areas are developed below as oppositions of current reality and desired future state:

- Short-term vs. Long-term relationships
- Inappropriate organisational structure to SCI vs. Structure based on SC flows
- Functional siloes vs. Outcome-based approach
- Decentralised planning vs. Integrated planning across the SC
- Discrete work packages vs. Continuous repeated work
- Ad hoc SC scope vs. SCI scope

2.4 The Need for a Systematic Literature Review

The construction sector's SCM is characterised by the creation of numerous SCs for individual projects, rather than developing SCI, able to serve various types and groups of projects. The actors involved in the delivery of these projects are often assembled at the start of a project and disbanded at the end. These realities in construction, lead to short-term relationships causing limited productivity, further exacerbated by disjointed flows of material information and finance across the SC. The initial review of the literature identified the need for developing four distinct pathways of integration: actors, flows, processes, and technologies. Furthermore, the literature points to the need for an in-depth review of the composition of practices that operationalise SCI in construction. Better understanding of these practices can develop the necessary practical mechanisms of activities that operationalise SCI and how those can lead to its improved state. Lastly, there is a need for better understanding of the benefits that can be realised from improved SCI. These can be explicated through a set of construction-specific outcomes focused on better value realisation.

The three areas of investigation in the literature (pathways, practices and outcomes) point to current knowledge gaps. In addition, SCI applied in the construction context is at a relatively nascent stage in academic research, with pockets of knowledge existing in various studies and journals. These considerations require improving the reliability of this study through taking a systematic approach. This is why an SLR was adopted as a way forward to achieving synthesis from the literature on improving SCI in construction. An SLR is thus positioned as the first step of the research design of this project.

2.5 Chapter Summary

This chapter has served as a general literature review in positioning the context of this thesis. The chapter has generated the following findings:

- SCI literature is in a relatively nascent stage with conceptual imprecisions inherited from coordination, collaboration and partnerships literature, but has developed from a value chain standpoint.

- Through problematisation of construction realities, there appears to be a strong need for introducing SCI in the construction sector, guided by four integration pathways: actors, flows, processes and technologies.
- Understanding of the practices that underpin integration is important for developing SCI specifically in the construction context and requires further investigation.
- The SCI literature on construction highlights the need for taking an outcome-based approach when realising value from SCI in construction.
- The literature highlights many inhibiting factors that have impeded transformation from traditional SCM to an SCI approach in construction
- The SCI literature, and this study in particular, can benefit from conducting an SLR, as there is a need for a systematic investigation into the practices, pathways and outcomes that characterise the concept in the construction context.

Chapter 3 : Overarching Research Design

3.1 Chapter Introduction

Following this introductory section, this chapter is split into four sections. Section 3.2 ‘Research Philosophy and the Researcher’, discusses in turn the ontological, epistemological and methodological perspectives adopted in this thesis. Section 3.3, ‘Methodology’ reviews in further detail the two phases that comprise the research design adopted in this thesis, Phase 1, SLR and Phase 2, Delphi study. Section 3.4, ‘Research Quality’ highlights the research quality considerations of this study. Finally, Section 3.5, ‘Chapter Summary’ concludes and presents a summary of the chapter. The structure of this chapter is illustrated in Figure 3-1.

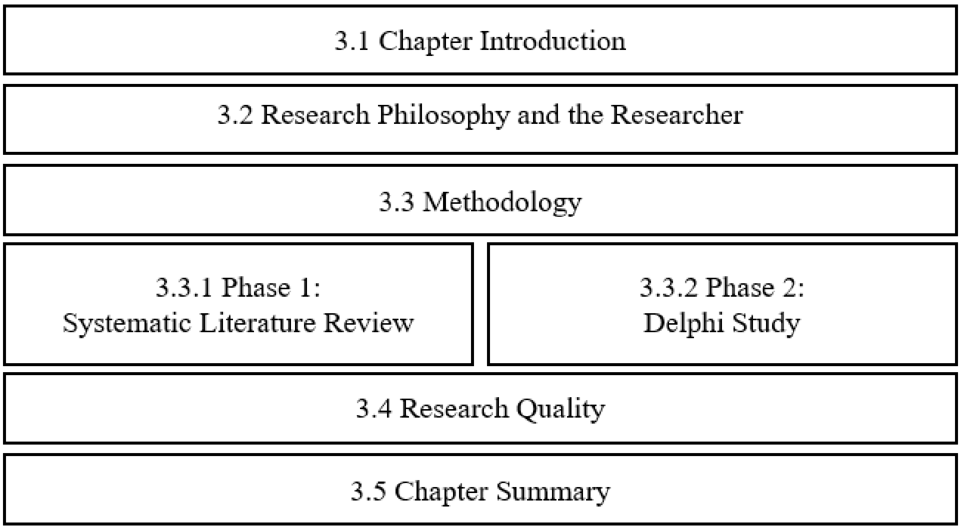

Figure 3-1: Structure of Chapter 3

3.2 Research Philosophy and the Researcher

Terre Blanche and Durrheim (1999) suggest that a research process is characterised by three major dimensions: ontology, epistemology and methodology. These different dimensions are reviewed in the context of the study and the researcher in the following: Section 3.2.1 ‘Ontological Position’, Section 3.2.2 ‘Epistemological Position’ and Section 3.2.3 ‘Methodology Selection: Two Phase Research Design’.

3.2.1 Ontological Position

First, ontology refers to the search for existence and aims at depicting the nature of reality. Easterby-Smith et al. (2002, p.31) define ontology as ‘the assumptions which are made about the nature of social reality’. Such assumptions concern the kinds of social phenomena that exist, the conditions that underpin their existence and how assumptions about their existence are related (Blaikie, 2010). Chia (2002) depicts two opposing views of ontology related to contemporary Western thought: Heraclitean and Parmenidean. The first view of ontology, Heraclitean, is one ‘of becoming’ and draws from a worldview of changeable, continual state of flux of the world. In this ontological view the underlying logic is of understanding social reality. The second view to ontology, Parmenidean, is one ‘of being’ and draws on a worldview of reality as formed by discrete entities with identifiable properties and characteristics that follow universal patterns or laws. In this ontological view, the underlying logic is of causality in social reality. In Western education, Parmenidean ontology has been predominantly adopted, which may be attributed to this perspective lending itself to facilitating research by investigating causes and effects, independent and dependent variables. This ontological view resonates with the researcher’s worldview and perception of the nature of reality, noting its practicality to the use of scientific methods. In the same time, particularly in social research, thinking about ontology refers to beliefs about the fundamental nature of reality. The beliefs of the nature of being and existence (ontology) are generally discussed in terms of dichotomy (Bryman, 2001) between on one hand, objective reality which exists independent of the observer and on the other reality as it appears subjectively as negotiated within groups. From the researcher’s ontological perspective, social reality, as explored in this thesis under the domain of social research, can be informed from constructivism and interpretivism and as such , may draw on both ‘of being’ and ‘of becoming’ ontological views. The epistemological positions informing these ontological views are further explained in the next section. The difference between these two ontological positions is summarised in Table 3-1.

Table 3-1: Comparison of two different ontological positions (Chia, 2002)

Ontology	Heraclitean	Parmenidean
Meaning	‘of becoming’	‘of being’
View of reality	Fluxing, changeable and emergent world	Permanent and unchangeable nature of reality
Basic unit of reality	‘event cluster’	‘atom’
Logic	Understanding	Causality

3.2.2 Epistemological Position

Epistemology is concerned with the perception and acquisition of knowledge (Saunders et al., 2009; Eriksson and Kovalainen, 2015). In a more general sense, from an epistemological perspective what we regard as knowledge can be viewed through three theoretical approaches: correspondence, coherence and consensus. The correspondence approach to knowledge holds that truth consists in agreement between judgements or propositions and an independently existing reality. This approach focuses on the facts, as what is suggested conforms to external reality (e.g. Austin, 1950; Popper, 1963). The coherence approach to knowledge is based on a belief of knowledge as true if it ‘coheres’ with other beliefs we regard as true. Unlike correspondence, the focus is not on the correspondence between a belief and a fact, but on a given belief to other beliefs in one’s mind (e.g. Bradley, 1914; Blanshard, 1939). Lastly, the consensus approach to knowledge refers to a process of taking statements to be true simply because people generally agree upon them. This notion is built on ‘consensus gentium’ (Latin for agreement of the people) and as stated by Ferm (1962, p.64) ‘that which is universal among men carries the weight of the truth’. These epistemological views of knowledge generally form distinct epistemological positions, positivism, realism and constructionism. Each of these epistemological positions is reviewed in turn.

First, positivism assumes that the social world exists externally from human perceptions and as such, the phenomena investigated can be measured through objective methods rather than through human beliefs or experiences. Research focused through a positivist logic aims at operationalising measurable constructs from observable facts in order to identify causal explanations about them. The findings are usually generated through the use of statistical analysis.

Second, constructionists view reality as not objective and not understood independently of the observers. According to Berger and Luckman (1966), social reality can be discovered by the ways people make sense of the world and particularly by sharing experiences with others. In constructionists' view a researcher takes part in what is observed and makes an interpretation of what can be characterised as meaningful social action. Here the findings are aimed at increasing general understanding of the social regularities underpinning a typical context (Blaikie, 2010).

Third, as a middle ground between the positivism and constructionism epistemological positions stands realism. In a realist view, reality is considered as being claimed to exist or has not yet been observed. In essence, realism focuses on both the observable and unobservable characteristics of the real world (Bhaskar, 1978). The main differences characterising these three epistemological positions are summarised in Table 3-2.

Table 3-2: Three main epistemological positions (Adapted from Easterby-Smith et al., 2018)

Positivism	*Realism*	*Constructionism*
The social world exists externally. Therefore, its properties should be measured through objective methods.	The world is real and exists independently of perception. Reality consists of different layers including both observable and unobservable characteristics.	Reality is determined by people rather than by objective and external factors. Therefore, it can be formed through the way people make sense of their experience.

As presented in Table 3-2, positivism and constructionism can be considered as two opposing ends of an epistemological position. Both can be characterised by sets of strengths and weaknesses with regard to conducting social research. Critical realism

(CR) is introduced as an epistemological position that sits between positivism and constructionism (Easterby-Smith et al., 2018). In CR the researcher distinguishes between the 'real' world and the 'observable' world. The former cannot be observed and exists independently from human perceptions, constructions and theories. In a critical realist's view, the world is constructed from perspectives and experiences formulated through what is 'observable'. In other words, unobservable structures cause observable events and the social world can only be understood if people understand the structures that generate events (e.g. Bhaskar, 1978; Archer et al.,1998). CR suits the researcher's epistemological perspective. This is because the knowledge derived from the investigated phenomena in this study, improving SCI in construction, is a social construct. In other words, CR acknowledges that knowledge is a social product, which is not independent of those who produce it (Bhaskar, 1978). For a critical realist, social structures are forces in social settings that enable or constrain the actions people can take. Such social structures represent a system that has an effect on and is affected by the outside world (Yucel, 2018). The CR epistemological position is particularly suitable to the methodology adopted in this study. The SLR presents a viable method in developing the social structure that generates events in SCI context and the Delphi investigation has and explanatory power to the events that govern this social structure through the perspectives and experiences of participants. By applying CR as an epistemological position to this research the author aims at presenting an alternative to current SCM reality in construction through explaining the applicability of SCI and its potential improvement.

3.2.3 Methodology Selection: Two Phase Research Design

As highlighted by Easterby-Smith et al. (2002), researchers are affected by underlying philosophical assumptions which focus choices on applied methodology and how data is gathered, analysed and used. Therefore, the author's epistemological position and research strategy need to be explained in accordance with the method choices applied to this research.

This study adopts a two-phase research design. The first phase uses an SLR to synthesise existing theoretical knowledge from prior research. As outlined in the literature review section, the focus here is on SCI 'practices', 'pathways' and 'outcomes' in the construction context as the basis for achieving greater clarity in understanding of the problem investigated (improving SCI in construction). This phase is aimed at developing a conceptual framework (CF) that depicts and defines the premises that characterise the concept of SCI in construction. The second phase of the research design applies a Delphi study as empirical validation to the set of RQs posed by the researcher and based on the emergent relationships derived from the literature review and CF. This research follows a deductive reasoning (deduction) process with the synthesised CF serving as a starting point of a set of SCI areas and relationships investigated and the Delphi study as the basis for specific conclusions drawing on empirical inferences from the CF. In accordance with the CR epistemological standpoint the research design adopted aims at using the empirical investigation from the Delphi towards understanding the underlying structure that can generate events (i.e. SCI improvement) as outlined in the CF. The two stages (phases) in the research design are outlined in the next section.

3.3 Methodology

This section reviews in detail the two phases of the research design adopted in this study. As a critical realist, the author follows a deductive research process, which suggests two phases of research design: theoretical and empirical. In Subsection 3.3.1 the first phase, SLR, focuses on describing the method in more detail, its applicability to this study and the processes involved in conducting an SLR. In Subsection 3.3.2 the choice of a Delphi method is reviewed in detail as empirical validation of the CF developed from the first phase. The subsections focus on the characteristics of a Delphi study as the chosen research method (3.3.2.1), review of different methodological approaches (3.3.2.2) and research design of the Delphi investigation in relation to this study (3.3.2.3).

3.3.1 Phase 1: Systematic Literature Review

The starting point of this research design involved the development of RQs and a CF. In the context of this thesis, the RQs led to the development of a systematic combination of theoretical developments from prior literature. It is suggested that such developments in the literature can be formulated as a CF that presents a visual representation, explaining the key constructs and their associated relationships that are to be further studied (Voss et al., 2002). The CF underlines the focus of this research (Miles and Huberman, 1994) and provides the researcher with a model when thinking about the involved constructs and variables logically and how to position them collectively in the context of the research.

The main element in the development of a CF included the SLR which was conducted in order to systematically review the existing literature on the emerging concept of improving SCI in the construction sector. This was conducted before administering the Delphi study. The choice of undertaking an SLR was taken, given the need for higher precision in explicating the concept of SCI in construction and the need for developing higher reliability in the study. As such, an SLR was considered as a highly valuable method to be applied to this study, as it offers the most rigour and high quality in identifying and evaluating the literature towards addressing specific questions (Mulrow, 1994). This study applies an SLR based on the five-step process proposed by Denyer and Tranfield (2009) as illustrated in Figure 3-2. The details of this process are discussed in the following sections.

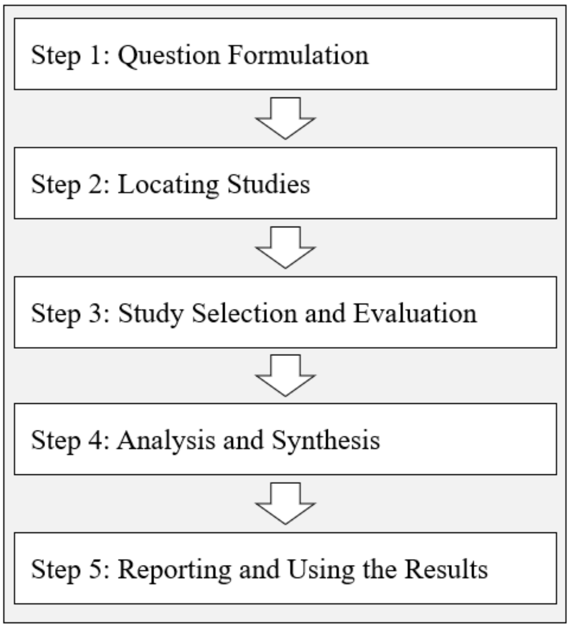

Figure 3-2: Five-steps of the systematic literature review process (Adopted from Denyer and Tranfield, 2009)

When selecting the SLR methodology to be followed, other well-known methods were also considered, including PRISM (Preferred Reporting Items for Systematic reviews and Meta-analysis). As there are no detailed step-by-step guidelines to conduct SLRs in operations management (Márcio et al., 2016), a decision was taken to adopt the available guidelines for general management (i.e. follow Denyer and Tranfield (2009)). The reasoning behind this decision was based on the scope of the SLR as SCM (subset of management), the familiarity of the review panel with Denyer and Tranfield's method and a track record of previous results achieved in studies using this method. The method consists of five steps, each discussed in turn below.

3.3.1.1 Question Formulation

Frameworks to improve SCI have been developed in a manufacturing context (e.g. van der Vaart and van Donk, 2008; Näslund and Hulthen, 2012; Zhang et al., 2015; Ataseven and Nair, 2017) characterised by relatively high volume, repeatable demand, rather than the relatively low volume, limited repeatable demand that characterises construction. Building on the leading practice from manufacturing, this study seeks to present a framework that synthesises the currently fragmented literature on improving

SCI in construction. Given the differences between manufacturing and construction, transferring knowledge requires a tailoring of the theoretical models as well as their empirical validations. Currently, it is unclear which management practices underpin all pathways, and which may be pathway-specific. Such an understanding is important for construction managers to understand the best way to approach improving SCI in their specific context, in particular the pre-existing enabling management practices. By exploring the management practices that are common and specific to the four pathways, and their relationship to performance in construction, practical pathways to improvement can be identified. Achieving this level of synthesis was guided by setting the following RQs in the SLR:

An overarching RQ:

How can the four integration pathways (actors, flows, processes, and technologies) improve SCI in construction?

The overarching RQ was supported by three sub-questions in the SLR, all set in the construction context:

a) What are the characteristics of each integration pathway?
b) What management practices enable improvement in SCI for each pathway?
c) What is the relationship between SCI and SC performance?

Following best practice in conducting SLRs, the author developed a review protocol explaining the review question and the search strategy. A panel consisting of two academic experts in SCI in construction and two SLR experts assessed the protocol and provided feedback for its improvement. The author used the feedback to create the final version of the protocol.

3.3.1.2 Locating Studies

Table 3-3 presents the search strings used for the location of the studies. The author selected three classes of keywords related to SCI, performance, and construction. The keywords were combined with Boolean operators to create search strings. Synonyms were used for the three classes of keywords (for instance: supply chain, demand chain, value chain; integration, coordination, collaboration, and partnering; construction, infrastructure, and projects). These search strings were then applied to search two databases (ABI/Inform Global and Scopus) with restriction to the title and abstract of scholarly articles published between January 1990 and December 2021.

Table 3-3: Specification of search terms used in the systematic literature review

Supply Chain Integration				Performance Measurement			Construction
Suppl*	Chain	Integrat*	AND	Perform*	Measur*	AND	Construct*
OR		OR			OR		OR
Demand		Coord*			Manag*		Infrastructure
OR		OR					OR
Value		Partner*					Project
		OR					
		Collabora*					

3.3.1.3 Study Selection and Evaluation

A first selection screened English language articles and removed duplicates thus resulting in 1249 papers. A second selection screened titles and abstracts against the inclusion and exclusion criteria shown in Table 3-4. A third selection screened title and abstract based on three relevance criteria: (1) relevant for SCI, (2) relevant for SC performance measures, and (3) relevant for the construction context; this selection left 105 papers for review. Only SCI papers in the context of the construction industry were included and all other sectors were excluded. The final selection screened the full text based on the relevance criteria and resulted in 33 papers. An additional 14 papers (30% of total selected) were included through snowballing (cross-referencing), because they were identified as relevant to the research, but did not appear in the initial literature search. Therefore, 47 scholarly publications were selected for the final analysis and synthesis (see Appendix A). The relatively low number of studies (33) identified from the SLR screening and selection process can be explained by the topic of SCI in construction as currently emergent area of study with limited number of publications. Here adopting the ‘snowballing’ approach to the 14 papers is justified in order to increase the depth of some of the studies from the ‘start set’ as extending the systematic literature review. The studies identified from snowballing were not core papers and are as such identified with (*) in Appendix A. The systematic selection process is illustrated in Figure 3-3.

Table 3-4: Criteria for including and excluding publications

Criteria	Rationale
Inclusion	
Publications since 1990	The notion of applying SCI in construction has its roots in the Egan report published in 1998. The term SCI is not entirely new, as "project partnering", "collaboration" and "coordination" cover aspects of SCI in construction. The search was limited to articles published after 1990 to avoid missing prior articles that may have related to SCI.
Publications included only academic journals	Conference papers, reports and chapters of edited books were not included to limit complexity in following the systematic process.
Peer reviewed publications	The subject of SCI in construction is developed enough to address the aim of this research and require rigorous consolidation of otherwise disjointed studies. Using only peer-reviewed publications was selected as a search strategy to develop cohesion on the subject matter and consistency in results.
Journal quality with good Scimago value	A share of the journals included in the SLR are of an engineering nature, which requires using an alternative quality index to ABS (Association of Business Schools). A Scimago H index value of over 20 was used as the benchmark for publications' impact. Only Q1 and a few Q2 Scimago ranking publications were selected as a benchmark for sufficiently good quality to be included.
Supply chain context of papers selected was triadic	Dyadic SC context of papers was dismissed to avoid artefacts of knowledge relevant to poorly defined constructs of SCI in construction. Studies with dyadic SC context were not selected as they usually concern transaction-based or buyer-supplier relationships rather than SCs.
Domain of the publication/journals	Include publications/journals from information systems, engineering, manufacturing, technology and construction management.
Subject of the paper	Papers considering SCI in the context of the construction sectors. All other sectors to be excluded in line with the focus of this study.
Exclusion	
Non-English language papers	Due to possibility of misinterpretation
SCI studies other than relevant to construction management	An objective of this paper is to describe how SCI can be adopted in the project-based construction sector, rather than developing a general framework stemming from other sectors.

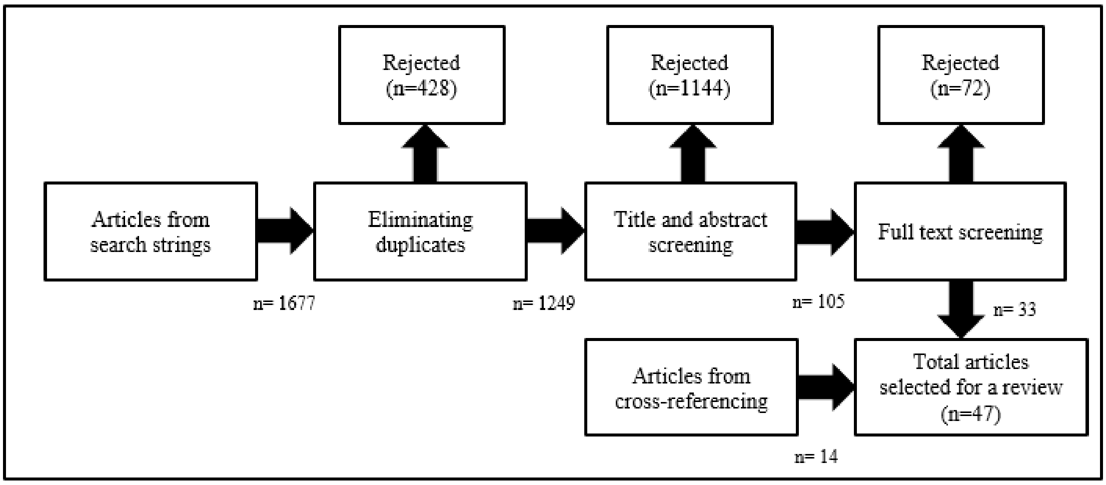

Figure 3-3: Systematic selection process

3.3.1.4 Analysis and Synthesis

The selected publications were classified and thematically analysed. The classification categorised the papers according to year, type, geographical location, methodology, and scientific direction of publications. The thematic analysis first identified artefacts of knowledge based on the set of RQs, which were later related to the different dimensions of SCI with their sub-constructs. The extracted data comprised quotations and keywords from the selected publications. The observations contributing to each SCI construct were clustered according to themes and presented to the SCI experts for discussion and feedback towards formulating distinct SCI practices.

The revised, final data extraction sheet, which included the constructs clustered by themes (based on the four dimensions of SCI in project-based organisations), was then used as a template, and applied to the analysis of all 47 papers. The results were used through an inductive approach for feeding into and formulating a CF, as one of the main contributions of the SLR. This required synthesising the connections between themes through significance analysis of the four SCI pathways. In addition, the SLR results revealed a strong link between SCI and a number of outcomes that can be achieved as a result thereof.

3.3.1.5 Reporting and Using the Results

This step focuses on presenting the results of the classification of publications and the thematic results, with a preliminary discussion of these results (see Chapter 4). The CF of SCI pathways is presented to guide future research and aid practitioners in identifying the route to viable SCI outcomes in line with construction organisations' investment decisions, given their current management practices and desired value outcomes. The relationships emerging in the CF, as derived from the SLR are empirically tested through the second phase of the research design.

3.3.2 Phase 2: Delphi Study

This section comprises three subsections. In Subsection 3.3.2.1, 'Delphi Method', further details are provided for the chosen method as Phase 2 of the research design. In Subsection 3.3.2.2, 'Review of Different Methodological Approaches', the different possible alternatives are reviewed with some of their strengths and weaknesses. Lastly, in Subsection 3.3.2.3, 'Research Design of the Delphi Study' the design of the Delphi study is outlined through four steps of empirical validation.

3.3.2.1 Delphi Method

This section specifies the adopted methodology for the empirical part of this thesis' research process. Based on the detailed considerations related to the currently nascent state of knowledge in the domain of improving SCI in construction and the need for expert input in how SCI can be improved, the methodology applied as the second phase of the research design is a Delphi study. The Delphi approach was chosen as the data collection and subsequent analyses technique, as it is particularly suitable for exploratory enquiries on complex, under-researched, and interdisciplinary topics (Grisham, 2009). Use of the Delphi technique is appropriate when the investigated issue is not suitable for precise analytical techniques but can benefit greatly from subjective judgements on a collective basis (Buckley, 1994). As such, the Delphi method relies on experts' consensus (Powell, 2003; Toepoel and Emerson, 2017). Delphi studies are conducted over multiple rounds of collecting, structuring, and analysing information on the research problem in order to build consensus (Häder, 2009). A key feature of a Delphi study is that it uses structured groups of participants who remain anonymous to each other and interact with the researchers only. As such, the Delphi method also eliminates 'seniority bias' and overly vocal representatives in the expert panel that can steer other members' judgement in a given direction. The second key feature of the method is that it aims at developing 'group wisdom' as shared knowledge arrived at by individuals and groups. Following Loo (2002) the use of the Delphi method should be considered when tackling significant decision-making that sets the future strategic direction for involved organisations.

Given the relatively underexplored state of SCI in construction, a key requirement in the choice of method was to allow for flexibility in the exploratory part of the study through qualitative enquiry of construction professionals. Therefore, a qualitative stage was included as a first step in the Delphi study. At the same time, a CF has been formulated using the SLR, that required empirical testing with construction SC experts. Addressing this, a quantitative part in the Delphi investigation, based on consensus-building ranking questions, has been designed throughout two stages of the Delphi study. Applied to the context of this study, a Delphi investigation including both qualitative and quantitative parts allows for both a sufficiently broad investigation to identify the major areas characterising transformation to an SCI approach in construction SCM, while being sufficiently narrow to pinpoint the relationships between variables investigated in the CF. Furthermore, given the encompassing nature of this investigation, the set of practices and outcomes are not measured via single item measures, because of their high number, diverse nature and composite effect. Instead, in line with its exploratory nature, this study is focused on accuracy by investigating the relative importance of practices between one another rather than investigating the individual effects of any given practice to SCI. Nevertheless, the construct validity of the composite practices revealed from the SLR has been assured through previously published studies. This is reviewed in further detail in the section 'study measures' in Chapter 5.

3.3.2.2 Review of Different Empirical Methodological Approaches

The choice of a Delphi method for this study is justified by comparing it with other possible methods that could be adopted. Following Ahlström (2016, p.68) an important message here is that 'different research approaches are not good or bad in themselves', they have 'different strengths and weaknesses'. This section aims at reviewing the various empirical methods available in O&SCM research and their potential methodological fit to this study.

First, surveys as a research method are suitable when the existing knowledge of a phenomenon has developed beyond the nascent stage and is entering the intermediate theory stage (Ahlström, 2016). Adopting a survey methodology requires provisional explanations for a given phenomenon to exist in the literature with some of the investigated constructs already defined. However, most often, surveys are applied in the theory-testing stage, where existing knowledge of a phenomenon is mature. The use of surveys in the development of knowledge for descriptive and exploratory purposes is less common. An area of consideration here is that the survey, as a method, relies on simple operationalisations (i.e. items) for achieving construct validity, which is not well suited to this study, given that it uses narrative in operationalisations and composite measures, although surveys do have the advantage of explaining the relationship among variables. However, the method is limited to finding the correlational relationships but does not offer any explanation for the causal relationships (Knemeyer and Walker Naylor, 2011). Furthermore, in the context of this research, following a survey approach is not suitable as the phenomenon studied is at a nascent stage of maturity. Practically, using a survey is expected to produce large dispersion in results as individual participants do not receive any feedback and develop their thinking on a given issue in isolation, instead of collectively. Given the encompassing nature of the subject studied, it is expected that using a survey could result in limited internal validity of the findings and if applied will not be sufficiently comprehensive in investigating the conceptual model in its entirety. On the other hand, surveys are usually associated with higher levels of generalisability.

The second alternative method considered is case research. Case research tends to be used for more exploratory and theory-building purposes where knowledge is at a nascent stage. It offers a high level of detail for the case, but often requires external confirmation via further studies in additional cases or larger scale studies (Yin, 2009). In this study, theory-building is conducted through an SLR, which would limit the potential impact if case research as a method had been selected. Furthermore, case research is often selected as a research method addressing 'how' and 'why' RQs, which does not represent a very good methodological fit to the sub-RQs in this study. Practically, following case research as a selected method has two major disadvantages, increased complexity in data collection and large subjectivity in the context of findings. First, adopting a case research method to this research would have necessitated conducting multiple cases. These cases would have involved multiple sources of data (including primary and secondary) and as such, the research is at risk of obtaining incomplete evidence on a complex investigated problem. Essentially, it is expected that many gaps in data collection would emerge, which poses a risk to effective comparison between cases, should this method be adopted. Second, through the literature review of this thesis, it became evident that SCI in construction is impacted by many factors in the construction context. This poses risk to internal validity, as findings from company cases may be highly context-specific and not necessarily objectively represent the targeted population investigated. In addition, the nascent stage of SCI in construction highlights the risk of the concept being recognised and implemented differently in different companies, which may not necessarily have internal consistency with the theoretical model developed in this thesis, posing the risk of poor methodological fit. Overall, the case research method could be useful with a not well-structured theory base.

The third methodological alternatives are longitudinal field studies and action research. Both these methodological approaches share a common characteristic; they are suitable for early stages of the development of knowledge of a particular phenomenon. These approaches are much less frequently used in more mature stages of knowledge development. Longitudinal study as a method is considered an appropriate methodological alternative in this research; however, this approach is most suitable for generating theory, not testing theory (Ahlström, 2016). Through the use of this method the researcher can get close to the studied phenomenon and discover the forces most critical to the object of enquiry. The method is particularly useful when studying processes of change and development in organisations (Barley, 1990; Van de Ven, 1993). Practically, longitudinal field studies are scarce in the O&SCM domain (Ahlström and Karlsson, 2016). The three major practical considerations to this approach as a possible alternative are that it implies continuous organisational access (Van de Ven, 1993), multiple sources of data for triangulation purposes and significant observable change in decisions taken in organisations. Out of these practical considerations, the presence, or lack thereof, of significant change in the studied organisations poses a significant risk to adopting this method. Alternatively, engaging with many organisations also poses a significant risk to the limited research resource constraints. As construction organisations and their supporting SC functions operate through well-established and tested processes, it is not clear whether a strategic change would in fact take place throughout the duration of the investigation. Furthermore, if such a change is present, it is not clear whether it will constitute partial change or capture fully what is investigated in the theoretical framework of this research, posing the risk of limited study contributions. Lastly, longitudinal studies are critiqued in terms of their relatively low level of reliability and generalisability power, dependent on the comparison of findings with evidence outside of the studied organisation. Given the under-researched area of SCI in construction, compiled external evidence is highly limited and so is the expected generalisation from using this method.

Action research on the other hand addresses some of these practical contributions, as the researcher plays an active role in both the enquiry process and the implementation process (Coughlan and Coghlan, 2016). The practical considerations here involve the divergence of goals at the individual level of organisation and researcher and the consecutive impact this can create on the direction of the project. More specifically, organisational characteristics such as historical factors, formal and informal organisations, degree of congruence and availability of suitable resources affect the readiness and capability of participating in action research (Shani and Pasmore, 1985). This is identified as a significant risk to this research as it poses considerable uncertainty to the success of the study. Furthermore, the outcomes of action research are twofold, the first is some level of sustainability (i.e. human, social, economic ecological) coupled with development of self-help and competencies out of the action; the second is development of actionable theory through the action and enquiry. Relating action research to this project, it is unclear if these desired outcomes will be divergent or convergent, as industry and academic agendas may not be supporting one another. To put it simply, with view to implementation, the industry agenda is risk-averse and aims to avoid poor decisions, while on the other hand, it can be highly beneficial to the enquiry process, developing knowledge and refining the framework. This in turn poses high risk to the quality of the relationships throughout the research process, which is also one of the main factors to the success of action research (Shani and Pasmore, 1985).

Lastly, the methodology of applying modelling and simulation is reviewed. Quantitative model-based research can be classified as a rational knowledge generation approach (Meredith et al., 1989). It assumes that the researcher can build objective models that explain the decision-making problems faced by managers in real-life operational processes (Bertrand and Fransoo, 2016). Within the model, all claims are unambiguous and verifiable; however, modelling is not a valid approach to claims that pertain to the world outside the model. In essence, modelling is often used to validate either the conceptual model or the solution proposed by axiomatic research results. Usually, modelling and simulation are used when the existing knowledge of a phenomenon is mature (Ahlström, 2016). There are a number of practical considerations with regard to the methodological fit between applying modelling and the scope of this research. First, the encompassing nature of this research, as presented in the theoretical framework, does not lend itself to be easily constructed into a model and if this approach is taken, the model needs to be reduced in its size and complexity. This will inevitably limit the scope of this study and its relevant contribution, as relationships outside the model are not investigated. Another consideration of adopting this approach is the availability, type and broad spectrum of relevant data needed to feed into the model. SCI, as researched in this study, is an inter-organisational subject matter which pertains to inter-linked data from various sources and organisations. Practically, adopting this approach will require a strong relationship between various inter-linked organisations that wish to take part in the research, have availability of the required data, but also need to exhibit the necessary conditions required to be tested. These considerations pose serious practical challenges to adopting this methodology. Overall, this method is viewed as not suitable because it requires existing theory to be mature, which is not the case in this research.

In this section some of the main research methodologies adopted by O&SCM researchers were reviewed with regard to their suitability for this study. The review also included some of the practical implications in adopting alternative methods to a Delphi study. This revealed that each reviewed method presents some trade-offs compared to other methods.

3.3.2.3 Research Design of the Delphi Study

Through the use of an SLR, the literature on SCI in construction was systematically reviewed and thematically analysed. This led to synthesis of the literature presented in a CF. The research design of this study aims at testing the applicability of the formulated CF of improving SCI in construction. More specifically, the research design (see Table 3-5) outlined in this section presents the processes followed in the Delphi investigation, as a sequence of stages of enquiry and data collection. The research design describes the stages of the investigation into the procedure followed in this study with the objective of empirically validating the relationships set in the CF and formulated through the set of RQs. Each of the stages in the research design addresses the relevant RQs set in the introductory section of this thesis. In Table 3-5, each stage is described in terms of what it involves and the expected output as well as how it relates to the RQs.

Before the start of the Delphi investigation, each panel member was briefed and issued with pre-reading material covering the main areas of the Delphi study (practices, pathways and outcomes). Additionally, the panel members were briefed on how the investigation would be conducted. This was again covered in a short presentation on the day of the Delphi event, so that expectations in terms of context, content and time-restrictions were clear to panel members.

The first stage, ‘Assess’ was designed as an exploratory stage where the participants were asked to reflect on the transformative power of SCI to current SCM reality in construction. Specifically, the panel members were asked to draw on their experience and provide examples of adopting an SCI approach to construction SCs. This stage was designed to validate the hypothesised transformative oppositions between SCM and the SCI approach presented in the literature review, and supplement them by providing relevant examples. The design of this stage aimed at using the provided anecdotal examples of the panel members in testing the hypothesised areas of SCI transformation.

In the second stage, ‘Select’, the participants were tasked with selection between the SCI practices derived from the literature review to arrive at the ones they determine to be significant. The aim of this stage was to narrow down the practices to the ones that have the biggest impact on SCI. This stage was designed as a quantitative enquiry using scoring between practices. A total of 10 points were given to each panel member to distribute among the practices they determine as most significant to improving SCI in construction. The research process employed in this stage used specific observations to reach broader generalisations in line with the CF and investigated RQ.

Table 3-5: Overarching research design of the Delphi study

Stage	Description of Stage	Output of Stage
Assess	RQ: What is the transformation needed in construction SCM to improve SCI?	
	At the first stage the Delphi panel members are already familiar with the underpinning theoretical model investigated and are asked to reflect on their experience in relation to improving SCI in construction by answering the question: 'What resonates with your experience?'	This stage provides an in-depth understanding of the transformational areas surrounding the improvement of SCI supplemented by anecdotal evidence. The evidence provided catalysed responses, with participants commenting on what resonates with their experience, and formulating several distinct viewpoints to improving SCI in construction.
Select	RQ: What are the most significant SCI practices to improve SCI?	
	At the second stage, panel members were asked to go into further detail from 'assess' and evaluate the SCI practices from the CF. Each panel member is given 10 points to distribute across the SCI practices, judging their significance in improving SCI in construction.	This stage provides a quantitative measure to SCI practices investigated, distinguishing the ones that are most important.
Define	RQ: What is the relative importance of each pathway in improving SCI in construction?	
	At the fourth stage, the output of 'select' is used as input for 'define'. The panel members are asked to rank the effectiveness of the four integration pathways in improving each of the significant practices from 'select'.	This process involved three rounds for each element, with responses shared between rounds and the opportunity to change responses. This round-based approach is a key feature of Delphi studies in developing convergence in responses on an issue towards reaching a consensus. As output the aggregated results show the four pathways' effectiveness to significant SCI practices.
Execute	RQ: What are the major outcomes that SCI delivers? RQ: What pathways lead to achievement of SCI outcomes?	
	At the fifth, final stage of the investigation the panel members familiarise themselves with the seven SCI outcomes. This is followed by three rounds of responses in judging the ones that are major value-driving outcomes in construction. This is followed by a second task of ranking each of the four pathways' effectiveness to achieving each of the seven outcomes.	Following the same approach as in 'define', panel members were presented with their responses between rounds and were given the opportunity to change their answer towards reaching a consensus.

At the third stage, ‘Define’ the participants were tasked with defining the overall effectiveness of the pathways, by ranking their effectiveness to each of the significant practices from the ‘Select’ stage. The aim of this stage of the research design was to test how the four pathways rank in their effectiveness to improving SCI practices. The design of the stage was deliberately narrow, providing no options outside of the four pathways in line with the relevant RQ. The research process in this stage was aimed at testing the relationship between practices and pathways informed by the derived CF from the SLR. This design of this stage allowed specific theoretical conclusions to be derived from the collected observations. This stage was designed as a quantitative stage of enquiry towards achieving convergence in input from panel members. The stage adopted a classical Delphi approach of three rounds of enquiry, providing the aggregated results of the panel between rounds.

At the fourth, final stage, ‘Execute’ of the Delphi research design, the participants were tasked with judging between the presented outcomes of SCI in construction, i.e. the ones that they determine as major (most value-driving outcomes). As a second task, similarly to the ‘Define’ stage, the panel members ranked the effectiveness of each of the four pathways to achieving each outcome. Similarly to ‘Define’ the research design in this stage was deliberately narrow, testing only the relationships outlined in the CF and framed through the relevant RQs. As in the ‘Define’ stage, here the research process employed followed the Delphi method of three rounds of enquiry, providing the aggregated results of the panel between rounds.

3.4 Research Quality

This section aims at assessing the research quality of this thesis by reviewing considerations of validity and reliability. A key consideration here is the relatively nascent stage of research in SCI applied to the construction context and the lack of empirical research to date that is both comprehensive and generalisable. Essentially, lack of generalisability in SCI in construction research, evokes the need for the broad scope of this study and findings that are more indicative than rigid. With that in mind, it is the author’s aim to position the findings obtained using the Delphi method, as a step in the right direction in the otherwise vast field of SCI in construction. In the following subsections the practical relevance (3.4.1), pragmatic validity (3.4.2), construct validity (3.4.3), internal validity (3.4.4), external validity (3.4.5) and reliability (3.4.6) of this study are discussed in turn.

3.4.1 Practical Relevance

Practical relevance is an essential quality for research that is not 'fundamental research'. In a framework by Hevner et al. (2004) practical research relevance is attributed to research that is driven by business needs and indicates how the research phenomenon investigated presents a valuable contribution to solving a significant field problem (Van Aken et al., 2016). According to Hevner et al. (2004) rigour entails the research phenomenon being assessed with regard to applicability and generalisability, and is anchored in existing knowledge and methodologies. In attempting to achieve rigour, this study has used the literature to position SCI in relation to some of the persistent problems experienced in construction SCs. The research problem of improving SCI in construction SCs has been researched in various ways in the past, but only partially and not systematically. Reality shows that the research problem is still a pressing issue in construction, indicating a need for this research. Furthermore, the applied method has demonstrated that what can be characterised as a relatively abstract idea as integration, can be explicated through sets of practices, pathways and outcomes, formulated into guiding mechanisms towards improving SCI in construction. As presented in the introduction to this thesis through the value chain paradigm, there is observed mismatch between value identification in the strategic planning of infrastructure projects and the value realisation that delivers this potential value through SCI. In the UK the infrastructure projects sector is an industry of over £20 billion per year, as such, the potential for new and better approaches to realising value from SCM, in particular SCI, is tremendous. Therefore, the practical relevance is high.

3.4.2 Pragmatic Validity

Following Van Aken et al. (2016), pragmatic validity in this thesis refers to the strength of evidence claiming that the investigated interplay between practices, pathways and outcomes can produce the desired results in terms of improving SCI in construction. It can be noted that the value of this research to the academic domain of operations and SCM is significant, since what is investigated contributes to a new research phenomenon explicated through the CF in this thesis, instead of simply adding to an already existing phenomenon. In reality, existing studies that focus on SCI in construction are relatively scarce and usually outline some of the essential characteristics of the SCI domain in construction, without taking a pragmatic stance to possible solutions. Essentially, studying what can be referred to as currently 'non-existent' in practice, highlights the issue of research quality and rigorousness. The choice of a Delphi method to gather evidence can be referred as a pragmatic choice that uses consensus between experts to reveal the logic underpinning the CF investigated with notional findings that are indicative rather than axiomatic. As such, pragmatic validity is acknowledged as a limitation in this thesis, since improvement of SCI in construction as investigated here has not been field-tested.

3.4.3 Construct Validity

Construct validity involves 'identifying correct operational measures for the concepts being used' (Yin, 2014, p.46). In this thesis, the measures used were informed by the use of an SLR for identifying what constructs need measuring and through the use of established measures for these constructs in the field of O&SCM, as used by many scholars before. This approach is in line with Yin (2014) who suggests using multiple sources of evidence that converge, to assure research quality through construct validity. It is noteworthy however, that given the comprehensive nature of this research, the measures in this thesis are only used at the top level as aggregated measures of constructs, rather than at the scale and objective item level. In addition, the results of SCI practices determined significant show notable face validity as three of the six selected practices demonstrate convergent validity to relational integration. The constructs that demonstrate convergent validity are commitment (CM), trust (T) and long-term orientation (LTO), which all relate to relational integration as part of the strength of SCI. This signifies that in the core of improving SCI sits relational integration as a critical link between demand profiling and productivity, developed through sets of SCI outcomes. This can be explained by the adversarial relationships and mistrust characterising the sector, currently impacting efforts towards improved

SCI. The main implication of the demonstrated convergent validity is that there is more to this relationship than what meets the eye, and further research can be focused on understanding how relational integration works within SCI in more detail.Addressing the convergence of past and future research requires tracing empirical data in time to develop convergence, which necessitates the data being stored and accessible over time. Careful attention was paid to securing the empirical data through video-recordings, transcriptions, datasets of responses and saving e-mail correspondence. In addition, secondary data from various stakeholders, highlighting the need for SCI in construction and available in academic, government and industry publications, was used for triangulation purposes (Voss et al., 2002). Lastly, key informants reviewed drafts of the research and relevant operationalisations of constructs, which is also a way to ensure construct validity (Yin, 2014).

3.4.4 Internal Validity

Karlsson (2016, p.31) explains internal validity as meaning that 'the study actually measures what it is meant to measure and that demonstrated relationships are explained by the factors described and not by other factors'. On the other hand, Yin (2014) suggests that internal validity is not applicable to exploratory research, which to some extent characterises the type of research in this thesis. Nevertheless, considerations for internal validity are evident in this thesis and are underpinned in the research design of the study. In contrast to other methods such as experiments, Delphi studies deliberately use an iterative process where experts exchange views towards reaching group consensus. The internal validity of this study is thus predisposed on the expertise of assembled panel members and their fit to the questions studied. Except for the 'Assess' stage, which was deliberately framed as an example-based reflection exercise, generally the observed stability achieved at consecutive rounds and high level of consensus in the investigation of practices and outcomes of SCI demonstrate the high internal validity of this study. Of course, there can always be other factors that intervene and influence the relationships studied, but the quantitative data collected has enabled higher internal validity.

3.4.5 External Validity

External validity means that 'the results are valid in similar settings outside the studied objects' (Karlsson, 2016, p.31). According to Yin (2014, p.46) this involves 'defining the domain to which a study's findings can be generalized'. Generalisability from Delphi results is predisposed on appropriate panel size, diverse representation of members from different specialties and geographical distribution. All members in the Delphi conducted in this study have predominantly UK experience and are employed in the UK, which points to the generalisability of the results to the UK construction sector. With regard to panel size and diverse representation of members, there is a trade-off here between a homogeneous panel of smaller size, better suited for resolving focused problem setting and a heterogeneous panel of a larger size, appropriate for studying a broader situational context. Homogeneous panels are better suited for internal validity, whereas heterogeneous panels have higher external validity (generalisability) power. Given the focused approach to this study depicted in the tested CF and the narrow specialism required from panel experts, the study is designed for homogeneity in panel members and thus is better suited for internal validity rather than generalisability. Nevertheless, the expert panel in this study comprises experts from various construction companies and the panel achieved high levels of agreement on many of the investigated SCI questions. This in itself signifies some extent of generalisability of the results, particularly across UK-operating construction companies. However, by design, the study is not specifically aimed at achieving high generalisability. Given the specificity in the context of this study, SCI in construction, generalisability of the results for construction companies delivering UK infrastructure projects is determined to be sufficient. Taking a broader view, it can be assumed that conceptually SCI in the UK construction infrastructure is not dissimilar to construction infrastructure in other countries; however, there are many factors (i.e., political, social, economic etc.) that can be in play, so generalisation is limited.

3.4.6 Reliability

Reliability means that 'the study is objective in the sense that other researchers should reach the same conclusion in the same setting' (Karlsson, 2016, p.31). More specifically, reliability involves 'demonstrating that the operations of a study, such as the data collection procedure, can be repeated, with the same results' (Yin, 2014, p.46).

Evidence of reliability in a Delphi study is often referred to as limited, as two panels that receive the same questions may not come to the same conclusions. However, to ensure reliability (repeatability), Yin (2014) suggests using study protocols and a study database. This enables the research to be repeated and protocols should be stored and accessible. Ensuring reliability in this thesis involved paying greater attention to face validity in describing the research processes in detail and transparency, especially when the methodological approach chosen lacks well-established guidelines. As presented in the methodology and construct validity sections, all collected data and the analyses thereof were stored in a database. To ensure that the data collection procedure can be repeated and is likely to have the same results, the applied procedure describes the content in the datasets so that another researcher would be able to gather all necessary data, complete the analysis and arrive at potentially the same conclusions. Furthermore, the results clearly define the relationship between the four pathways of SCI and practices and outcomes, making it feasible for another researcher to analyse the data with respect to these relationships. Overall, the replicability of the tested relationships in the conceptual model is made possible through the explicitly described design of the investigation, with all notions, study measures and equations explained for replicability purposes.

3.5 Chapter Summary

This chapter has served as an overview of the research design applied in this thesis, in line with the two phases of the research design, an SLR and a Delphi study. The chapter has generated the following findings:

- The research philosophy of the thesis was reviewed with the researcher's ontological, epistemological and methodological positions explained.
- The overarching research design of the thesis was described in accordance with Phase 1, a Systematic Literature Review.
- The overarching research design of the thesis was described in accordance with Phase 2, a Delphi study.

- The main methodological alternatives to conducting an empirical investigation were discussed, highlighting some of the practical considerations and trade-offs with each alternative
- The research quality considerations were reviewed and addressed, as appropriate for this thesis.

Chapter 4 : Systematic Literature Review: Conceptual Framework for Improving SCI in Construction

4.1 Chapter Introduction

Following this introductory section, this chapter is split into five sections. Section 4.2 ‘Descriptive Analysis’, classifies and analyses the publications in the conducted SLR descriptively. Section 4.3, ‘Thematic Analysis’ reviews in detail the findings of the SLR and analyses the results thematically, in turn reviewing the pathways, practices and outcomes of SCI in construction. Section 4.4, ‘Conceptual Framework Development’ presents systematically the findings of the SLR in a conceptual framework (CF) offering empirical validation. Section 4.5, ‘Insights from the Conceptual Framework’ highlights some of the preliminary insights from the CF regarding improving SCI in construction. Finally, Section 4.6, ‘Chapter Summary’ concludes and presents a summary of the chapter. The structure of this chapter is illustrated in Figure 4-1.

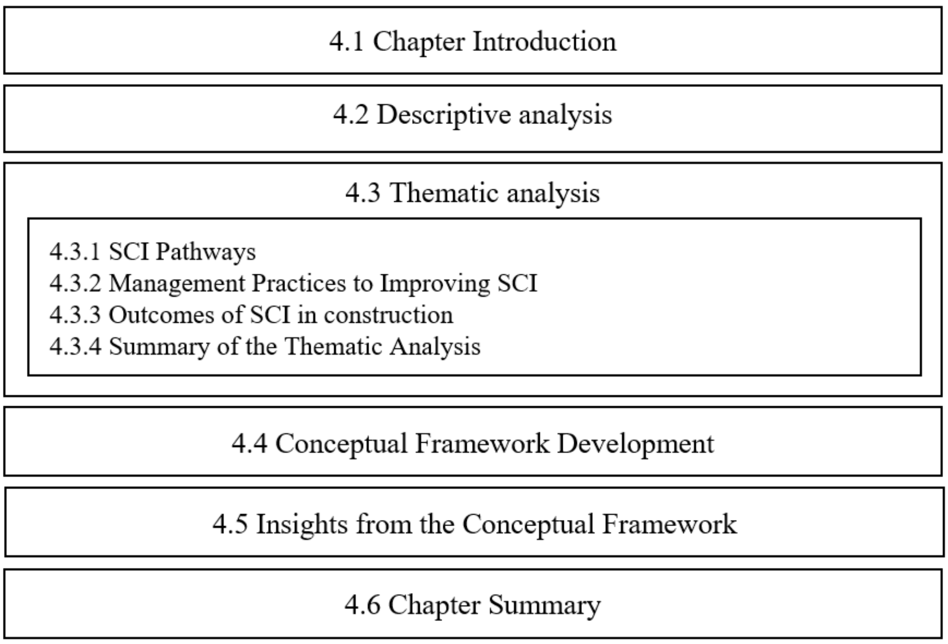

Figure 4-1: Structure of Chapter 4

4.2 Descriptive Analysis

This section summarises the results of the classification of the 47 academic publications based on the year of publication, research methodology, type of publications, geographical location, and journal domain. As illustrated in Figure 4-2, the results of the SLR show that SCI in construction can be traced back to 1998, albeit labelled as project partnering. This is the same year the influential report by Sir John Egan was published, calling for the adoption of SCM principles in the construction sector. Soon after, the term 'integration' of the construction SC, has started to gain traction in academia with a gradual increase of studies on the topic through the years leading to 2005. While some studies discuss SCI in detail, others adopt the term partially, as an element in addressing a specific aspect (e.g., waste minimisation, innovation, commercial relationships, design capabilities in construction). From 2005 to 2012, SCI in construction continued to evolve, not by number of studies, but through clarification of the terminology and constructs relevant to SCI in construction. The limited number of publications in this timespan is not surprising, given the sector experienced stagnation between 2008 and 2010 in the UK. It seems the uncertainty in the sector impacted negatively on both the interest and funding of research in SCI. In addition, the lack of case studies on the subject indicates low adoption and little traction of the term SCI to construction businesses' reality, instead primarily relying on anecdotal examples collected through interviews. As activity in the sector started to surge in 2013, the research on SCI significantly increased. In addition, the use of multiple methods highlights strong interest in academia in how empirical work is approached, towards utilising SCI principles in construction. Understanding the outcomes that SCI can realise and how it can transform construction businesses became more apparent, as indicated in the increase of case study methods applied. In recent years, empirical studies have become more common in construction, which bodes well for the SC discipline and its place in academia. In addition, the more recent continuum of quantitative studies applying a modelling approach has started to address tentative theory development and validation as well as generalisation in the subject.

The papers selected for a systematic review are all published in academic journals, with conference proceedings, chapters of edited books, business reports and company materials excluded from the review. Following the selection criteria, the SLR process consolidates and builds a single source of evidence in an otherwise still disjointed and relatively nascent formulation of body of knowledge. Most articles are in the domain of construction management journals (45%), indicating the topic of SCI is recognised by experts in the sector, although often only partially developed. The selected studies were published in 26 different journals, as illustrated in Table 4-1, indicating a large fragmentation of knowledge. A considerable share of the journals investigating the topic is in the SC domain (17%), where research on the subject is more holistic. Other types of journals where the topic appears are various operations- and business-related journals (19%) and project management journals (19%).

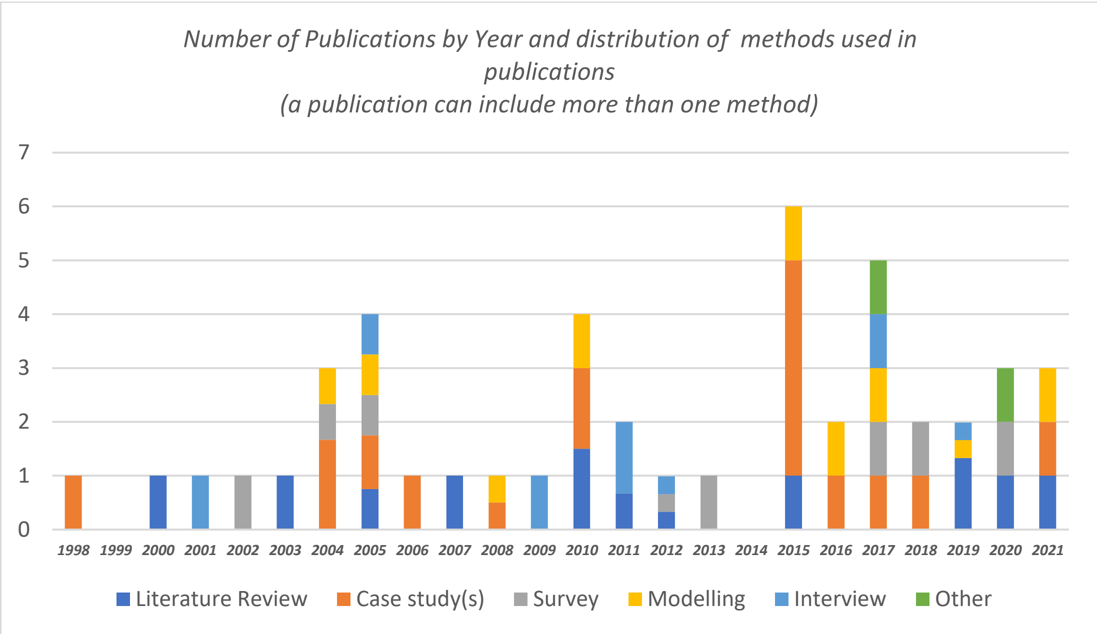

Figure 4-2: Analysis of publications across years and research methodology applied

Table 4-1: Distribution of papers in SLR by journals

Type of Journal	Total number of papers by type	Number of Papers in SLR from Journal	Journal Name
Construction Management	21 (45%)	7	Construction Management and Economics
		3	Construction Innovation
		2	Automation in Construction
		2	Engineering, Construction and Architectural Management
		1	IEEE Transactions on Engineering Management
		1	Built Environment Project and Asset Management
		1	Canadian Journal of Civil Engineering
		1	Journal of Construction Engineering and Management
		1	Building Research & Information
		1	Structural Survey
		1	Renewable and Sustainable Energy Reviews
Supply Chain Management	8 (17%)	3	Journal of Purchasing & Supply Management
		3	Supply Chain Management: an International Journal
		1	Journal of Transport and Supply Chain Management
		1	International Journal of Production Economics
Project Management	9 (19%)	5	International Journal of Project Management
		2	Project Management Journal
		2	International Journal of Managing Projects in Business
Operations Management	9 (19%)	2	Journal of Management in Engineering
		1	Total Quality Management
		1	Journal of Business & Industrial Marketing
		1	Business Process Management Journal
		1	Benchmarking
		1	Production Planning & Control
		1	International Journal of Operations & Production Management
		1	International Journal of Networking and Virtual Organisations

The nature of the papers included in the review makes classification according to the Association of Business Schools (ABS) ranking inappropriate. Instead, Scimago journal ranking (SJR) value was used to evaluate the studies' journal impact and prestige. In addition, all except one of the journals of the selected papers have a SCImago H (Hirsch) index of over 20, which is considered good in terms of individual researchers' productivity (citations and number of publications), as shown in Figure 4-3.

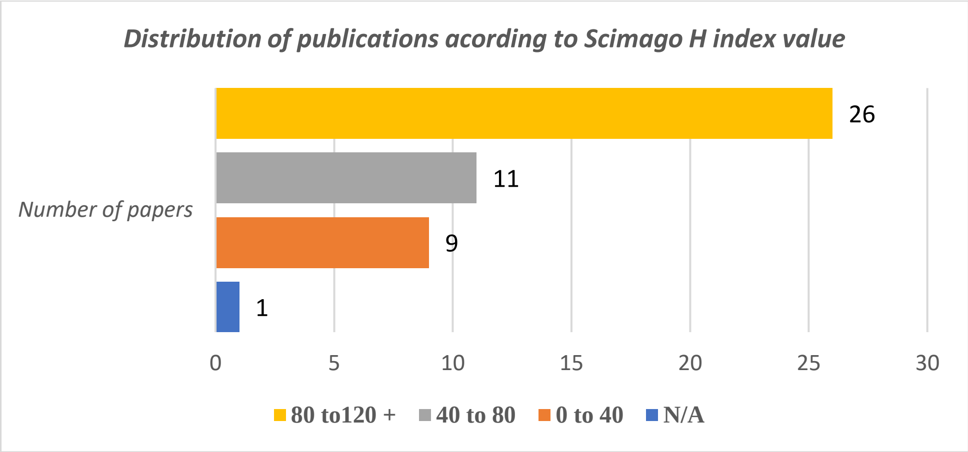

Figure 4-3: Distribution of journals according to Scimago H index value

As noted by Hirsch, one of the limitations of the index is in penalising early career scientists, which is the case with that one publication, albeit being of significant academic value. Furthermore, all selected journals rank in Scimago quartiles one and two and only three of the 47 papers are classified with an SJR value below 0.5, demonstrating high impact, as illustrated in Figure 4-4.

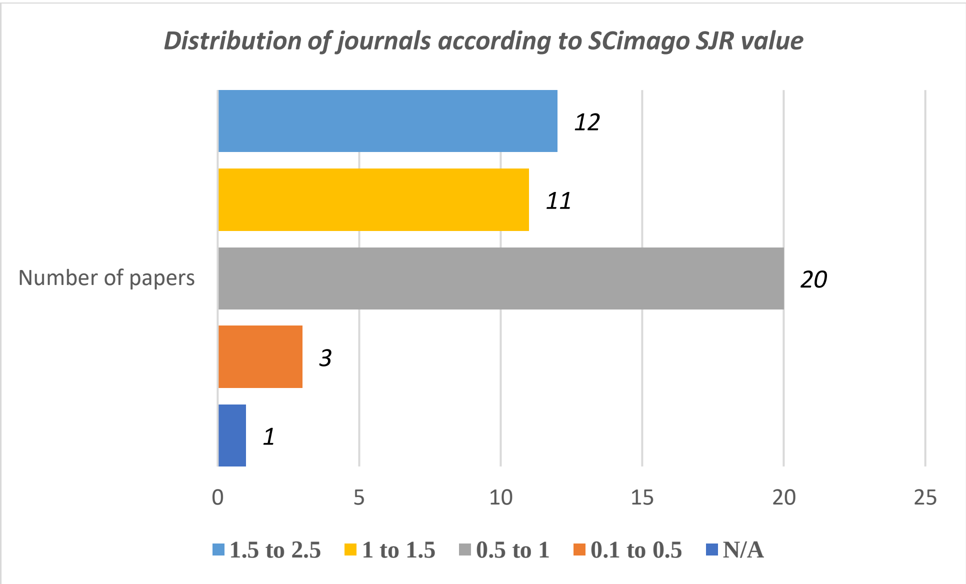

Figure 4-4: Distribution of journals according to Scimago SJR quality value

In terms of authors' geographical location, the interest in SCI in construction is distributed over five continents (i.e. Europe, North America, Asia, Africa and Australia). Most contributors come from European countries, and account for 70% of the total number of papers, suggesting a strong interest in the topic in Europe, especially the UK (51%), Sweden (10%) and Italy and the Netherlands (8%). This could be attributed to the idea and need for aggregation of value through SCI, to otherwise numerous competing construction companies operating across Europe. The US, Canada, China and south Korea account for 20% of total papers, equally distributed with two publications each, apart from Canada represented with three publications. Other single local studies are also evident in Australia, Taiwan, Singapore, South Africa and India, accounting together for 10% of total papers in the SLR, as illustrated in Figure.4-5.

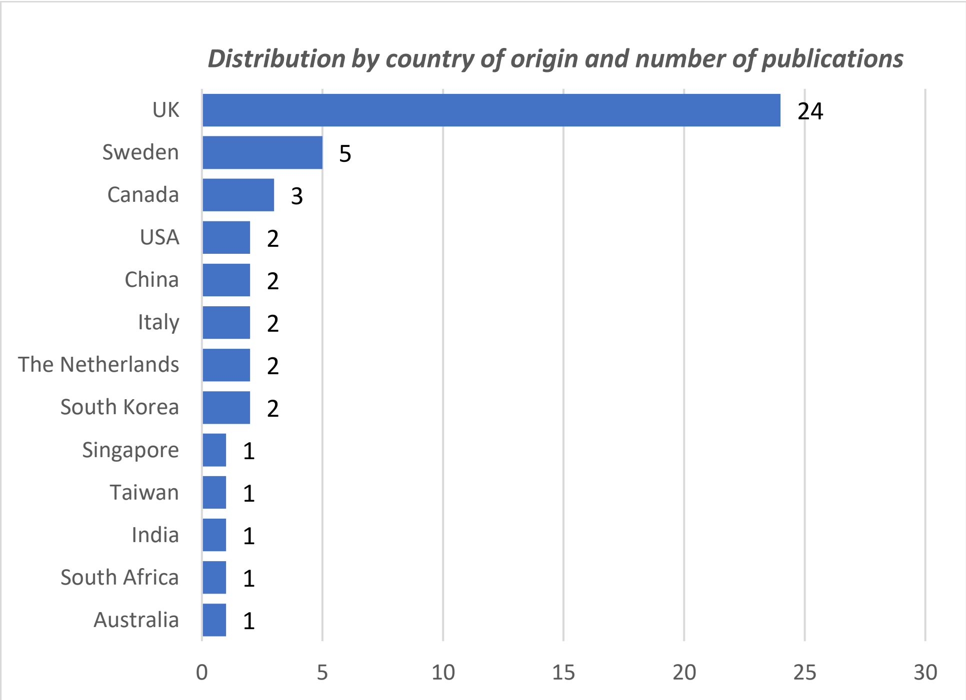

Figure 4-5: Distribution by country of origin of publication

The descriptive analysis shows that research activity on the topic of SCI in construction has increased markedly over the years in conjunction with increased activity in the sector. This trend signifies strong interest and practical relevance.

However, actual adoption of the subject matter is challenging due to its wide spread in conceptualisation and diffusing relationship with performance. While the term SCI is defined, knowledge on its applicability in construction is highly fragmented and the topic has been approached from a variety of angles and in a number of journals.

4.3 Thematic Analysis

The following sections will present the SLR thematic analysis, namely the pathways that frame improvement in SCI in construction (see Subsection 4.3.1), the management practices (generic, focused, and specific) that operationalise integration efforts (see Subsection 4.3.2), and the outcomes of integration (see Subsection 4.3.3).

4.3.1 Supply Chain Integration Pathways

Focusing on the first sub-research question:
What are the characteristics of each integration pathway?

Fabbe-Costes and Jahre (2007) develop an SCI framework classifying the studies according to integration layers, and outline four intertwined integration layers: integration of actors (structures and organisations), flows (physical, informational, financial), processes and activities, and technologies and systems. The applicability of these layers to SCI can be traced to the seminal work by Childerhouse and Towill (2003); however, the suitability of this nexus (e.g. Kesidou and Sovacool, 2019) to a project-based construction context needs reviewing in more detail. In fact, the construction-based literature gives high importance to the integration of actors (e.g. Briscoe et al., 2004; Alderman and Ivory, 2007; Bygballe et al., 2010), flows (e.g. Bankvall et al., 2010; Segerstedt and Olofsson, 2010; Doran and Giannakis, 2011; Thunberg et al., 2017), processes and activities (e.g. Lu and Yan, 2007; Shelbourn et al., 2007; Vennström and Eriksson, 2010; Foerstl et al., 2013; Pero et al., 2015) and technologies and systems (e.g. Papadonikolaki and Wamelink, 2017; Papadonikolaki et al., 2017). Importantly, the layer of actors also captures the intrinsic complexity of human resource factors, which are often viewed in isolation (Chan et al., 2001; Izam Ibrahim et al., 2013; Van Tam et al., 2021).

It appears that focusing SCI efforts in construction can be framed through these four pathways of integration. This presents a holistic approach of how construction organisations can embark on and manage their integration efforts.

4.3.1.1 Integration of Actors

Construction SCs on large projects typically involve hundreds of different companies supplying labour, materials, components, equipment and a wide range of professional services (Cox and Ireland, 2002; Briscoe and Dainty, 2005). Working with fewer suppliers (as opposed to a high degree of subcontracting) is increasingly becoming more attractive to main contractors in construction, as it reduces complexity and improves communication on projects. Furthermore, consolidated work packages, executed by fewer, integrated suppliers can improve construction management through better value identification and value realisation on projects (Akintoye and Main, 2007; Anvuur et al., 2011; Adam and Lindahl, 2017). For construction organisations developing SCI, through the pathway of integration of actors (structures and organisations), it is important to understand the competencies and capabilities (Eriksson et al., 2008; Eriksson, 2015; Broft et al., 2016) of each actor. This enables the 'optimum' number of organisations to be involved and appropriately structured for value realisation within the integrated SC.

4.3.1.2 Integration of Flows

Productivity in construction is a worldwide issue, as low productivity adds cost to projects without adding value. Many studies provide lists of factors impeding productivity, but few focus on identifying a pathway to reduce productivity losses (Seadon and Tookey, 2019). From an SCI perspective, productivity involves taking an end-to-end SC perspective and integrating flows (of material, information, and finance) to achieve stability and predictability in series of construction activities (Dubois and Gadde, 2001; Eriksson et al., 2008; Sacks, 2016). As such, construction organisations embarking on the pathway of integration of flows need to focus on developing continuous recurring flows (of information, materials and finance) between construction partners to improve productivity.

4.3.1.3 Integration of Processes and Activities

The demand for construction work can show considerable variation due to both the frequency (intermittence) and size (lumpiness) of projects in a pipeline (Godsell et al., 2018). This makes projects appear both unpredictable and non-repeatable while high commonality in requirements may exist between them. Not accounting for the possible efficiencies locked in SCM, construction companies often create a new SC for each project, in contrast to SCI principles. Research has shown that many construction projects contain processes and procedures that are repeatable across projects, enabling improvements in performance obtained by economies of repetition (Davies and Brady, 2000). Construction organisations embarking on the pathway of integrating processes and activities need to develop a clear understanding of the types of projects and what these mean from SCI requirements perspective. As such, this pathway involves integration of SC members into an overriding SC processes and activities aligned by type and groups of construction projects.

4.3.1.4 Integration of Technologies and Systems

Without the adoption of technologies and systems, construction organisations may be unable to fully utilise SCI and therefore miss out on opportunities to develop seamless processes, recurring flows, integrated planning, visibility and effective buffer management (e.g., Papadonikolaki and Wamelink, 2017). Recently, construction organisations have focused on the adoption of digital technologies in four key areas: (1) collection and analysis of digital data, (2) creation of autonomous systems, (3) connectivity and synchronisation of activities across SCs, and (4) digital access to SC data (Schober and Hoff, 2016). For construction organisations embarking on the pathway to integrating technologies and systems, this involves the integration of various available technologies and systems between SC members into a unified whole (e.g., product platforms) (Jones et al., 2021). Examples include integration of building information modelling (BIM), digital solutions, specialist equipment and production technology.

4.3.2 Management Practices to Improving SCI

Focusing on the second sub-research question:

What management practices enable improvement in SCI for each pathway?

Leuschner et al. (2013) and Eriksson (2015) characterise SCI through four dimensions: the strength, scope, duration, and depth of integration (see Table 4-2) and these are used as a framework for synthesis in conjunction with the four pathways for SCI .

Table 4-2: Description of the four SCI dimensions

Dimension of SCI	**Description**
Strength	The strength of SCI in project-based organisations depends on the extent of informational, operational, and relational integration.
Scope	The scope dimension is associated with the number and nature of SC partners and their interdependencies.
Duration	The duration dimension involves the length of the relationship over a series of projects and the timing of involvement in a single project.
Depth	The depth of integration relates to customer involvement and top management commitment in integrative activities across the partnering organisations, thus also capturing the aspect of internal integration.

The SLR revealed that SCI in construction can be operationalised through a number of management practices (see Appendix B-1) that support the pathways towards improved SCI. These practices are classified as generic (required in all four pathways), prevalent (required in three pathways), focused (required in two pathways) and specific (to one pathway).

The practices are also clustered into relational dimensions: strength, scope, duration, and depth. This classification of management practices was developed by Eriksson (2015) and helps to provide some structure to the 20 individual management practices. Ten of the management practices relate to the strength of relationship, a strategic connection among partners based on attitudes of trust, commitment, and long-term orientation (Leuschner et al., 2013; Eriksson, 2015); six to the scope, highlighting the use of resource sharing and the importance of demonstrating the right behaviour in SCI (e.g. Wagner and Johnson, 2004; Van der Vaart and van Donk, 2008); two to duration, as required for establishing continuity in SCI over a series of projects and setting the right expectations and timing of involvement in single projects (e.g., Wood and Ellis, 2005; Eriksson, 2008; Crespin-Mazet and Portier, 2010); and the final two to the depth of the established relationships, which relates to customer involvement and top management commitment in integrative activities across the partnering organisations, thus also capturing the aspect of internal integration (Eriksson, 2015). Whilst 20 practices were initially identified by the SLR thematic analysis identified five practices (CDM, DA, CSB, PP, IDN) from the SLR, but compared to other practices these did not appear as frequently in the literature.

Table B-1 in Appendix B-1 provides an overview of the thematic classification used for synthesis from the literature with supporting evidence from the articles in the SLR. The table classifies the literature in terms of the 20 management practices, their relationship to each of the four pathways, and their associated related dimensions (strength, scope, duration and depth).

4.3.2.1 Generic Practices

There are four generic practices identified that are required for all SCI pathways. Two are focused on the strength of relationship (commitment and long-term orientation) and two on the depth of relationship (customer involvement and top management commitment). Each of these is discussed in turn.

Commitment (CM)

Low or uneven commitment is often attributed as a major inhibitor to SCI in construction (Davis and Love, 2011; Broft et al., 2016; Kim and Nguyen, 2018). Commitment includes the contractual relationships between partners, risk allocation practices and objectives alignment. In construction, SC contractual relationships indicate the level of expected commitment from partners. In increasing order of commitment, construction contracts are usually as follows: normal tendering contract, preferred partners, SC framework agreement and uniform administrative conditions contract (translated from the Dutch 'Uniforme Administratieve Voorwaarden' UAV-GC). The UAV-GC is an integrated form of contract, which has a strong project-based orientation, provides reusable information across projects, resonates with prior partnering commitments and encourages future long-term relationships (e.g. long-term goals such as maintenance of assets) (Papadonikolaki et al., 2017). Commitment also relates to risk allocation, which describes, 'how the risk is allocated and the reward is given' (Meng et al., 2011, p.99). In construction, this usually executes through gain and pain sharing schemes, which define 'the level of sharing of profits or cost savings as well as losses or cost increases among the owner, the designer, and the constructor' (Mesa et al., 2016, p.1092). As SCI maturity improves, partners are expected to develop relational integration through commitment in risk sharing, allocation and balance of risk and reward (Meng et al., 2011). Lastly, commitment in SCI also depends on 'the level of alignment of interest and objectives among the owner, the designer, and the constructor' (Mesa et al., 2016, p.1092). Uneven commitment among the project participants is often identified as a major problem to the success of partnering arrangements (Kim and Nguyen, 2018). As highlighted by Meng et al. (2011), the three areas of setting objectives in construction are alignment (towards long-term mutual objectives), benefits (towards win-win in the long-term) and continuity of work (towards guaranteed future work).

Long-term Orientation (LTO)

Long-term orientation refers to supplier relationships based on recurring arrangements and supplier involvement, instead of competitive bidding and arm's length relationships (Turkulainen et al., 2017b). Such orientation is established through perceiving and striving for suppliers as long-term partners. Developing LTO relies on high levels of collaboration between partners, often based on a close working relationship, no-blame culture, teamwork and attitudes of mutual help (Mesa et al., 2016). In addition, LTO requires procurement practices based not solely on price, but multi-criteria from a long-term perspective (Meng et al., 2011).

Customer Involvement (CI)

Customer involvement is characterised by communicating with and integrating clients' end users in engineering projects (Kleinsmann et al., 2010). This enables SCI, as end users can contribute to the design work with valuable insights based on their high level of expertise and infrastructure network intelligence. Importantly, the client can commit to the end product before handover. This approach is minimising discrepancies between partners' different internal functions, which are involved at different stages of a project (Olson et al., 2001). Reciprocally, educating the customer in how SCI realises value can enhance CI and its practical adoption in construction.

Top Management Commitment (TMC)

In the context of engineering projects, it is argued that TMC is critical for integration (e.g. Johnsen, 2009), while personnel at lower hierarchical levels can strengthen collaboration (Zheng et al., 2008) by increasing behavioural transparency and reducing information asymmetry (Dyer, 1996). In practice, this could mean that main contractors need to increase the depth and strategic importance of their relationships with subcontractors, especially where the majority of work efforts take place (Eom et al., 2008). Appropriate TMC can focus SCI efforts and facilitate capturing value through the SC echelons. Davis and Love (2011) point out that TMC is demonstrated through the way in which a firm organises patterns of contact with its partners, the frequency of contact and the level of personnel involved.

4.3.2.2 Prevalent Practices

Prevalent pathways are those where management practices apply to all but one of the pathways. There are two sets of prevalent management practices. The first set applies to all pathways except technology and systems. There is one management practice in this category, timing of involvement, which relates to depth of relationship. The second applies to all pathways except actors, and three management practices (joint strategic planning, joint operating planning and trust) that relate to strength of relationship. Each will be discussed in turn.

4.3.2.2.1 All Pathways Except Technology and Systems

Timing of involvement in a single project (TI) is the only management practice that occurs in all pathways except technology and systems. It relates to the duration of the relationship.

Timing of Involvement (TI)

Rönnberg-Sjödin et al. (2011) convey that the length of engineering projects also allows achieving strong integration within a single project, especially if partners collaborate over the many project stages. The importance of timing relates to procuring contractors and suppliers early, in order to contribute to collaborative and customised design (Salvador and Villena, 2013) and set up continuous flows (Bankvall et al., 2010). In addition, from initiation to later phases of a construction project, actors are known to change their views on desired partnering characteristics (e.g. cost, cooperation and teamwork) (Wood and Ellis, 2005). Thus, the timing of involvement in a single project can provide actors with more time to socialise and tune in to the partnering spirit (Eriksson, 2008) and set the right expectations (Dainty et al., 2001b).

4.3.2.2.2 All Pathways Except Actors

All three of the prevalent management practices that exist in all pathways except actors (joint strategic planning, joint operational planning, and trust) relate to the dimension 'strength of relationship'.

Joint Strategic Planning (JSP)

Joint strategic planning in SCI is characterised by 'the extent to which supply chain partners actually forecast demand and plan business activities jointly while taking into account each other's long term success' (Kim and Lee, 2010, p.959). In other words, JSP defines an advanced level of inter-firm interaction (e.g., Johnson, 1999; Hult et al., 2007) that leverages the coordination of information to develop informed, inter-firm, and long-term decisions (Richardson, 1990).

Joint Operational Planning (JOP)

Joint operational planning refers to systemic co-ordination of information between partners in the integrated SC. Systemic co-ordination enables partners in inter-firm forecasting and planning (Sanders and Premus, 2005; Rai et al., 2006), building on the consolidated and routine electronic transactions and information exchanges along the SC.

Trust (T)

In SCI, 'trust has a significant influence on the relationship between the parties' (Meng et al., 2011, p.99). The level of trust that exists between partners manifests through the type of trust exhibited, confidence in others' behaviour, monitoring of others' work, as well as situational trust influencing factors.

In increasing levels, the type of trust shared can be: contractual, competence-based, short-term goodwill and long-term goodwill trust (Meng et al., 2011). Regarding confidence in others' behaviour, partners can exhibit from little to full confidence. Limited trust can also manifest through checking and monitoring others' work, while high levels of trust make checking almost unnecessary. Trust influencing factors relate to situational expectations and views that influence trustworthiness and trustfulness attitudes. Examples include perception of future work opportunity, project-specific circumstances, economic climate, payment practices, etc. (Manu et al., 2015).

4.3.2.3 Focused Practices

In addition to the generic practices, the SLR also revealed management practices that applied to pairs of pathways; two practices applied to the actors and flows pathways and two to actors and processes & activities. Each set of focused practices will be discussed in turn.

4.3.2.3.1 Focused management practices: actors and flows pathways

The first focused management practice, for the actors and flows pathways, relates to the scope of the relationship, and is resource sharing. Duration of relationship only has two management practices (timing of involvement in a single project and length of relationship over a series of projects) from which LR is focused on the actors and flows pathways. Each of the two management practices is discussed in turn.

Resource Sharing (RS)

Integration of actors and flows relates to the extent of adoption of resource sharing practices. This is characterised by 'the strategic integration of buyer resources with supplier resources and the extension and blending of relevant activities between the buyer and seller firms' (Wagner and Johnson, 2004, p.725). Partners with high levels of resource sharing can affect prioritisation in the allocation of resources in the integrated SC. Furthermore, high levels of resource sharing can foster value engineering, but also create implications for maximising 'value and responsiveness with optimal number of SC actors to changing customer needs and market dynamics' (Pillay and Mafini, 2017, p.8).

Length of Relationship over Series of Projects (LR)

A longer duration span over a series of projects strengthens integration, because the partners become familiar with each other, develop mutual trust and enhance possibilities of future work, as they develop collaboration rather than opportunism (e.g. Zheng et al., 2008). Low frequency and separation of projects into different stages, often executed by different actors, make the duration dimension critical for SCI (e.g. Crespin-Mazet and Portier, 2010). In practice, strategic arrangements in construction, spanning a series of projects are unusual (Bygballe et al., 2010). While there is evidence in the literature of partnering ventures between main contractors and their clients, partnering agreements with production subcontractors and materials suppliers are less common (Dainty et al., 2001a). This is largely due to the client applying commercial pressure, translating into switching suppliers between partnering projects, regardless of actors' good performance (Alderman and Ivory, 2007). Such practices lead to the abandonment of partnering, send shocks to the SC, inhibit effective and efficient flows (of information, materials and finance) and exacerbate fragmentation, thus preventing SCI from aggregating value. In contrast, successful strategic partnering arrangements spanning a series of projects and involving subcontractors, strengthen integration over time and allow for continuous improvements (Bresnen and Marshall, 2002; Caniëls et al., 2012).

4.3.2.3.2 Focused Management Practices: Actors and Processes Pathways

There are two management practices that enable the actors and processes pathways: joint work processes (related to strength of relationship) and behaviour of SC actors (related to scope of relationship). Each will be discussed in turn.

Joint Work Processes (JWP)

Pursuing better operational integration through joint work processes associates with the ‘intention of the firms within the supply chain to integrate their actions and interactively adjust their behaviours while pursuing opportunities over time’ (Leuschner et al., 2013, p.39). Such integrative actions include both short-term actions, such as improving supplier scheduling, resource visibility and capacity planning, and long-term actions, such as developing joint flexibility and SC adaptability (e.g. Ireland and Webb, 2007).

Demonstrating the Right Behaviour in SCI (B)

Van der Vaart and van Donk (2008) outline how integration includes patterns of behaviour. According to Wagner and Johnson (2004) and Johnston et al. (2004), evident behaviours in SCI are joint responsibility, shared planning and flexibility arrangements. However, these are often displayed only in a dyadic level buyer-supplier relationship. In a project-based construction context, behavioural aspects are guided by the role actors play in SCI (e.g. Titus and Bröchner, 2005) and as suggested by Turkulainen et al. (2017b) and Tsanos et al. (2014), a set of common antecedents that can moderate their behaviour towards improved value. Examples of antecedents can include: design class, value engineering, concept select planning, and availability assurance and reliability.

4.3.2.4 Management Practices: Specific to Each Pathway

Three practices were identified as being specific to an individual pathway. One management practice was specific to the actors (type of SC interdependencies) and two specific to the technologies and systems pathway (communication and use of supporting technology).

4.3.2.4.1 Specific Management Practices for Actors' Pathway

Understanding the types of SC interdependencies was the only specific practice for the actors' pathway and relates to scope of relationships.

Understanding the Types of SC Interdependencies (TSI)

Understanding the types of SC interdependencies shared between partners involves the TSI and the interdependent networks they constitute. The types of interdependencies between actors in the construction SC are important because 'difficulties in SCI might relate to how the temporary supply chains (for specific projects) meet with the permanent supply chains in production of raw material and components' (Bankvall et al., 2010, p.388). A way to understand these challenges is through the different types of interdependencies (pooled, sequential, reciprocal and synchronic) (Bankvall et al., 2010). For example, distinguishing pooled interdependence between activities relates different SCs to each other as well as different construction projects to one another. However, the types of interdependencies may give only a partial picture of the construction processes involved; they do not account for interdependencies based on the networks (of contractual relationships, performance incentives and information exchange) that may exist between partners. Discrepancies in and between these network categories can shift the point centrality of SCI and form coalitions that can lead to suboptimal results (Pryke, 2004).

4.3.2.4.2 Specific Management Practices for Technologies and Systems Pathway

Through the SLR, two practices appeared as critical to improving the integration of technologies and systems in construction. These are communication and use of supporting technology, both of which relate to the strength of relationships. Each is discussed in turn.

Communication (CM)

In construction, 'communication refers to the level of exchange of information, knowledge and skills openly timely and adequately among the owner, the designer, and the contractor' (Mesa et al., 2016, p.1092). In terms of information, this refers to 'the degree and breadth of exchanging information with supply chain partners' (Turkulainen et al., 2017b, p.1122). Regarding exchange of knowledge, team members in a construction project have not necessarily worked together before (Titus and Bröchner, 2005) and partners may not be familiar with the level of complexity underlying the integration of differentiated knowledge (Huang and Newell, 2003; Addis, 2016). Examples of such differentiation include the possibility of building offsite a proportion of the assets, modularity (Pero et al., 2015) or the buildability of design ideas (Godsell et al., 2018). It is thus necessary for SCI to establish communication channels that enable data and knowledge exchange. Lastly, communication also refers to exchange of skills. As pointed out by Costa et al. (2019, p.3) 'multi-skilled groups could mitigate problems related to customization and variability because they make it possible to overcome functional fragmentation and to cope better with every unpredictable situation'.

Use of Supporting Technology (ST)

In order to integrate, organisations need supporting technologies that facilitate information exchange across firms' boundaries (Rodrigues et al., 2004). To enable this, certain Information Technology (IT) attributes and functionality are required. In terms of attributes, SCI requires compatibility of Information Systems (IS) between construction partners (e.g. Xue et al., 2007), and flexibility that supports backward integration in suppliers' value chains (Elliman and Orange, 2003) and allows for project-based SC efficiency (Titus and Bröchner, 2005). Regarding functionality, SCI requires IT that offers speed and quality of information exchanged, and uses core building blocks as linked IS facilitating inter-organisational processes, consistent measures, aligned goals and share of risk and reward (Näslund and Hulthen, 2012).

The functionality of IT also needs to consider SCM as a cultural orientation and philosophy (Papadonikolaki et al., 2017), as ‘IT-enablement causes change in work culture and nature of work of some of the employees’ (Kumar and Pugazhendhi, 2012, p.2153).

4.3.2.5 Other Management practices

Four practices were identified, but not attributed to any of the pathways. These practices included co-ordinated decision making (CDM), developmental activities (DA), configuration of supply base (CSB) and power position of firms in the SC (PP).

Co-ordinated Decision-making (CDM)

Not accounting for the possible efficiencies locked in SCM, construction companies often create a new SC for each project, in contrast to SCI principles. As pointed out by Pillay and Mafini (2017, p.8) ‘supply chain integration is a common approach for resolving supply chain coordination issues within and between supply chains’. Thus, coordinated decision making ‘refers to the redeployment of decision rights, work and resources to the best positioned supply chain member’ (Leuschner et al., 2013, p.39). In practice, coordinated decision-making in SCI can align the demand profile (different construction project characteristics) to the best-suited SC configuration, resulting in systemic production channels facilitating material, information and finance flows (Xue et al., 2005; Godsell et al., 2018).

Developmental Activities (DA)

Developmental activities in operational integration include product and process engineering, joint investment, use of knowledge and capabilities within the strategic SC, and supplier development activities. Product and process engineering concerns the integration of products and processes across firms within the strategic SC (da Rocha and Kemmer, 2018). In practice, this is achieved by allowing suppliers to assume responsibility for product engineering and development activities, including suppliers’ understanding of the complexity and scope of coordinated processes within work packages (Koufteros et al., 2005; Ireland and Webb, 2007). Joint investment is simply ‘the extent to which supply chain members jointly invest in projects of mutual interest' (Leuschner et al., 2013, p.40). Examples include capital and equipment investments, financial investment, partial ownership or provision of resources (Modi and Mabert, 2007). Use of knowledge and capabilities is indicated by the extent to which members of the integrated SC have developed joint knowledge sharing routines and capabilities, applied to actual innovative practices, sharing of new ideas, and working together in identifying and implementing improvement initiatives (Saad et al., 2002; Saeed et al., 2005; Khalfan et al., 2010; Ataseven and Nair, 2017; Turkulainen et al., 2017a). Lastly, within the construction industry, suppliers are often classified via the use of preferred supplier arrangements, framework agreements and approved lists (Thorpe et al., 2003; Gosling et al., 2010). Addressing operational integration requires focused supplier development (Gosling et al., 2015). In order to develop SCI, supplier development initiatives should not be seen as 'one-size-fits-all', as many initiatives require significant investment. Instead, they should be deployed towards shaping the integrated supplier portfolio in accordance with the construction SCI needs (Wagner and Johnson, 2004).

Configuration of Supply Base (CSB)

The number of SC partners in the integrated SC is a supplier portfolio concept related to the configuration of the supplier base. Configuring the supplier base encompasses a number of sub-activities including reducing the number of suppliers, segmenting the supplier base, and assessing and selecting suppliers (Wagner and Johnson, 2004). A supply base that is best positioned to realise value from SCI, requires a healthy balance across partnership categories (approved, preferred, strategic) to allow main contractors to effectively configure the SC for different project requirements (Gosling et al., 2015).

Power Position of Firms in SC (PP)

The nature of actors involved in SCI also relates to their power position in the SC. Such a position is characterised by the 'extent to which the product or service is standardised or commoditised, number of alternative suppliers available to the buyer, number of alternative buyers available to the supplier, switching costs for both buyers and suppliers and the level of information asymmetry advantage that one party has over the other' (Manu et al., 2015, p.1496).

4.3.3 Outcomes of SCI in construction

Focusing on the sub-research question of:

What is the relationship between SCI and SC performance?

The SLR process revealed a loosely coupled relationship between SCI and SC performance measures. These span from broad strategic and business-related measures (Kagioglou et al., 2001; Bassioni et al., 2005), to project performance-related (i.e. Demirkesen and Ozorhon, 2017b), Supply Chain Operations Reference (SCOR) model-related (Pan et al., 2010), contractor-focused (Butcher and Sheehan, 2010) and supplier-focused (Eom et al., 2008; Gosling et al., 2015). In addition, some of the SLR articles investigate the link between SCI and performance by standalone, specific performance aspects (i.e. fabricator cost, owner cost, uncertainty in price, service level, dynamic demand) (e.g. Liu et al., 2017).

These findings suggest two areas for consideration. First, there is a missing link between the outcomes of SCI and performance improvement in construction. Second, SCI requires a set of outcomes that span all construction actors (customer, main contractor and subcontractors and suppliers). The work of Broft et al. (2016), building on the work of Holti et al. (2000), outlines seven construction-specific outcomes that SCI enables. These are: (1) compete through superior underlying value, (2) define client values, (3) establishing supplier relationships, (4) integrate project activities, (5) manage costs collaboratively, (6) develop continuous improvement, and (7) mobilise and develop people. Keung and Shen (2017) also highlight outcomes related to SCI, which fundamentally can be traced to the seven listed here. The SLR revealed that the relationship between SCI and these outcomes is well recognised in construction (see Appendix B-2, Table B-2); however, a framework showing the pathways and practices that can lead to achieving these outcomes has not been formulated until now. Following the work of Broft et al. (2016) and Holti et al. (2000) a synopsis of what each of these seven outcomes entails is presented in more detail in this section.

Compete through Superior Underlying Value (CTSV)

This outcome involves leveraging SCI for enhancing the value of what is actually delivered in principle, by a combination of improving quality and cutting underlying costs in whatever terms matter most to the client . The underlying assertion is that if the main contractor and key suppliers work together to offer lower prices or better solutions to meet the client's needs, this may provide the basis for increasing market share. Furthermore, this could also mean achieving routinely better and more predictable profit margins. It is worth noting that taking an SCI approach is far from the opportunistic practices of putting in bids at negative margins and then extracting profit by squeezing suppliers. This is achieved by using SCI to allow for collaboration between SC actors, each with their respective capabilities, in taking the 'right' costs out in order to arrive at competitive prices and mutual benefit. Practically, this outcome requires a good understanding of the customer's perception of value, insight into cost components, margins protection and taking out inefficiencies and waste in the SC. As the SC becomes integrated, margins are protected and partners have the security and investment to undertake the continuous improvement or innovation required.

Define Client Values (DCV)

Practically, this outcome involves applying a more rigorous way of assessing value, through clarification of the functional requirements, design character and target though-life cost profile of the delivered asset. In practice this involves assessing value through defining client value in output terms and the design of through-life cost performance. This outcome involves applying a more sophisticated way of measuring the cost of providing the desired functional requirements.

Establishing Supplier Relationships (ESR)

This outcome is one of the fundamental requirements of taking an SCI approach, as main contractors must demonstrate their commitment to forming long-term relationships with those companies, which represent the majority of suppliers of products and services to the kinds of construction projects they see as making up their business. The outcome aims at establishing encompassing relationships based on the long-term commitment of a small number of suppliers within each key supply category of the core business. This is done in a way that still allows variety and flexibility for different types of projects in various regions. In practice, arriving at this outcome is based on developing strategic relationships with the major organisations in the SC, which deliver approximately 80% of the value of any project.

Integrate Project Activities (IPA)

The outcome of integrating project activities aims at establishing mechanisms to decide which suppliers are seen as strategic long-term partners and through which effective management of suppliers on projects can be achieved. The outcome applies SCI as a mechanism for selecting strategic long-term partners best positioned to direct the effective management of partners collaborating on a project. The goal is to create clusters of actors and use concurrent engineering techniques applied by cluster leaders together with specialist suppliers, in order to respond at each key project interface and resolve all design-related issues early. In practice, this also requires focused effort by selected strategic partners in involving specialist suppliers early into the work clusters, agreeing prices with each of their cluster members and establishing structured commitment to processes and subsequent phases.

Manage Costs Collaboratively (MCC)

Traditional practices in construction often involve developing designs that later prove to be too expensive for the client and frequently result in profit margins and build quality being eroded. The outcome of managing costs collaboratively is essentially a process unlocked by SCI. This outcome utilises a specific approach in optimising costs referred to as “target costing”. In practice, SCI allows partners to work backwards from the client’s functional requirements and the maximum price for the item. Margins are detached from risk allowances and costs through ring-fencing, which allows security to look at underlying costs. Practically, this outcome involves suppliers identifying the impact of any design option on both the level of functionality and cost. Design options are generated and evaluated until a combination of options is found that meets the functionality and cost requirements.

Develop Continuous Improvement (DCI)

The outcome of continuous improvement is traditionally viewed as a vehicle for achieving long-term performance improvement, both in terms of what is delivered to the client and the profitability of the whole SC. The key aspects to achieving continuous improvement are: preventing construction activities going wrong rather than identifying subsequently that they were not done properly to begin with and a determination to utilise the contributions of everyone in the business continually to seek better ways in construction. In practice, this means paying far greater attention to planning how to do construction activities in advance, and seeing how problems can be anticipated and avoided. The emphasis of continuous improvement is on planning in the sense of mapping out the detailed work processes or methods, and then improving them so that they are compatible with whatever genuine client priorities are driving the overall project or programme**.**

Mobilise and Develop People (MDP)

The outcome of mobilising and developing people represents a key task in leading SCI towards learning the benefits of the approach, whilst recognising there are challenges to be met and some level of resistance and difficulty is to be expected. This outcome is associated with the substantial cultural change necessary in the construction industry. In practice, SCI allows better mobilisation and development of employees through four mechanisms: displayed systematic top-level commitment, focused training and acquisition of new skills, project teams' facilitation, and establishing economic incentives.

4.3.4 Summary of the Thematic Analysis

The thematic analysis, applying the lenses of dimensions and pathways of integration, has proven effective in structuring the knowledge of applying SCI in the construction of infrastructure projects. This led to establishing four distinct pathways that focus on integration through SCI management practices. The pathways form the basis of inductive reasoning towards what improvement SCI enables in construction, presented in this study as a set of outcomes. It is likely that the field will consolidate in future publications covering the four areas of integration: actors, flows, processes and activities, and technologies and systems, as the viability and configuration of emerging industry and academia developments in SCI appear to be within this nexus. The thematic analyses of the conducted SLR has proven useful in developing a CF for improving SCI in construction, as presented in the next section of this chapter.

4.4 Conceptual Framework Development

A comparatively large number and variety of management practices exist in the context of adopting the SCI approach in construction, which is reflected in recent research activity in this area that has outpaced research on other SCM developments. The conceptual framework developed fits the gap in the literature as identified through gap spotting. In particular, 'neglect spotting' of current research in concise management practices (e.g. van der Vaart and van Donk (2008), 'confusion spotting' in terms of defining the pathways characterising SCI (i.e. Fabbe-Costes and Jahre, 2008) and 'application spotting' as how it is utilised towards achieving the outcomes of SCI (e.g. Broft et al., 2016). Based on a review of the literature, 20 individual management practices appeared as relevant to SCI in construction. It is worth noting that these practices were inductively developed by the author based on similarities in SCI research by different scholars. These practices highlight the high level of complexity in SCI in a project-based context such as construction. Using the synthesis from the SLR has proven instrumental in differentiating between these practices and recognising the ones with higher impact and their relevant classification (generic, prevalent, focused and specific). In addition, the SLR positioned the four pathways (actors, flows, processes and technologies) as areas of synergy in converging integration efforts, explaining their role in SCI in further detail. Lastly, the SLR reviewed the relationship between SCI and SC performance to reveal seven value-based outcomes from improved SCI in construction. The synthesis of these main findings of the SLR led to the development of a CF, as presented in Figure 4-6.

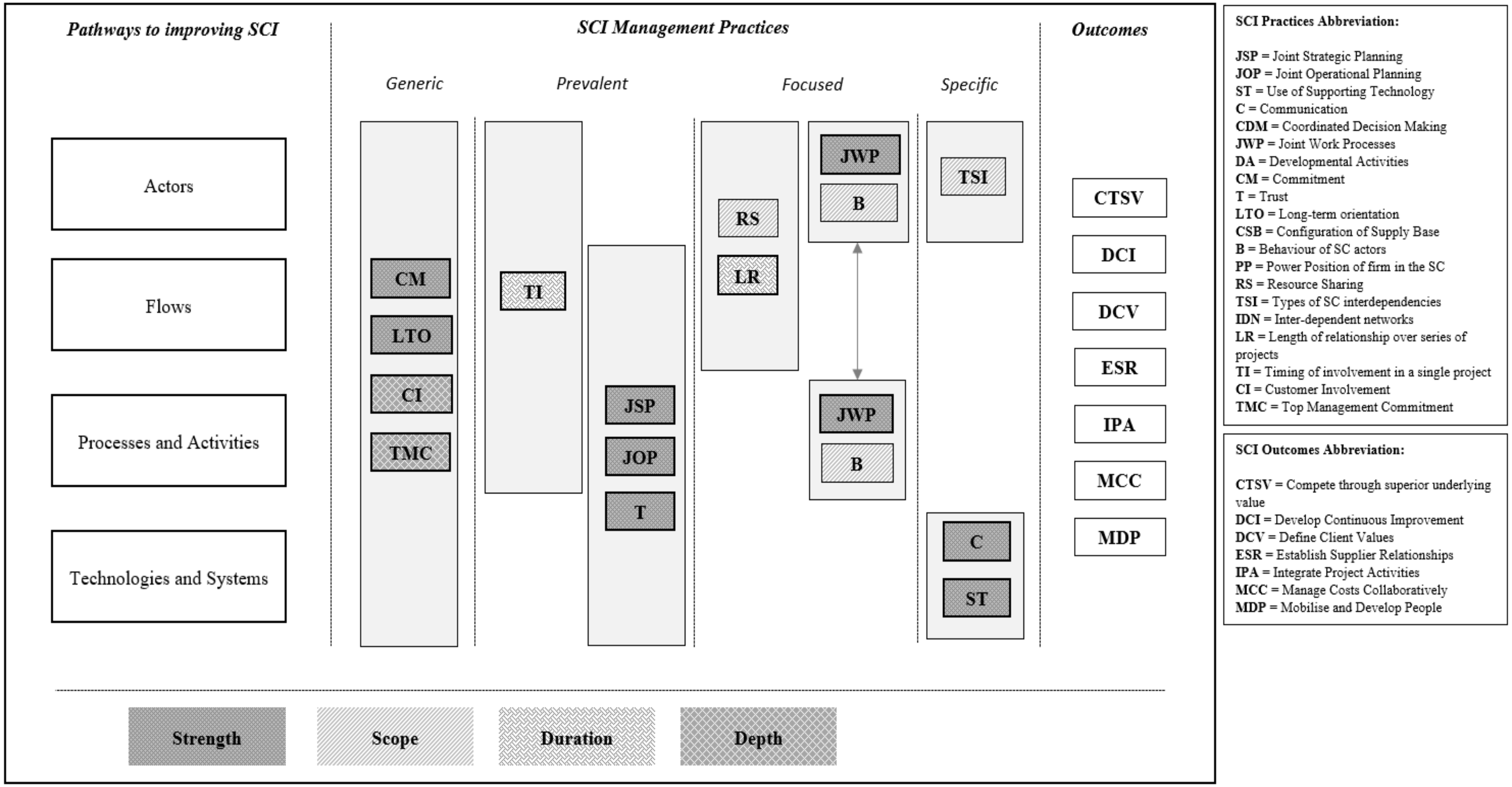

Figure 4-6: Conceptual framework of improving SCI in construction

4.5 Insights from the Conceptual Framework

This section aims at reviewing some of the preliminary insights from the developed conceptual framework of this study. As presented in the CF, the analysis of management practices for SCI by pathway, identified categories of practices that were generic, prevalent, focused and specific. The number of management practices specific to an individual pathway were relatively limited.. What this suggests is that there is a foundation of management practices that are common to all pathways and an essential ***prerequisite*** to improving SCI in construction. As illustrated in Figure 4-6, these prerequisites start with top management commitment (TMC) from the focal construction firm (often the managing contractor). The top management team need to work closely with the client, to intimately understand the customer requirements, involving the customer (CI) in the development of the contract that will underpin the project. The contract is critical to the project's success, as it is an articulation of the required level of commitment (CM) and long-term orientation (LTO) required by client, focal construction firm and their supporting SC. The initial contract with the client needs to be tuned in to the appropriate supporting types of contracts for the supply base.

With the prerequisites in place, the next level of common management practices required relates to ***planning***, both strategic and operational. This is a capability that is often missing within organisations in the construction industry, that more commonly focuses on project management capabilities rather than SC planning (Godsell et al., 2018). The contract enables the focal construction firm to work jointly with the client to translate the contract into a strategic plan (JSP), which in turn can be translated into a series of operational plans (JOP) to align demand and supply across the supporting SC. This determines the appropriate timing for the different suppliers to be involved in the project (TI). It also helps to build trust (T) across the SC, as all parties have visibility and a long-term perspective that enables them to effectively manage resources in their organisations.

With a solid and co-ordinated approach to planning, the focal construction firm is in a position to co-ordinate the ***execution*** and delivery of the project. At this stage there are two potential pathways for execution. The first focuses on the pathways related to the integration of actors, processes and activities. It is based around establishing the right behaviours (B) across the SC to develop a joint set of work processes (JWP) to deliver the project. The second focuses on actors and flows pathways. It focuses on understanding the type and length of relationship (LR) that is required to effectively share resources (RS). It can be further enhanced if the focal contractor has the capability to identify and manage the different types of SC interdependencies (TSI) that may occur within the SC.

Either of the pathways for execution can be ***technology enabled***. For technology to be an effective enabler, it is important to identify the most appropriate types of supporting technology (ST) that can communicate © the real time visibility of information required to effectively deliver the project.

4.6 Chapter Summary

This chapter has reviewed the existing literature through the method of conducting an SLR. The following outputs have been generated in this process:

- The descriptive results from the SLR were presented, outlining some of the main trends in SCI research in the construction context.
- The thematic results based on the SLR were presented in line with the three sub-questions formulated, highlighting a systematic approach to improving SCI in construction
- A CF of improving SCI in construction was presented as an outcome of the SLR, depicting the relationships to be empirically tested.
- Some preliminary insights from the CF were revealed and discussed towards a process of improving SCI in construction

Chapter 5 : Phase 2 Research Design: Delphi Study

5.1 Chapter Introduction

Following this introductory section, this chapter is split into three sections: Section 5.2 ‘Application of the Delphi Method’, Section 5.3, ‘Data Collection’ and finally, Section 5.4, ‘Chapter Summary’. The structure of this chapter is illustrated in Figure 5-1.

5.1 Chapter Introduction

5.2 Application of the Delphi Method

- 5.2.1 Delphi Characteristics
- 5.2.2 Study Procedure
- 5.2.3 Stability and Agreement
- 5.2.4 Delphi Study in Online Environment
- 5.2.5 Pilot Study

5.3 Data Collection

- 5.3.1 Relevant Population
- 5.3.2 Sampling Technique and Participant Selection
- 5.3.3 Required Sample Size
- 5.3.4 Questionnaire Design
- 5.3.5 Study Measures
- 5.3.6 Implementation of Research Ethics

5.4 Chapter Summary

Figure 5-1: Structure of Chapter 5

5.2 Application of the Delphi Method

In this section, first the Delphi method characteristics are described, giving an overview of the essential features of this Delphi study (see Section 5.2.1). Second, the design of this study is outlined in terms of the applied procedures to the stages of the Delphi (see Section 5.2.2). Following from this the choice of statistical techniques applied for analysis of the results is reviewed in line with stability and agreement requirements (see Section 5.2.4). In Section 5.2.4 the supporting technology as the medium for conducting the study in an online environment is reviewed. Lastly, in

Section 5.2.5, the use of a pilot study is reviewed as a means for examining the feasibility of the approach intended to be used in the actual, larger scale Delphi study.

5.2.1 Delphi characteristics

This section reviews the main characteristics of a Delphi study and how they are applied in this thesis. Following von der Gracht (2012), generally, the Delphi method is used in order to facilitate an efficient group dynamic process. It is conducted through an anonymous, written, multi-stage survey process with feedback from group opinions provided after each round. The Delphi methodology focuses on opinion building and aims at arriving at consensus among experts. There are four characteristics that underpin the success of applying the Delphi method: anonymity, iteration, controlled feedback and statistical group response. These characteristics are in turn reviewed in the context of this study.

In accordance with most Delphi studies, this study guarantees anonymity as the research design procedure is coordinated by a moderator, in this case the researcher. The questionnaires were filled in by the individuals and returned to the facilitator, who then used supporting software to provide the group response feedback in real time. This procedure has advantages over other group communication methods, such as committees and face-to-face group encounters, in a number of ways. First, anonymity assures specious persuasion does not occur, since anonymity reduces the effect of dominant individuals (Fisher, 1978). Second, there is no evident socio-psychological pressure on the panellists. Third, anonymity ensures that panel members can abandon publicly expressed opinions if they wish to do so, as they are not accountable for changing previously held opinion (Strauss and Zeigler, 1975). Fourth, anonymity often leads to higher response rates as participants feel more comfortable giving their input on uncertain issues in an anonymous form. Strauss and Zeigler (1975) highlight the benefits of anonymity in Delphi studies. In their research on political philosophy, most participants agreed that anonymity was one of the key factors contributing to the success of the research (von der Gracht, 2012). In this study, anonymity was guaranteed by the facilitator through the appropriate use of technology and was highlighted as a requirement to panel participants when briefed on their participation.

The second characteristic of a Delphi study is that the procedure is executed in a series of rounds (i.e. iterations). In this study this is the case for the 'Define' and 'Execute' stages of the research design. Considering the research design in accordance with timing and resource requirements, it was determined that a maximum of three rounds be provided on any given question. For each round, the judgements of respondents were aggregated by the supporting software and the facilitator provided them as feedback for the following round. An important point here is that in Delphi studies, this process is reiterated until stability in responses is attained, but not necessarily when consensus is achieved, which is often a mistaken impression (Linstone and Turoff, 2011). This iterative procedure permits social learning and the modification of prior judgements (Dunn, 2004). Previous Delphi studies have applied many different ways of determining when to stop the iterative process; these can include subjective analysis, descriptive statistics, and inferential statistics defining a stopping criterion. As is the case in this study, the provision of feedback from group response and possible refinements of the Delphi questions by the facilitator, usually led to declining statistical variance (convergence over succeeding rounds) (von der Gracht, 2012).

The third characteristic of a Delphi study is controlled feedback. It is termed 'controlled' because the facilitator has the role in deciding on the type of feedback and its provision. In this study as with most classical Delphi studies, after each Delphi round, the response data was statistically analysed and restated in aggregated form to the panel members.

The fourth characteristic of a Delphi study is statistical group response. This can be presented either numerically or graphically. In this study the use of the supporting software enabled presenting the group response graphically. Statistical group response usually comprises measures of central tendency (median, mean), dispersion (interquartile range or standard deviation), and frequency distributions (histograms and frequency polygons). In this study, the aggregated data was presented back to the panel members through the use of histograms and mean values of each round in relation to the question investigated. In this Delphi study, as with most other Delphi studies, after reviewing the group statistics, each participant was given the option of deciding whether to change their previous answer or to remain with their initial decision. Analysis of the data over successive rounds allows for measuring not only the existence of consensus and its strength, but also convergence of opinions.

5.2.2 Study procedure

The logic of the Delphi study procedure is presented in Figure 5-2. Overall, there are two important criteria to the success of a Delphi study; the first is stability in responses over consecutive rounds and the second is consensus. The first criterion 'stability' represents the stopping criterion of the Delphi study. Whether stability in responses is reached determines if additional rounds need to be undertaken. Following Dajani et al. (1979), consensus in panel members' responses is meaningless, if group stability has not been reached beforehand. Group stability is thus considered the necessary criterion. Dajani et al. (1979, p.84) define stability as 'the consistency of responses between successive rounds of a study'. There are two approaches to testing for stability in responses, individual stability and group stability (Chaffin and Talley, 1980). It is argued however that a lack of individual stability is unlikely to occur without group stability (Dajani et al.,1979). In this study, following Dajani et al. (1979) and Scheibe et al. (1975), testing for group stability was adopted as stability criteria, as the interest of the Delphi method lies in the opinion of the group rather than the individual.

Following Dajani et al. (1979, p.84) stability 'occurs when the responses obtained in two successive rounds are shown statistically to be not significantly different from each other, irrespective of whether a convergence of opinion occurs'. It is possible for different levels of agreement (convergence of opinion) among respondents to occur in any given round, regardless of whether that round is stable when compared to the preceding round. In essence, stability does not necessarily imply a given level of agreement, but only when a stable answer is reached analysis of the level of agreement should be conducted. In a hierarchical sense, the overriding criterion is that of stability, as it determines if results are of value in the final analysis. As stability is measured in consecutive rounds, a minimum of three rounds are required in the Delphi investigation. As suggested by Fan and Cheng (2006, p.218) 'research indicated that three iterations are typically sufficient to identify points of consensus'. Following their guidance and given the resource constraints of this study, a maximum of three rounds for any question investigated were used in this study.

Following on with the Delphi procedure further, provided stability in responses is reached, the results need to be analysed regarding whether consensus is reached. Consensus is one of the most controversial components of a Delphi study, as its measurement greatly varies (Crisp et al., 1997; Rayens and Hahn, 2000; Yang, 2003). This is caused by the controversial understanding of the term, which has caused researchers to adopt many different measures. Mitchell (1991) and von der Gracht (2012) point out that the standards for consensus in Delphi research have never been rigorously established. Due to the lack of established standards, it is often left to the researcher to define and explain how consensus is measured. In this study, following von der Gracht (2012, p.1528) and based on the American Heritage Dictionary of English Language, consensus is defined as 'an opinion or position reached by a group as a whole or by majority will'. Table 5-1 presents an overview of the Delphi terminology and statistical techniques, based on the hierarchical stopping criteria for Delphi studies presented in Figure 5-2. In the section 'Stability and Agreement', different techniques are reviewed in further detail with the choices for this study justified.

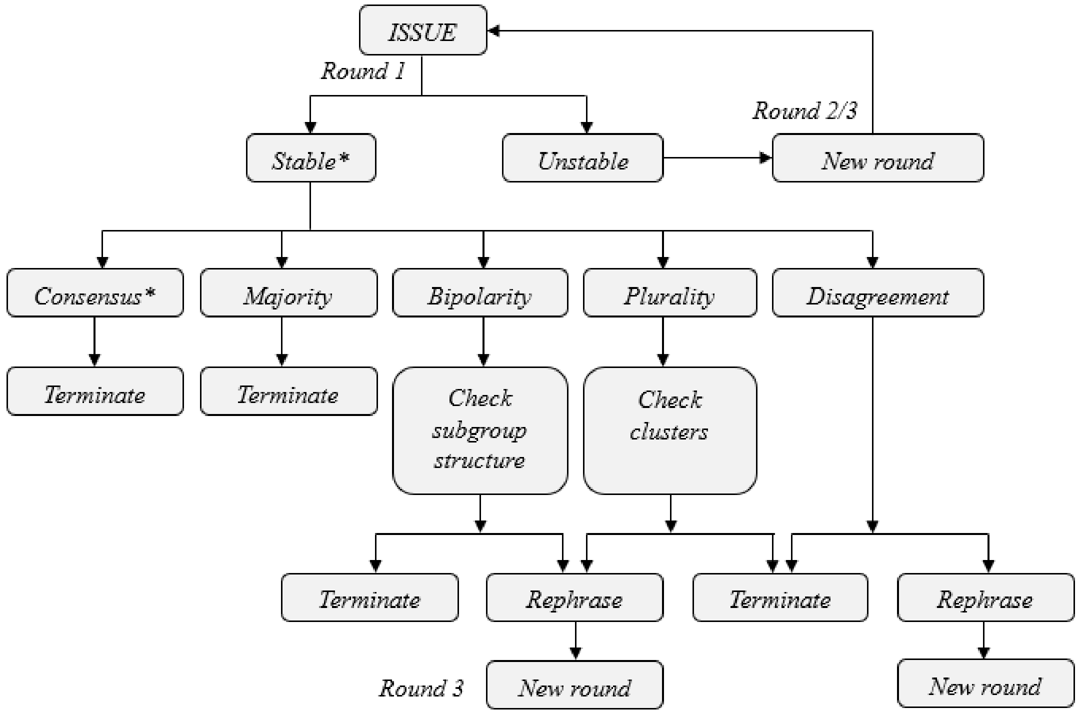

Figure 5-2: Hierarchical stopping criteria for Delphi studies (Adopted from Dajani et al., 1979)

Table 5-1: Terminology and measures adopted in this study

Delphi term	Description	Measuring Technique	Reference
Group stability	Group stability is the consistency of responses between successive rounds of a study. It is measured as the percent change in the projection distributions from round to round. A 15% change or lower in any two distributions can be considered a stable situation.	-Coefficient of variation (CV) $0<CV\leq 0.5$ -Central tendency Technique selected: ≤15% change between two rounds to determine as stable	English and Kernan (1976); von der Gracht (2012)
Consensus	Consensus can mean a group opinion, general agreement, or group solidarity in sentiment and belief. In this study a stipulated number of rounds is used. Due to the scope of the study, time frame for executing the study and resource constraints, no more than three rounds are performed. After the third round the investigation of the question is terminated.	Technique selected: Identify the degree of agreement with Kendall's concordance coefficient ($W \geq 0.7$)	Fan and Cheng (2006); Schmidt (1997); von der Gracht (2012)
Majority	Majority is defined as more than 50% of the respondents	Technique selected: Use of descriptive statistics with majority represented as more than 50% of respondents have selected one of the choices	von der Gracht (2012); Dajani et al. (1979)
Bipolarity	Bipolarity refers to two of the choices having a higher than and similar score to the rest as most effective	Technique selected: Use of descriptive statistics with two of the choices having a higher than and similar score to the rest	von der Gracht (2012); Dajani et al. (1979)
Plurality	Plurality refers to a larger portion of the respondents (but less than 50%).	Technique selected: Use of descriptive statistics with larger portion of respondents (but less than 50%) supporting more than one choice.	Von der Gracht (2012); Dajani et al. (1979)
Disagreement	Disagreement refers to the degree of agreement (or lack thereof) over that which would be expected by chance. Occurs when each respondent's views are independent of other respondents, such that the responses cannot be brought into consonance.	Technique selected: Use of descriptive statistics with degree of agreement (or lack thereof) over that which would be expected by chance measured with Kendall's W	von der Gracht (2012); Dajani et al. (1979)

5.2.3 Stability and Agreement

There is a wide range of different statistical techniques and measures adopted in previous Delphi studies. As outlined in the previous section, the two crucial criteria for a Delphi study are stability between rounds of the investigation and level of agreement (i.e. consensus) between panel members. Each is in turn reviewed in further detail in this section according to the different available approaches in line with their suitability to this study.

5.2.3.1 Stability testing

There are different approaches available in the literature, that have been used in past Delphi studies to analyse stability. In this study, stability is applied to the 'Define' and 'Execute' stages involving three rounds for the relevant questions in these stages. Stability refers to the consistency of responses between successive rounds of a study. It occurs when responses obtained in two successive rounds (distributions) are shown statistically not to be significantly different from each other, regardless of whether a convergence of opinion occurs. The criteria set for stability in this study is based on the use of coefficient of variation (CV) (standard deviation divided by the mean) of responses, with $0<CV\leq0.5$, following English and Kernan (1976) and von der Gracht (2012), as stability criteria. In this study, the investigation included three rounds for each question, ensuring that two consecutive rounds are present for each question. In the event of no stability having been reached at the third round, no further analyses on the question investigated were conducted and the results classified as not representative. A similar approach was adopted in the first task of the 'Execute' stage, following Scheibe et al. (1975), but formulated on the bases of change in responses of ≤15%. The analysis of stability in the 'Define' and 'Execute' stages, in line with adopted measures, is provided in the data analysis section of this study. Different choices of techniques used for measuring stability are presented in Appendix D-1. In Table 5-2, a summary of the different measures of stability applied in past Delphi studies is presented with discussion on their applicability to this study.

Table 5-2: Overview of measures of stability and discussion on applicability to the study

Measure of stability	Discussion on application
Coefficient of variation (CV)	To reduce the arbitrary nature of CV as a stability criterion, cut-off points are applied. In the context of this study the CV has been used for stability analysis in the ‘Define’ stage and the second task in the ‘Execute’ stage. In this study, stability is determined as a function of a good degree of CV between two rounds in each of the four rankings (distributions).
Change level of ≤15%	In this study, this technique was adopted in the identification of major outcomes in construction as part of the ‘Execute’ stage. Given that the selection task was not based on interval scale, instead of distance from the mode, the level of stability between rounds was calculated based on proportion of change in answers submitted per outcome.
F – test	This stability test is considered inappropriate for the purpose of this Delphi study. The samples of respondents between rounds are not independent and the questions are based on ranking, inclusive of four variables, which does not imply normal distribution.
F and X^2	The technique is not suitable because the panel members are considered as a group and it is not suitable to analyse subgroups of members in responses.

5.2.3.2 Reaching consensus

The technique used for measuring consensus is Kendall’s W coefficient of concordance following von der Gracht (2012) for the ranking questions in the ‘Define’ and ‘Execute’ stages. This technique is particularly suitable for ranking types of questions in Delphi studies. When stability is present, the responses were further analysed using Kendall’s W coefficient of concordance, with a measure of W≥0.7 indicating strong agreement (i.e. consensus). Given that the Delphi panel was a homogeneous group of members, the analyses were conducted on a group basis, making the use of Kendall’s W suitable.

Kendall’s W was calculated using the following formula:

$$\mathrm{W} = \frac{Variance\ over\ column\ totals}{Maximum\ possible\ variance\ over\ column\ totals}$$

$$W = \frac{12S}{m^2(n^3 - n)}$$

where S (the sum of squared deviations) is:

$$S = \sum_{i=1}^{n} (Ri - \bar{R})^2$$

and Ri is the total rank given by participants to the question and $\bar{R}$ is the mean value of these total ranks, respectively calculated with equations (1) and (2):

$$(1) \quad R_i = \sum_{j=1}^{m} r_{i,j}$$

$$(2) \quad \bar{R} = \frac{1}{n} \sum_{i=1}^{n} R_i$$

In some cases of applying this equation, a T value is used as a correction value for tied ranks. In this study, however, there are no tied ranks, as such a response option was not provided to the expert panel, reducing the overall complexity of the study. The parameters in the equation are: number of respondents to the question (m), number of available ranking options (n), the sum of squared deviations (S) and rank given to the question I.

A high W value represents high statistical significance and means that the participants are applying essentially the same standard in judging the importance of the issues. Usage of Kendall's coefficient of concordance (W) in ranking-type Delphi studies for measurement of level of consensus, is represented by its relative strength, as indicated by the pre-existing set benchmarks W=0.1 (very weak agreement), and W=0.7 (strong agreement).

For the step in the research design aimed at identifying the major outcomes out of the set of seven in the ‘Execute’ stage, the technique used for consensus, in accordance with the definition provided, is certain level of agreement (i.e., based on the majority of respondents, with more than 50% selecting one of the outcomes).

Generally, different techniques available from previous Delphi studies use descriptive statistics or inferential statistics, as presented in Appendix D-2 and Appendix D-3 respectively. In these tables provided in the appendix, the different techniques for measuring consensus are reviewed in further detail with justification for their potential use to this study. In Appendix Table 5-3 and Table 5-4 respectively, a summary of the different measures of consensus using qualitative analysis and descriptive statistics is provided through the use of inferential statistics.

5.2.4 Delphi Study in Online Environment

The type of Delphi study applied to this project is Real Time (RT) Delphi using a computer system (Geist, 2009; Xia and Chan, 2012). The Delphi was conducted online through Microsoft Teams, which was key supporting technology for the flow of communication throughout the event. All panel members were provided with joining instructions and a link for the event. Additional supporting technology was used throughout the event and was integrated through the MS Teams application. For the ‘Select’ stage MS Teams was integrated with ‘Miro’ as supporting software. For the Delphi stages ‘Define’ and ‘Execute’ where three rounds and feedback of ranking was required, MS Teams was integrated with ‘Slido’. This provided the software functionality for collecting, aggregating and displaying the results between rounds, so that participants could observe how other experts had answered the question at hand. This is a key part of the Delphi process and serves as a way to converge towards consensus in an ‘agreed’ collective answer.

5.2.5 Pilot Study

In order to ensure success of the Delphi event, a pilot study was conducted beforehand. The aim was to facilitate any required planning and modification of the main study. The pilot study was aimed at testing the research protocols, data collection instruments and the statistical techniques applied in analysis of the results in preparation for the actual Delphi event. This involved assembling a panel of seven university faculty staff with good knowledge of SCM, but not necessarily of SCI or construction. The pilot study was timed rigorously and feedback of the panel members' experience throughout the study was considered. Importantly, although the results were not included in the main study, the pilot study process confirmed that the planned number of activities included in the main study were manageable, the technology enabling the Delphi had been tested and the Delphi event could be expected to reach desired levels of stability and consensus in the findings. Based on the pilot study's feedback, a few minor changes were introduced in the 'Assess' stage of the Delphi investigation to ensure greater clarity and engagement with panel members.

5.3 Data Collection

In this section, the data collection process will be further detailed by defining the relevant population (5.3.1), the sampling logic (5.3.2) and sample size (5.3.3). In addition, this section reviews the questionnaire design (5.3.4), the relevant measures the research is drawing from (5.3.5) and the implementation of research ethics (5.3.6).

5.3.1 Relevant Population

The review of existing literature has shown that SCI is predisposed on two principles, both grounded in the value-chain paradigm, as explained in the introduction. The two principles are used as a consideration for the relevant population of this study.

The first principle is 'end-to-end' value chain orientation. Following this first principle, SCI starts with the customer and involves a minimum of three echelons. In construction these are the customer, the main contractor, and suppliers and subcontractors. Previous research has identified the critical role of the customer in setting up the right conditions for SCI to take place through their strategic planning processes (Briscoe et al., 2004; Godsell et al., 2018). In addition, it has been highlighted that value identification from strategic planning requires an alternative approach to value realisation, posed in this study as SCI. The current reality in value realisation can be described as the limited and disjointed involvement of different SC actors in construction. Here, the key consideration is the type of organisation as positioned in the SC (i.e., supplier, main contractor, customer). This means that the population of interest to this study comprises top-level management representatives of the three types of organisations across the SC, taking part in delivery of an infrastructure project. Essentially, the Delphi study population represents the different actors with decision-making power in their organisations with the common objective of improving SCI, enabling them to reach consensus. Given the power of the method, it would be most worthwhile to assemble a panel that is representative of the different actors (organisations) throughout the SC. Alternatively, focusing on a specific type of organisation (e.g., main contractor) in the SC, poses the risk of addressing only their perspective to SCI, thus limiting the pragmatic stance and external validity of the findings.

The second principle underpinning this study is ‘innovation through repeatability’. This principle positions this study in light of the better value realised as a result of improved SCI. The key supporting factor to this principle is use of differentiated SCI practices, pathways and outcomes to support effective and efficient delivery in construction. As outlined in the introduction, through improved SCI, it is suggested that through integration organisations can realise better value by developing ‘economies of recombination’ and ‘economies of repetition’. The critical requirement here is a population of experienced individuals possessing cross-functional expertise in construction SCs. Following the second principle, it is the interplay between different organisations involved in construction SCs that is of interest to this study.

As such, the relevant population is top-level management personnel with decision-making power and cross-functional experience, as well as highly experienced SC advisors with specialist knowledge of SCI.

5.3.2 Sampling Technique and Participant Selection

The RQs outlined in this thesis point towards the exploratory nature of this study with regard to its qualitative stage, and explanatory nature with regard to its quantitative stages. First, given the narrow context of the study in improving SCI in construction, a high level of specialism was needed in the Delphi expert panel. As the study tests the potential of key decision variables, the Delphi panel needs to consist of well-informed individuals able to provide expert judgement. Second, it is recognised that research on SCI in construction is in a nascent stage and involves a large amount of novelty as opposed to 'business as usual' practices. Conceptually, SCI can be relatively abstract subject matter as this study is positioned to some extent towards what is currently limited in practice. Addressing these two considerations, the Delphi panel was assembled to include key stakeholders with a SC in construction background, and all classified as domain experts (Scheele, 2002). Therefore, the panel was comprised both of academics with practical experience and practitioners. The panel members classified as academics were chosen not only on the basis of their academic merit in SCI, but also on the basis of their relevant practical experience in construction. The choice of including academics was justified by their ability to better capture SCI conceptually, while practitioners on the other hand better indicate how SCI can pragmatically work in construction. A sample size of 11 participants was selected based on the quality of the academic participants (i.e. level of construction experience) rather than based on quantity of participants. It is worth noting that although some of the experts in the panel are classified as academics, they also possess over 10 years of practical experience in construction SCs through various industry engagements. For the category of practitioners in the panel, the selection criteria were set as A minimum to: (1) education to undergraduate degree level and (2) over 15 years of experience in SCM in construction. Out of the 11 panel members, six are classified in the category of practitioners and five in the category of academics. Following the consideration above, to objectively understand the issues surrounding the adoption of SCI in construction from a systematic perspective, it was vital to gain responses from stakeholder groups with different types of involvement, positions in construction SCs and roles. The description of the strata of panel members is presented in Table 5-5.

Table 5-3: Description of strata of panel members by two categories

Category	Description	Number of representatives
Academics	• Leading academics in SCI in construction with 10 years of practical experience in construction (n=5)	5
Practitioners	• Construction experts with experience including as infrastructure clients (n=2) • Global construction and professional services organisations (n=2) • SC consulting organisations in construction (n=2)	6

The justification for the two categories of panel members is described in further detail below.

5.3.2.1 Academics category

This category of panel members consisted of academics with practical experience in construction. The in-depth knowledge and experience in SCI in construction of members in this group is evidenced by their highly ranked publication(s) on the topic and experience in various roles in the sector (i.e. SC consultants, technology consultants and other). The role of this category was particularly beneficial in supplementing and extending the insights to SCI in construction through their work experience across various SC functions and organisations. The nascent state of the topic of improving SCI in the construction context and the exploratory nature of this study benefited from this group, as experts with academic involvement were better positioned to grasp and narrow conceptualisations in responding to the questions investigated.

5.3.2.2 Practitioners category

This category consisted of top-level managers in large construction companies, specialist consultants and representatives of large infrastructure clients. This panel member group comprised highly experienced professionals in construction with clear decision-making and advisory responsibilities. The roles included principal consultants, SC directors, project director and procurement director in large UK organisations (over 5000 employees). The role of the practitioner panel was that of contributing to the study through reflecting on their industry expertise and providing clear practical judgement to the conceptual framework. All representatives in the practitioner panel are employed by organisations that have a span of operations involving first tier suppliers, main contractors as well as infrastructure clients in the UK.

The literature presents individual empirical choices on Delphi expert sample selection made on the basis of ‘convenience’, ‘purposive’ or ‘criterion’ sampling (Akins et al., 2005). The sampling technique used in this research is based on applying ‘criterion sampling’ in order to develop a homogeneous panel group (Hasson et al., 2000). The goal was to create a representative panel with sufficient expertise to answer the RQs. Following Karthy et al (2007), this approach to sampling involves the identification and use of cognate participants who are capable of addressing the issues raised by the investigated RQs. This goal was supported by two objectives. The primary objective in assembling the panel members was in developing a homogeneous panel of experts based on their SCM specialism, rather than a heterogeneous panel. As such, only SCM experts in construction were included in the panel, ensuring the sample matched the population of interest. The second objective was in setting inclusion criteria for panellist identification and selection. This ensured the selected participants are qualified to provide expert judgement and have strong interest in the topic. The criteria applied to each panel member were:

Identification

1. Education to an undergraduate degree

AND

2. Industry experience in construction SCM and relevant academic track record

OR

3. Industry experience in construction SCM of over 15 years

Selection criteria

1. Professional interest in SCI in construction
2. Cross-functional experience in construction SCM
3. Managerial decision-making power in their organisation

Assembling the experts to take part in the Delphi panel was rigorously documented throughout the selection process. This included identifying an initial 42 potential participants; out of those 42 potential participants, 20 were invited to take part in the study based on their response rate and the applied selection criteria. Out of the 20 potential participants, 12 followed up by confirming their attendance and returning their signed consent forms, and were accordingly briefed in preparation for the event. On the day of the Delphi event, 11 participants actually took part in the study.

5.3.3 Required Sample Size

There are no predetermined, strict guidelines, for sample size as an appropriate number of Delphi participants, existing in the literature, as Delphi studies have been done with few or many panel members. The panel size can be as small as three members and as large as 80 (Mullen, 2003; Grisham, 2009). Nevertheless, in this study deciding on appropriate sample in terms of the panel size was informed by other similar studies done in a construction context (see Table 5-6). The sample of 11 panel members in this study was decided as appropriate, taking into account the panellists' qualifications (specific and prequalified) and the complexity involved in the Delphi procedure through the number of rounds (three rounds required for each of the 14 questions with feedback between rounds). Evidence from previous similar Delphi studies undertaken in construction, suggests a number of 7 to 14 panel members (11 on average) with prequalified panel members and more than one round of investigation. Additional Delphi studies with similar number of participants, but not necessarily in construction context exist in the broader literature. This signifies the universal nature of the Delphi method to studies in other domains. With regards to sample size in other Delphi studies, use of large sample size is often overestimated. For example, Staggers et al. (2002) exemplifies this by showing in their study that appropriate level of participants is 9 to 11.Other Delphi studies without prequalified panel members and just one round of investigation have been done with 20 panel members, but often applying poor measures of consensus. Given the scope of the study (relatively complex consisting of three rounds) and the nature of participants (prequalified and with in-depth expertise in SCM), a sample of 11 panel members was deemed satisfactory. It is worth noting that a large sample, especially if heterogeneous, on a complex and nascent subject area such as SCI in construction, can shift the focus of the study with high levels of consensus difficult to be obtained within three rounds per question. This can represent significant risk to the success of the Delphi event, given the time constraints and the time dedicated by the expert participants.

Table 5-4: Studies applying the Delphi method in construction research (Adopted from Hallowell and Gambatese, 2010)

Study	Panellists' qualifications	Number of rounds	Number of panellists	Feedback	Measure of consensus
Arditi and Gunaydin (1999)	Specific prequalified	3	14	Mean	Standard deviation
Del Caño and de la Cruz (2002)	Specific, not prequalified	1	20	None indicated	None indicated
de la Cruz et al. (2006)	Specific, not prequalified	1	20	None indicated	None indicated
Gunhan and Arditi (2005a)	Specific, prequalified	2	12	Mean	Standard deviation
Gunhan and Arditi (2005b)	Specific, prequalified	2	12	Mean	Standard deviation
Hyun et al. (2008)	Specific, prequalified	3*	7	None indicated	None indicated
Robinson (1991)	Not specific	3	26	Mean	Standard deviation

*Involve three rounds of independent and unique surveys with no apparent feedback between rounds.

5.3.4 Questionnaire Design

The design of the final questionnaire for the Delphi event, beyond the pre-screening questions for selection of participants, followed a relatively complex structure. Given the encompassing scope of this study, the questionnaire included a qualitative part of collecting evidence in the form of 'anecdotal examples' and commentary drawing on the experience of panel members. In addition, the Delphi investigation included two quantitative parts comprising 14 questions in total. Essential for the success and efficiency in execution of the Delphi event was using a pre-loaded 'template-based' structure and pre-loaded questionnaire flow in Slido, facilitating the administration of the event. Sufficient time was provided for participants wishing to comment on the question investigated, review the results of the previous round and reiterate their response in the software. The relatively complex questionnaire structure and large amount of terminology used were key considerations for the reliability and validity of the results. To address these concerns, each of the participant members was briefed by the main investigator on the topic investigated, objectives of the study and relevant terminology through one-to-one 30-minute sessions conducted a week before the start of the Delphi event. This ensured participants were well-informed and gave an opportunity for any questions to be answered and clarification provided ahead of the event, as preparation for the actual event. Furthermore, the terminology included in the114evelop114nnaire was summarised In the invitation letter sent to each participant. This also included an overview of the design of the Delphi event and the areas and structure of the enquiry. In addition, on the day of the Delphi event all participants were briefed again through a 15-minute presentation on the planned activities in the investigation and the relevant terminology.

Data collection throughout the event was automatically recorded in the relevant software used. This included video and voice recording in MS teams, which was later transcribed in accordance with the 'Assess' stage of the Delphi event, feeding evidence to the qualitative part of the study. Recordings of 'anecdotal examples' and comments in responses were analysed after the event. A data extract from Miro was used for analysis from the 'Select' stage. A dataset extract from Slido was used to analyse the quantitative round-based questions in the study.

Throughout the questionnaire, no responses were mandatory, and this was stated in the participant information leaflet (PIL) and in the introductory presentation of the event. However, considering attrition rates of respondents to individual questions, participants were strongly advised not to terminate their involvement between rounds if they submitted responses to a given question.

5.3.5 Study Measures

Measures used in this study were informed from the SLR and measured at aggregated top level. This included 16 individual SCI practices and seven outcomes of SCI, ranked by four integration pathways. The focus of the study was on selection of importance between relevant SCI practices and their ranking in accordance with the four pathways of SCI, as opposed to measuring within individual practices. Nevertheless, aiming at higher reliability of this study, the SCI practices as individual constructs or as a composite of constructs that define them have been adopted by numerous other authors before. This highlights the relevance of this thesis to the SCM discipline and the continuity of this research to that which has been operationalised before. Given that this thesis' study measures links to previous operationalisations of used constructs with items and scales, this demonstrates the higher rigour of this study. In this section, the study measures used are reviewed, providing a synopsis of the measures' definitions and relevant operationalisations that can be used for future research of individual constructs in greater detail.

A synopsis of the definitions for each of the 20 practices is provided in Appendix C-1, with Table 5-7 below, exemplifying the aggregated 16 practices that were actually tested by the panel. Relevant support of these measures' operationalisation in the broader O&SCM literature is also provided. In terms of the four pathways of SCI, support for each was evident throughout the literature in the SLR. The synopsis of the definitions used for each pathway, as measures in this study, is provided in Appendix C-2. These definitions were constructed following Fabbe-Costes and Jahre (2008) and further refined by key informants who reviewed drafts of the research. Regarding the outcomes of SCI, the definitions of each outcome were based on the work of Broft et al. (2016) and Holti et al. (2000). The synopsis of relevant definitions for each outcome, as measures in this study, are provided in Appendix C-3. Given the narrative nature of the outcomes, a summarised synopsis was provided for each outcome also with regard to what it means in practice.

Table 5-5: Relevant operationalisations from the O&SCM literature for each of the 16 consolidated practices

	SCI Practice at consolidated top-level measure (n=16)		Related Practices from Literature Review (n=20)	Supporting reference of SCI practices as constructs adopted and measured by other authors
Strength Informational	1	Coordination of information transfer	-Joint strategic planning -Joint operational planning	Kim and Lee (2010); Johnston et al. (2004); Cua et al. (2001); Park et al. (2001); Samson and Terziovski (1999); Black and Porter (1996);
	2	Communication	-Communication	Wieland and Wallenburg (2013); Meng et al. (2011); Chesteen et al.(2005); Li et al. (2005); Goldstein and Naor (2005); Escrig-Tena and Bou-Llusar (2005); Chen and Paulraj (2004); Rosenzweig and Roth (2004); Koste et al. (2004); Karuppan and Ganster (2004); Ahmad and Schroeder (2003); Droge et al. (2003); Brockman and Morgan (2003); Goldstein (2003); Young-Ybarra and Wiersema (1999); Monczka et al. (1998); Adam et al. (1997); Gilgeous (1995); Roth and Jackson (1995); Karlsson and Ahlström (1995); Flynn et al. (1994); Roth (1993);
	3	Use of supporting technology	-Use of supporting technology	Pflughoeft et al. (2003); Carr (2002); Byrd and Turner (2001); Swamidass and Kotha (1998); Roth and van der Velde (1991);
Strength Operational	4	Coordinated Decision Making	-Coordinated decision making	Schilke and Goerzen (2010); Prasad et al. (2005); Hill and Scudder (2002); Frohlich and Westbrook (2002); Frohlich and Westbrook (2001); Flynn et al. (1999); Monczka et al. (1998); Sakakibara et al. (1997); Safizadeh and Ritzman (1997)
	5	Joint work processes	-Joint work processes	Swink et al. (2005); Cua et al. (2001); Young-Ybarra and Wiersema et al. (1999)
	6	Developmental activities	-Developmental activities	Shah and Ward (2007); Benton and Maloni (2004); da Silveira (2005); Swink et al. (2005); Koufteros et al. (2005); Chen and Paulraj (2004); Fullerton et al. (2003); Nassimbeni (2003); Krause et al. (2001); Curkovic et al. (2000); Krause (1990); Powell (1995); Ward et al. (1994); Roth (1993);
Strength Relational	7	Commitment	-Commitment	Lavie et al. (2012); Handley and Benton (2009); Jambulingam et al. (2005); Min and Mentzer (2004); Flynn and Saladin (2001); Krause (1999); Monczka et al. (1998); Ho (1996);
	8	Trust	-Trust	Lavie et al. (2012); Benton and Maloni (2005); Young-Ybarra and Wiersema (1999); Monczka et al. (1998);
	9	Long-term orientation	-Long-term orientation	Griffith et al. (2006); Chen et al. (2004); Chen and Paulraj (2004); Menor et al. (2001); Krause (1999)
Scope	10	Configuration of supply base	-Configuration of supply base	Schoenherr and Mabert (2008); Prasad et al. (2005); Chen and Paulraj (2004); Chen et al. (2004); Carr and Pearson (1999); Lawrence and Hottenstein (1995);
	11	Nature of partners	-Behaviour of SC partners -Power position of firm in the SC	Verwaal et al. (2009); Boyer and Hult (2006); Chen and Paulraj (2004); Nahm et al. (2004); Ahmad and Schroeder (2003); Atuahene-Gima and Li (2002); Venkatesh et al. (2002); Young-Ybarra and Wiersema (1999);
	12	SC interdependencies	-Resource sharing -Types of SC interdependencies -Interdependent networks	Carter and Carter (1998); Monczka et al. (1998); Gilgeous (1995); Dean and Snell (1991);
Duration	13	Length of commitment over series of projects	-Length of commitment over series of projects	Erikson (2015); Kaufmann and Carter (2006); Bagchi et al. (2005);
	14	Timing of partners' involvement in a single project	-Timing of involvement in a single project	Somers et al. (2003); Youngdahl et al. (2003); Karlsson and Ahlström (1995)
Depth	15	Customer involvement	-Customer involvement	Shah and Ward (2007); Hong et al. (2005); Koufteros et al. (2005); Cua et al. (2001); Flynn et al. (1999); Morita and Flynn (1997); Flynn et al. (1994);
	16	Top management commitment	-Top management commitment	Chen and Paulraj (2004); Douglas and Fredendall (2004);Forker et al. (1997); Ahire et al. (1996); Flynn et al. (1995);

5.3.6 Implementation or Research Ethics

Ethical considerations were addressed throughout this study as appropriate. In particular, informed consent was ensured by providing a PIL (see Appendix H). In the PIL, the study was described to the potential respondents in greater detail, including the study's purpose and funding, their right to withdraw and matters of compensation, confidentiality, and data anonymisation. Each respondent had the opportunity to view and download the PIL prior to participation and was encouraged to do so. Informed consent defining the premises of how participant data can be used constituted the return of a signed consent form.

Participant confidentiality was ensured by Outlook and MS Teams as invitations were sent for participation in the Delphi event without participant names and data being shared. Anonymity was also ensured through the use of MS Teams, as chosen software for gathering 'anecdotal evidence' as part of the qualitative data collection in the 'Assess' stage. Anonymity was further ensured through the use of Miro, as supporting software for the 'Select' stage and by Slido, as software used for hosting the Delphi event in the 'Define' and 'Execute' stages. Miro assigns a nickname to individual participants for administration purposes and Slido assigns numbers to respondents, therefore no identifiable information, such as names, addresses, email addresses, or other information that could be used to identify or contact the participants, was shared between participants. No participant compensation was included for taking part in the event and this was clearly stated in the PIL and in supporting emails.

Ethical approval from the University of Warwick's BSREC Research Ethics Committee was therefore granted to this study under the reference number: BSREC:BSREC 31/21-22 on the 20th of December, 2021 (see Appendix H, figure H-1).

5.4 Chapter Summary

This chapter has reviewed in further detail the Delphi study as the research methodology applied to this thesis. The main findings of this chapter are listed in the following:

- The characteristics of this Delphi study were described.
- The study procedure of the Delphi study was outlined with the relevant terminology and logic of the study.
- Different measures of stability and agreement were reviewed and the ones used in this study explained in further detail.
- The use of supporting software for conducting the Delphi event in an online environment was reviewed.
- A pilot study was executed and reviewed in order to test the real-time application of the study and the practical constraints of the Delphi.
- The relevant population of interest to this research project was reviewed and discussed.
- The choice of sampling techniques and participant selection approach were discussed.
- The required sample size was discussed in line with previous Delphi studies.
- The design of the Delphi questionnaire was reviewed in accordance with the relevant stages of the Delphi investigation and the relevant data collection software.
- The study measures were reviewed in further detail drawing on the literature for formulating them.
- The implementation of research ethics throughout the study was discussed.

Chapter 6 : Delphi Study: Results and Analysis

6.1 Chapter Introduction

This chapter is split into five sections. After this introductory section, Section 6.2 ‘Summary of Participant Response Rate’ reports on participants’ response throughout the stages of the Delphi event. Following on from this, in Section 6.3 ‘Qualitative Exploratory Results’, the qualitative data gathered from the ‘Assess’ stage, in the form of commentary and examples is analysed. In Section 6.4 ‘Conceptual Framework Results’ the results of the Delphi investigation in accordance with the presented conceptual framework are presented and analysed. Finally, Section 6.5, ‘Chapter Summary’ concludes and presents a summary of the chapter. The structure of this chapter is illustrated in Figure 6-1.

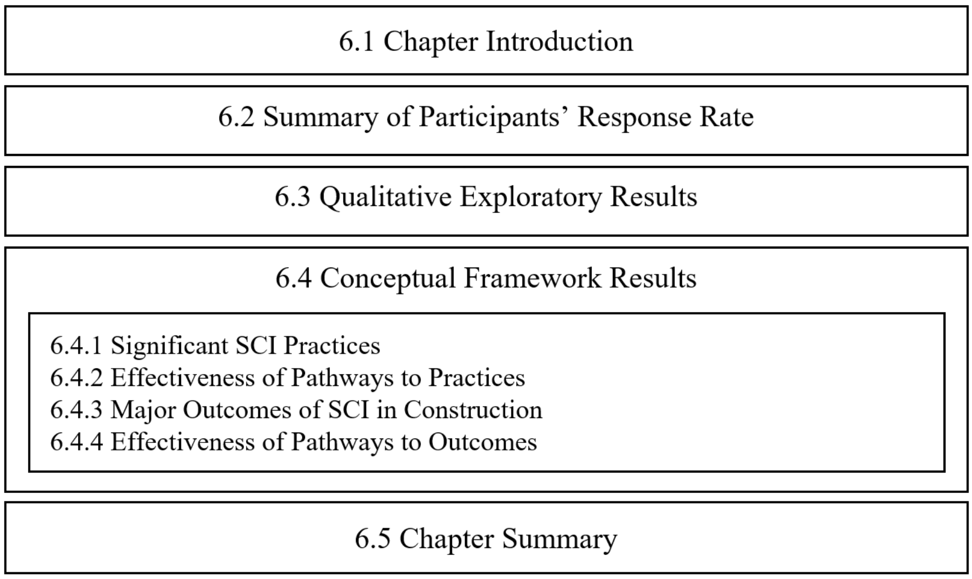

Figure 6-1: Structure of Chapter 6

6.2 Summary of Participants’ Response Rate

Table 6-1 reports on the participants’ response rate (in number of participants) throughout the stages of the Delphi event. A total of 11 respondents participated in the Delphi event. In the iterative three round process there was no deviation in the questions in the total number of respondents per round and no fewer than eight respondents per question. The total number of respondents in each stage is in line with accepted recommendations for Delphi panel sizes (Ludwig, 1997; Hallowell and Gambatese, 2010).

Table 6-1: Number of respondents per question in the Delphi study

<table>
<tr><th>Stage</th><th>Type</th><th>Question</th><th>Round 1</th><th>Round 2</th><th>Round 3</th></tr>
<tr><td rowspan="2">Assess</td><td colspan="5">Assess stage of practical relevance: Providing ‘anecdotal evidence’ in line with how SCI resonates with the real-life practical experience of panel members in construction</td></tr>
<tr><td>Assessment</td><td>Providing practical examples of applying SCI to construction</td><td>11</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">Select</td><td colspan="5">Selection of most significant practices: 10 points were given to each panel member to distribute across the SCI practices they regard as significant for improving SCI in construction</td></tr>
<tr><td>Selection</td><td>Significant practices from the SCI framework</td><td>11</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="7">Define</td><td colspan="5">Effectiveness of the four perspectives (Actors, Flows, Processes and Technologies) to each practice</td></tr>
<tr><td>Ranking</td><td>Supporting technology</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Joint work processes</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Commitment</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Trust</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Ranking</td><td>Long-term orientation</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Ranking</td><td>Length of commitment over series of projects</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td rowspan="11">Execute</td><td colspan="5">Selection of three major outcomes out of the seven to determine which are the major ones (achieving best value)</td></tr>
<tr><td>Selection</td><td>Selection of three major outcomes</td><td>9</td><td>9</td><td>9</td></tr>
<tr><td colspan="5">Effectiveness of the four perspectives (Actors, Flows, Processes and Technologies) to each outcome</td></tr>
<tr><td>Ranking</td><td>Compete through superior value</td><td>9</td><td>9</td><td>9</td></tr>
<tr><td>Ranking</td><td>Defining client values</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Integrate project activities</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Develop continuous improvement</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Establish supplier relationships</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Manage costs collaboratively</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>Ranking</td><td>Mobilise and develop people</td><td>8</td><td>8</td><td>8</td></tr>
</table>

6.3 Qualitative Exploratory Results

This section of the results presents the exploratory results of this study from the 'Assess' stage. This stage of the study was less restrictive and facilitated wider data collection from the expert panel in terms of suggestions, commentary and real-life 'anecdotal' examples of what constitutes improving SCI in construction. Responses of participants were recorded in the Delphi event and later transcribed. These quotes were then each attributed to the appropriate transformative areas identified through the scoping study. This was based on key words, meaning and context of each participant's input on improving SCI in construction.

Examples 1 to 7 present the results of the 'Assess' stage in the form of commentary and examples generated by the experts in the Delphi study. This data generated was transcribed from voice and video recordings collected on the day of the Delphi event. Accordingly, in the 'Assess' stage the expert panel members were asked to comment on how SCI resonates with their experience. The data collected from their commentary comprised evidence in the construction context where taking an SCI approach in value-realisation has proven beneficial in their work. In the literature review section of this thesis, the literature was used towards formulating six transformation areas from traditional SCM in construction to an SCI approach. Using a deductive logic of the research process, the transformational areas from the literature review were tested through the use of qualitative data. In this section the collected evidence was analysed by thematically linking each of the seven examples to the six transformational areas.

Each of the examples provided by the expert panel relate to one of the following transformative areas:

- Short-term vs. long-term relationships
- Function-based organisational structure vs. structure based on SC flows
- Functional siloes vs. outcome-based approach
- Decentralised planning vs. integrated planning across the SC
- Standalone work packages vs. continuous repeated work
- Ad hoc SC scope vs. SCI scope

Commentary 1: There is a need to establish the right context and type of integration

'We have to understand which SCI dimension is critical for which suppliers. From experience, I see multiple different situations that require a tailored approach. In some cases, integration is not desirable at all for the contractors, because if we assume it is a one-off transaction for the project it is likely that it will not happen again. In that case integration is not desirable at all. In other cases, main contractors might want to have it to a medium level for some strategic suppliers. Integration might be desirable, but still, it is desirable while understanding what is the cost at which it comes. As you know, all the contractors work under limited resources and so there is always a cost-benefit analyses, that drives the understanding of a match where integration can be pushed. In my opinion it is quite challenging which is the ideal level of integration. From my experience, understanding the desired level of integration is needed in the right context and for this it is critical to focus on the shared flows between construction organisations taking part in integration, rather than on individual functions. For example, it could be challenging if we move to sharing any intellectual property and processes within a firm, or not. Each of these areas can take a lot of time to be implemented in practice.'

Evidence attributed to:

- Function-based organisational structure vs. structure based on SC flows

Commentary 2: SCI requires the right conditions in order to take place

'The approach of SCI needs to be contextualised for a given setting and project that you are undertaking. From experience, we did exercise for different clients, segmentation of supply base and we adopted the classic Kraljic approach borrowed from the manufacturing world, but still quite effective to understand which are the purchased commoditised items compared to the strategic ones. Also, within Kraljic, within the four categories there were huge differences between different suppliers that were classified as strategic, because they were operating on different projects of strategic importance. So, it's really a challenge and in some cases, it looks as one-to-

one decision that has to be made on how to move the different levers of strength, scope, duration and depth of integration in order to understand what the different level of integration is. In essence, 'one size doesn't fit all' is often the case. In my experience, supply chain integration needs to be applied when the right long-term conditions are present by integrating planning of the supply base with the customer base. We need to get this right as for supply chain integration, financial security and trust play a big part, for example we may need to tie in capital in inventory. The same is true if we think of the customer in the downstream side of the SC. When we think of our customer, what level of integration do we want to have? Not all customers are the same, not all market segments are the same. Some customers are strategic and I want to follow them long-term, but cannot do it for all my customers. So, there are decisions to be made and, given the volatility of the market and the speed at which the conditions of the customer evolve, it would be difficult to make such a decision.'

Evidence attributed to:

- Decentralised planning vs. integrated planning across the SC

Commentary 3: SCI in construction requires moving away from a procurement mindset

'I don't wholly agree with taking the classic Kraljic approach because you are taking a procurement-oriented view of thinking about SCI. Kraljic would help you look at things from a 'strategic', 'bottleneck', 'commodity' perspective. For example, in a pharmaceutical company, because the bottle they used for three months was used as a commodity, they had no drugs for a while because they had no plastic bottles, so actually sometimes you need to think if things are critical materials or whether they are deemed as a commodity. So, we need to be careful, as one of the issues in construction is this procurement mindset and just looking at your supply base, as opposed to starting at client demand. Quite often this is the government or other big clients and actually we really need to think about the patterns that the demand sets up. Actually, this is where legal needs to come in a bit more, thinking about different contract types and more about the demand type of whether it could be repeatable or

it is something that is one-off. When we think of the demand patterns that are repeatable, integration can help us set up continuous repeated work and drive productivity. We then need to align the SC around that. For me personally, I think one of the biggest issues in construction is the procurement mindset.'

Evidence attributed to:

- Standalone work packages vs. continuous repeated work

Commentary 4: Attention should be focused on power of relationship, particularly, in the area of behavioural contracting and type of construction.

'I have been researching this area for probably about 15 years. So, I guess I have a bit of a head start for understanding some of this, because I looked at the issues at some of the client side contracts. Yes, you know, you have project 13, but many of the clients still favour the traditional contracts, so most of the contracts are set with penalties, not incentive mechanisms, so actually it sets the turn of the behaviour from the outset. You have this together with the fact that a common misconception is that contracting with another organisation means that you get the same results as the last project, while the reality is that you do not, because they are different individuals, therefore the behaviours and the dynamics that you get are totally different. Therefore, for me there are so many variables here, it is almost a question of saying 'I have to make sure that for instance, if I target something and develop these skills and develop these relationships then I'd better do it at something as modular construction, so that I narrow the number of variables to make SCI possible'. Otherwise, if you think about the different construction types from a very simple example as a structural example of a precast concrete frame, you keep going on and on and on. There are very different practices involved in each and every one of these, therefore there are a lot of variables involved. For me, a critical step is to define the scope of integration.'

Evidence attributed to:

- Ad hoc SC scope vs. SCI scope

Commentary 5: There is a need to develop an outcome-based approach to SCI

'The overarching point is that we need to think about this functional, contractual, procurement-based approach that we engage in. We need to move to much more value-driven outcomes approach. Clients like me and the NHS have conducted case studies, where we demonstrate that the use of a value-based approach results in large savings. We then translate savings back by using a simple green book analysis by partnerships with NHS trusts and factor significant capital savings on individual projects. This involves value outcomes that relate to the core business of a client and to the partnering organisations. From other cases I have been involved in, in construction, we can see how you direct the integration process based on higher productivity. Outcome-based approach to supply chain integration is essential.'

Evidence attributed to:

- Functional siloes vs. outcome-based approach

Commentary 6: There is a need for investment in relationships

'I would like to comment on where relationships' strength comes from. In my experience, part of this is what you might call 'one-shot games' and that is where the long-term comes in. So, if people think forming a relationship will have a benefit across time, across phases of a project and across projects, they are much more likely to put the time in the relationship than just a standard engagement and moving on. I think we slightly underestimate the time it needs to actually build a relationship; it is not something you can do quickly or easily; you really need to invest in it and therefore you need to make sure there is sufficient return.'

Evidence attributed to:

- Short-term vs. long-term relationships

Commentary 7: Less spent on procurement does not equal profitability

'I will give you some practical examples. When I was responsible for commissioning facilities, what we started to focus on is the way we procured professional services and facilities by working on more relational bases. At the time I had not fully formulated my thinking on approaches such as relational contracting. It was quite interesting the outcome that we got, based on the longer-term relationships with architects, engineers and professional service providers and key enabling organisations within the SC (equipment and modulated facilities providers). Actually, we did so much better in terms of on-time, solving problems, integrating with different suppliers. The outcomes were better in terms of production of the facilities. An example was that we actually spent more money on a facility in a year, which was hard for a procurement director to advocate spending more money and go to the board and support this as a business case, but in reality, the profitability of that facility was a million more than the other facilities. This is simply because we approached it in a different way, absentees in the workplace dropped as well as other benefits.'

Evidence attributed to:

- Short-term vs. long-term relationships

6.4 Conceptual Framework Results

This section presents the results of the Delphi event in accordance with the conceptual framework as devised from the SLR. The SLR applied in this study suggests 20 individual practices (as described in Appendix C-1). Given the high number of practices and the added complexity, the practices were reduced to 16 by consolidating them in accordance with other studies where the same underpinning constructs have been investigated (see Subsection 5.3.5 'Study Measures'). Following the research design of the study, the results from the 'Select' stage present the SCI practices determined as significant by the panel and served as input to the consecutive 'Define' stage. The 'Execute' stage follows the same logic of application of the Delphi method as in 'Define', but investigated the relationship between the four pathways and seven outcomes of SCI. In addition, in the 'Execute' stage the Delphi process was applied towards identifying the 'major' outcomes of SCI in the construction context. The results of the ‘Select’, ‘Define’ and ‘Execute’ stages are in turn reviewed in this section derived from the conceptual framework developed through the SLR. As such, the applied logic of the research process is deductive. The full dataset and developed instrument for analysis can be obtained from Appendix G.

6.4.1 Significant SCI Practices

The 16 SCI practices were presented to the expert panel with the opportunity to score them by distributing 10 points to the practices they chose as being essential to improving SCI in construction.

This exercise represented the ‘Select’ stage of the Delphi event as outlined in the research design. All 11 panel members took part in choosing between the 16 practices which represents a total of 110 points distributed between practices. Based on the results, the following heat map (see Figure 6-2) of practices was developed, classifying them into three categories (most significant practices, practices with medium significance and least significant practices). The heat map provides an overview of the practices with relevant aggregated score to each, as determined by the expert panel.

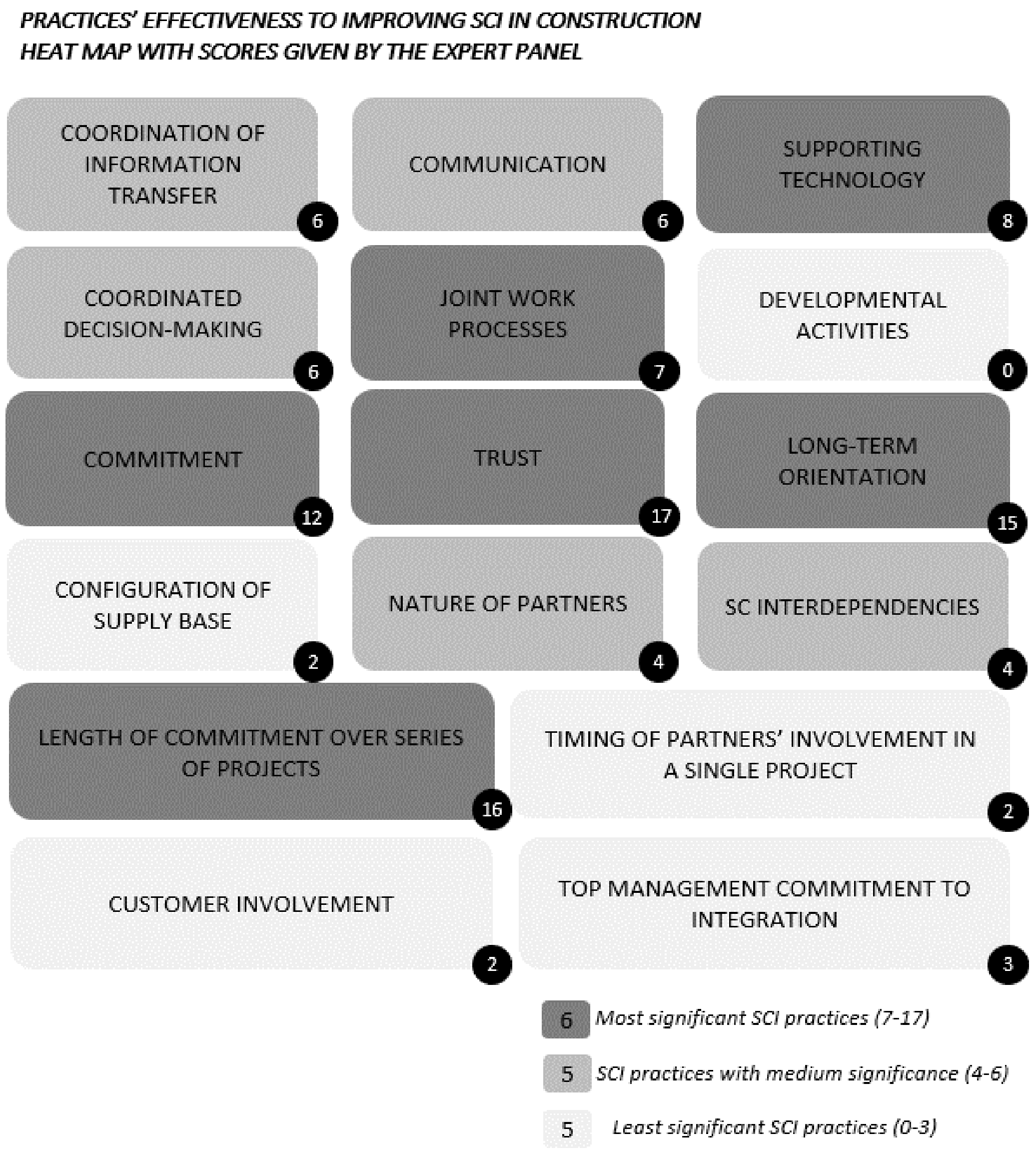

Figure 6-2: Heat map of practices' effectiveness to improving SCI in construction

The scores awarded by the expert panel allowed applying descriptive statistics in identifying the practices that are categorised as significant (score above average) from the rest. Table 6-2 presents the results, indicating practices scoring above the average ($\bar{x}$) of 6.875. In addition, in descriptive statistics, the median is sometimes used as a more representative statistic, as opposed to the mean, when there are outliers in the sequence that might skew the average of the values. The median of a sequence can be less affected by outliers than the mean. The dataset has a median value ($\tilde{x}$) of 6, which also corroborates the significance of practices with a score of above 6.

Table 6-2: Overview of scores of SCI practices and the ones determined as significant

SCI Practice	Points Awarded	Score above average
Coordination of Information Transfer	6	
Communication	6	
Use of Supporting Technology	8	✓
Coordinated Decision-Making	6	
Joint Work Processes	7	✓
Developmental Activities	0	
Commitment	12	✓
Trust	17	✓
Long-Term Orientation	15	✓
Configuration of Supply Base	2	
Nature of Partners	4	
SC Interdependencies	4	
Length of Commitment over a Series of Projects	16	✓
Timing of Partners' Involvement in a Single Project	2	
Customer Involvement	2	
Top Management Commitment to Integration	3	
	Total: 110	$\bar{x}$ = 6.875

In addition, Figure 6-3 was designed for a better visual representation of how the aggregated scores awarded by the panel members position the importance of some practices over others. The figure signifies the aggregated scores awarded to four of the practices, positioning them as outliers amongst the rest.

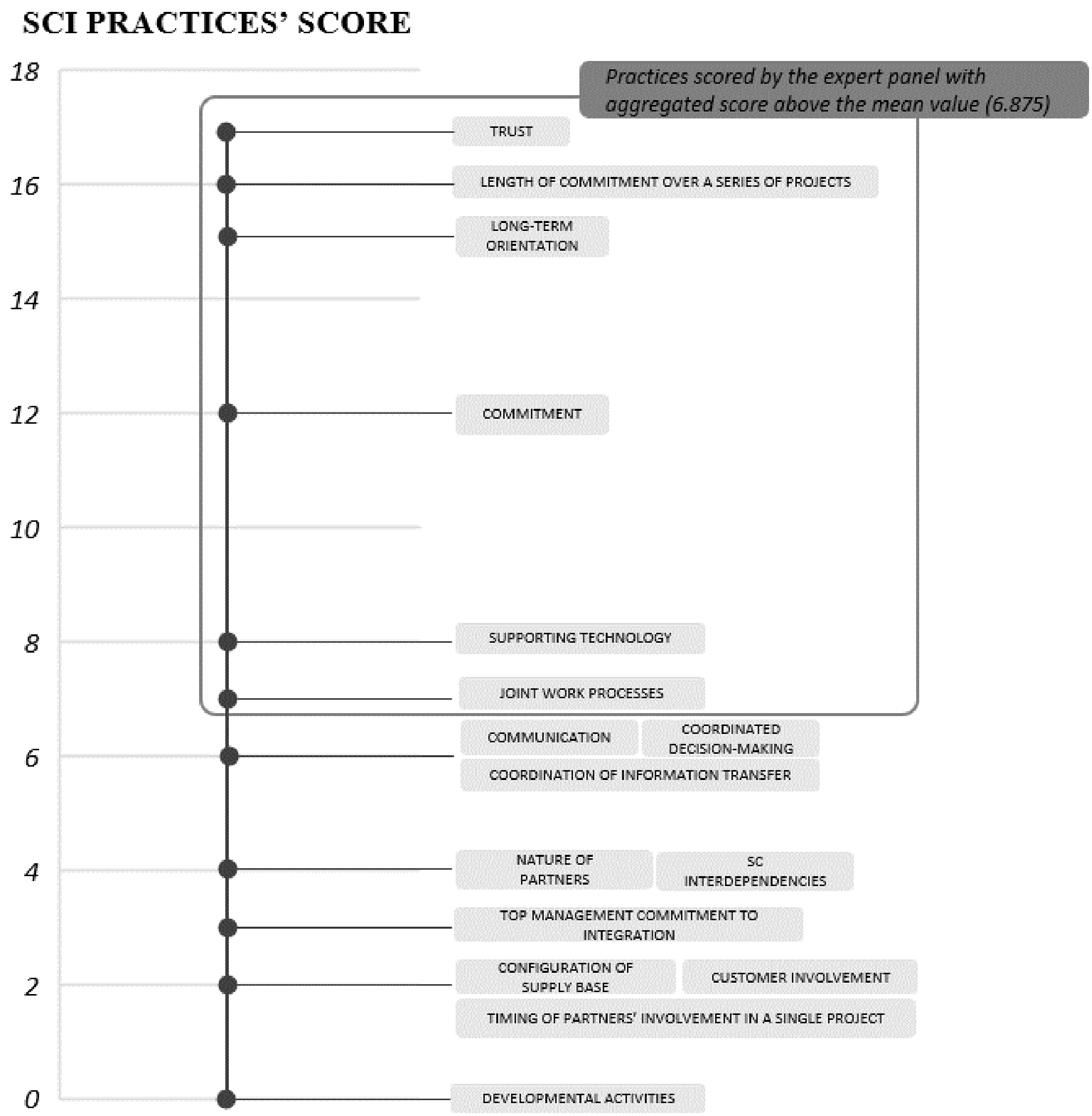

Figure 6-3: Visual representation of SCI practices and relevant scores

Overall, the scoring method applied in the 'Select' stage of the Delphi event signifies the following six practices as significant to improving SCI in construction:

- Trust
- Length of relationship over a series of projects
- Long-term Orientation
- Commitment
- Supporting Technology

- Joint Work Processes

6.4.2 Effectiveness of Pathways to Practices

The six SCI practices identified as significant by the expert panel served as input to the ‘Define’ stage of the Delphi investigation. In accordance with classical round-based Delphi investigations, the expert panel was presented with the opportunity to go over three iterative rounds towards ranking the most effective pathways of integration (actors, flows, processes and technologies) to achieving each of the practices from ‘Select’.

First, Table 6-3 reports on the results in terms of the analysis of the practices investigated for reaching stability. In accordance with the research methodology section, the criteria set for stability in this study was through the use of the coefficient of variation (CV) (standard deviation divided by the mean) of responses. The stability criteria was set as $0<CV\leq0.5$, following English and Kernan (1976) and von der Gracht (2012). As presented in the table, a stable response is characterised by a CV of less than 0.5 in two consecutive rounds (rounds 2 and 3) in each of the four ranked pathways. The statistical analysis demonstrates that stability was reached in five out of the six practices investigated. Further analyses were conducted only on the practices that have achieved stability.

Table 6-3: Coefficient of variation for each practice across the three rounds in the 'Define' stage

SCI Practice	***Pathways***	***Round 1***	***Round 2***	***Round 3***	***Stability $0<CV\leq0.5$***
Supporting technology	***Actors***	0.43	0.55	0.52	No
	Flows	0.48	0.37	0.40	
	Processes	0.30	0.28	0.22	
	Technologies	0.57	0.64	0.64	
Joint work processes	***Actors***	0.60	0.31	0.31	Yes
	Flows	0.32	0.22	0.22	
	Processes	0.30	0.30	0.30	
	Technologies	0.43	0.09	0.09	
Commitment	***Actors***	0.65	0.50	0.38	Yes
	Flows	0.22	0.30	0.39	
	Processes	0.38	0.38	0.30	
	Technologies	0.29	0.00	0.00	
Trust	***Actors***	0.00	0.00	0.00	Yes
	Flows	0.28	0.28	0.22	
	Processes	0.22	0.20	0.20	
	Technologies	0.11	0.08	0.00	
Long-term orientation	***Actors***	0.47	0.37	0.29	Yes
	Flows	0.36	0.34	0.36	
	Processes	0.41	0.36	0.18	
	Technologies	0.08	0.08	0.08	
Length of commitment over series of projects	***Actors***	0.53	0.47	0.29	Yes
	Flows	0.45	0.42	0.28	
	Processes	0.34	0.29	0.28	
	Technologies	0.28	0.08	0.08	

Following on with the practices that have achieved stability in responses, Appendix E (Tables E-1 to E-5) presents the results of the panel members in each practice with the supporting analyses of whether consensus was reached. Each of the five practices where stability in response was present have demonstrated a high level of consensus ($W>0.7$) signifying the high internal validity of the findings. In accordance with the research methodology section, the consensus was analysed using Kendall's W coefficient of concordance following von der Gracht (2012). When stability is present, the responses were further analysed using Kendall's W coefficient of concordance, with $W\geq0.7$ indicating strong agreement (i.e. consensus). Given that the Delphi panel was a homogeneous group of members, the analyses were conducted on a group bases, making the use of Kendall's W suitable.

A high W value means that the participants are applying essentially the same standard in judging the importance of the issues investigated. Usage of Kendall's coefficient of concordance (W) in ranking-type Delphi studies for measurement of reaching consensus, is characterised by its relative strength, as indicated by a set benchmark from W=0.1 (no agreement) to W=0.9 (very high agreement). Following Schmidt (1997) and Schmidt et al. (2001) a W of above 0.7 is indicative of strong agreement between participants, which is the case for each of the five practices where stability in responses was present and therefore the level of consensus analysed. Table 6-4 presents the different W benchmarks and how they are interpreted.

Table 6-4: Interpretation of Kendall's W (Adopted from Schmidt, 1997)

W	***Interpretation***	***Confidence in Ranks***
.1	Very weak agreement	None
.3	Weak agreement	Low
.5	Moderate agreement	Fair
.7	Strong agreement	High
.9	Unusually strong agreement	Very high

In terms of statistical significance of the results, following von der Gracht (2012) a chi-square test is often applied as a significance testing method in Delphi studies. The chi-square is a nonparametric test by which the researcher can assess whether there is any relationship between observed and expected variables. The statistical test has been proposed as a method to check for independence of the Delphi rounds from responses obtained in them. The purpose of this test is to determine if a difference between observed data and expected data is due to chance, or if it is due to a relationship between the variables investigated. Essentially, the chi-square (x^2) computation is checked against a predefined tabulated value, with chi-square over the expected value signifying that the results have statistical significance. The test takes into account the number of respondents (m), the degrees of freedom in responses (n) (i.e., rank options) and the computed W result. It is calculated using the following formula:

$$x^2 = m(n-1)w$$

Each one of the five practices are tested with the following H_0 and H_1 hypotheses:

H_0: There is no difference in participants' rankings to the investigated practice
H_1: There is a difference in participants' rankings to the investigated practice

Using MS Excel, the exact p value was calculated for each practice that has achieved stability. The statistical analyses of the results of the Kendall's W value and p value with a significance level of 0.05 are presented in Table 6-5.

Table 6-5: Kendall's W and p values for the final third round of the Delphi stage 'Define'

SCI Practice	Kendall's W	W > 0.7	Consensus	p value	p < 0.05	Significance
Joint work processes	0.813	Yes	Yes	0.00022	Yes	Yes
Commitment	0.731	Yes	Yes	0.00054	Yes	Yes
Trust	0.904	Yes	Yes	0.00001	Yes	Yes
Long-term orientation	0.800	Yes	Yes	0.00002	Yes	Yes
Length of commitment over series of projects	0.784	Yes	Yes	0.00003	Yes	Yes

The analyses of the effectiveness of the four pathways to each individual practice were aggregated to present the overall effectiveness of each pathway to improving SCI. Following von der Gracht (2012) and Argyrous (2005) there are some data considerations that need be taken in account. One such consideration is the fact that the mean is solely valid with interval/ratio data. In many Delphi studies, the mean is calculated without considering that the scales used are actually ordinal. As highlighted by Argyrous (2005) (see Table 6-6), the calculation of the mean for ordinal data is strictly speaking not a correct procedure; he suggests using the mode can be a better approach, as it can be used with all levels of measurement. Generally, using mode values is not useful when the scales (i.e. rankings) have many values, which is not the case in this study. Following these considerations, the aggregated results of the relative ranking between the four pathways were analysed by using two measures of central tendency: first through the use of mean value of the individual practice results and second, through the use of mode. Both measures applied present the same results in overall rankings.

Table 6-6: Measures of central tendency and applicability to the study (Adapted from Argyrous, 2005)

Measure	Data considerations	Applicability to this study's analyses
Mode	Can be used with all levels of measurement, but not useful with scales that have many values	Potentially useful for demonstrating the results
Median	Can be used with ranked data (ordinal and interval/ratio), but not useful for scales with few values	There are only four values (requiring ranking), so it is not appropriate
Mean	Can be used for interval/ratio data that are not skewed	Potentially useful for demonstrating the results. Skewness is not applicable, as only four values are investigated.

An overview of the results of each pathway's relative effectiveness to each outcome is presented in Table 6-7.

Table 6-7: Overview of results of the Delphi investigation at end of round 3 of stage Define

SCI Practice	Number of respondents	Perspective	Mean	Mode
Supporting Technology	8	Actors	Results are not meaningful as no stability was reached at round three of this practice.	
		Flows		
		Processes		
		Technologies		
Joint Work Processes	8	Actors	1.125	1
		Flows	2.875	3
		Processes	2.125	2
		Technologies	3.875	4
Commitment	8	Actors	1.38	1
		Flows	2.13	2
		Processes	2.50	3
		Technologies	4.00	4
Trust	10	Actors	1.00	1
		Flows	2.40	2
		Processes	2.60	3
		Technologies	4.00	4
Long-term Orientation	10	Actors	1.10	1
		Flows	2.30	2
		Processes	2.70	3
		Technologies	3.90	4
Length of Commitment Over Series of Projects	10	Actors	1.10	1
		Flows	2.50	2
		Processes	2.50	3
		Technologies	3.90	4

Following on from the analysis of this stage of the Delphi investigation, Tables E-6 and E-7 in Appendix E report on the overall rankings of the four pathways from the 'Define' stage, using mean values and mode values respectively. Taking different approaches to the results' analysis, both tables concur in the overall ranking of the four pathways. Overall effectiveness is placed on the pathway of actors first, followed by flows as second in effectiveness, processes as third and technologies as last.

6.4.3 Major Outcomes of SCI in Construction

In the 'Execute' stage of the study, members of the expert panel were asked to select which of the seven outcomes of SCI they determine as 'major' in construction. The term 'major outcome' was defined in the study as an outcome that is most value-adding in the construction context. Each participant was given the opportunity to select the three outcomes out of the seven they determine as 'major outcomes' over three rounds, with aggregated results of all panel members shown between rounds. An overview of the results over the three rounds is presented in Figure 6-4.

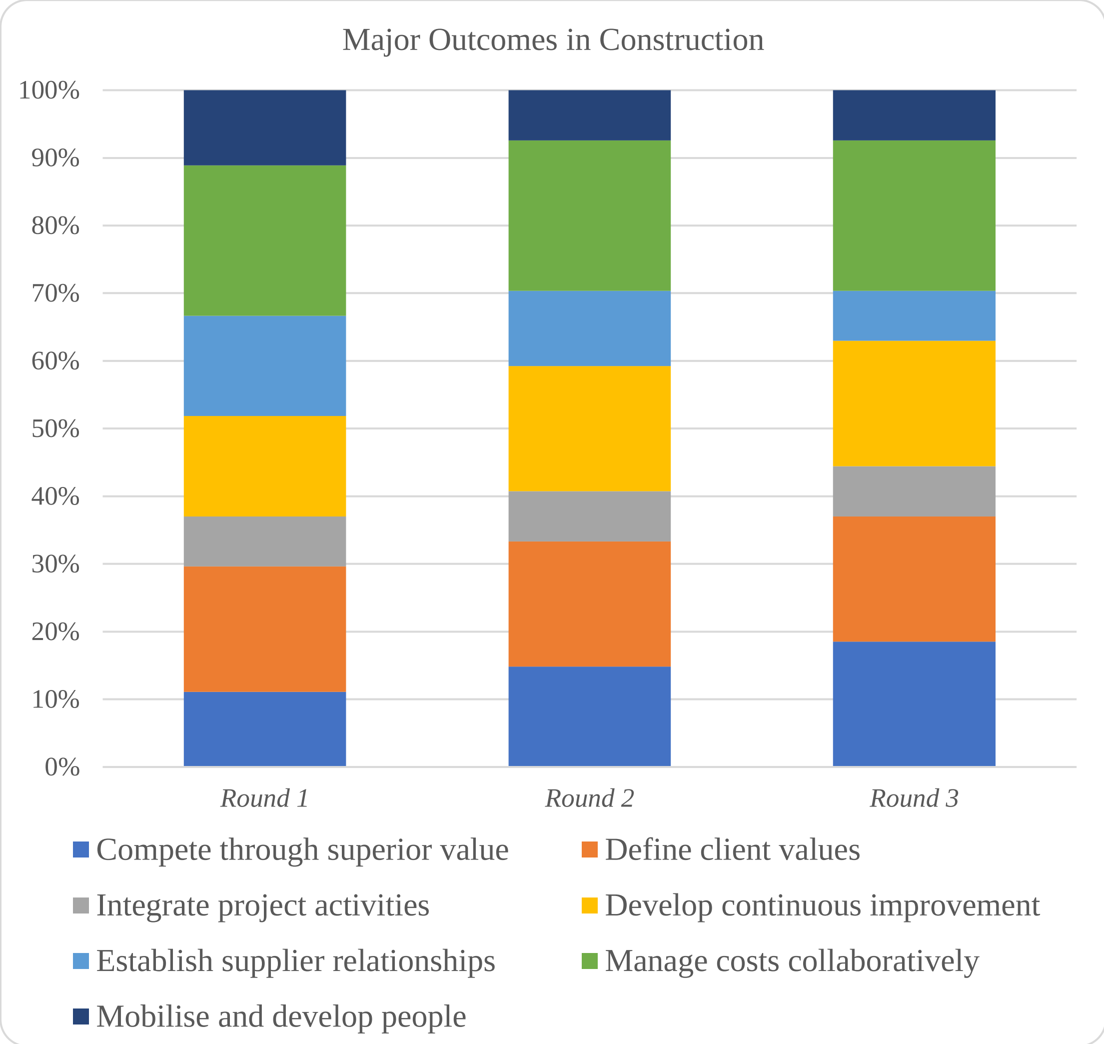

Figure 6-4: Overview of major outcomes selection by panel members over the three rounds

Following the Delphi guidelines, a stability criteria over consecutive rounds was set as variation in two consecutive rounds of ≤ 15%. This approach is in line with Dajani et al. (1979) and Scheibe et al. (1975) who recommend testing for group stability instead of individual stability in responses, since the interest of the Delphi method lies in the opinion of the group, rather than the individual. In their research, stability is measured as a percentage change in distributions from round to round. In other words, following their guidelines, a 15% change or lower in any two distributions is considered a stable situation. The analysis of this task in the 'Execute' stage shows a high level of stability between rounds. As presented in Table 6-10, the percentage change between rounds 1 and 2 is 14.8% and between rounds 2 and 3, 7.4%. This signifies a stable situation in responses and the reduced change between rounds exemplifies convergence in opinions. Given that stability is present, the results are further analysed in terms of consensus. Following Dajani et al. (1979), measuring the level of agreement is analysed only if a stable answer is reached. Following their guidelines, a majority (more than 50% or respondents) is used as a criterion for agreement. This approach uses 'certain level of agreement', explained by Loughlin and Moore (1979, p.103) as 'in keeping with most other Delphi studies, consensus was defined as 51% agreement among respondents'. Analysing the data at round three, the outcomes that have a majority (i.e., agreement) are: compete through superior value, define client values, develop continuous improvement and manage costs collaboratively. Following the analysis of the Delphi, these four outcomes are classified as 'major outcomes' in construction.

Table 6-8: Panel members' responses with stability and consensus analyses

Participant	CTSV	DCV	IPA	DCI	ESR	MCC	MDP	Group difference in responses
Round 1								
Participant 1	✓	✓					✓	
Participant 2	✓			✓		✓		
Participant 3		✓			✓	✓		
Participant 4			✓	✓		✓		
Participant 5	✓		✓			✓		
Participant 6		✓			✓	✓		
Participant 7				✓		✓	✓	
Participant 8		✓			✓		✓	
Participant 9		✓		✓	✓			
Total	3 (11%)	5 (19%)	2 (7%)	4 (15%)	4 (15%)	6 (22%)	3 (11%)	
Round 2								
Participant 1	✓	✓					✓	
Participant 2	✓				✓	✓		
Participant 3		✓			✓	✓		
Participant 4			✓	✓		✓		
Participant 5	✓		✓			✓		
Participant 6		✓		✓		✓		
Participant 7	✓			✓			✓	
Participant 8		✓		✓		✓		
Participant 9		✓		✓	✓			
Total	4 (15%)	5 (19%)	2 (7%)	5 (19%)	3 (11%)	6 (22%)	2 (7%)	
Changes	1	0	0	1	1	0	1	4 (14.8%)
Round 3								
Participant 1	✓	✓					✓	
Participant 2	✓			✓		✓		
Participant 3	✓	✓				✓		
Participant 4			✓	✓		✓		
Participant 5	✓				✓	✓		
Participant 6		✓	✓			✓		
Participant 7	✓			✓			✓	
Participant 8		✓		✓		✓		
Participant 9		✓		✓	✓			
Total	5 (19%)	5 (19%)	2 (7%)	5 (19%)	2 (7%)	6 (22%)	2 (7%)	
Changes	1	0	0	0	1	0	0	2 (7.4%)
Agreement level	55%	55%	22%	55%	22%	66%	22%	

6.4.4 Effectiveness of Pathways to Outcomes

This section presents the results of the 'Execute' stage in terms of effectiveness of the four pathways to achieving each of the seven outcomes. The approach and logic in analysis here is the same as in the 'Define' stage with the difference that instead of SCI practices it is the outcomes that are investigated.

First, Table 6-11 presents the stability analyses for each of the seven outcomes investigated. Out of the seven outcomes, six reached stability in responses. The outcome of 'Managing costs collaboratively' did not reach stability and as such was not further analysed.

Table 6-9: Coefficient of variation for each outcome across the three rounds in Delphi stage 'Execute'

SCI Outcome	***Pathway***	***Round 1***	***Round 2***	***Round 3***	***Stability $0<CV\leq0.5$***
Compete through superior value	***Actors***	0.53	0.50	0.30	Yes
	Flows	0.38	0.44	0.30	
	Processes	0.36	0.30	0.24	
	Technologies	0.20	0.34	0.09	
Define client values	***Actors***	0.37	0.31	0.00	Yes
	Flows	0.31	0.20	0.20	
	Processes	0.37	0.39	0.28	
	Technologies	0.09	0.09	0.19	
Integrate project activities	***Actors***	0.53	0.47	0.38	Yes
	Flows	0.38	0.18	0.17	
	Processes	0.45	0.37	0.45	
	Technologies	0.26	0.20	0.00	
Develop continuous improvement	***Actors***	0.45	0.47	0.34	Yes
	Flows	0.37	0.34	0.18	
	Processes	0.56	0.50	0.37	
	Technologies	0.26	0.22	0.09	
Establish supplier relationships	***Actors***	0.00	0.31	0.00	Yes
	Flows	0.28	0.28	0.31	
	Processes	0.28	0.31	0.22	
	Technologies	0.12	0.32	0.12	
Manage costs collaboratively	***Actors***	0.65	0.56	0.37	No
	Flows	0.25	0.35	0.31	
	Processes	0.46	0.38	0.30	
	Technologies	0.27	0.19	0.21	
Mobilise and develop people	***Actors***	0.77	0.31	0.31	Yes
	Flows	0.21	0.36	0.32	
	Processes	0.17	0.21	0.21	
	Technologies	0.31	0.14	0.09	

Following on with the analyses on the effectiveness of the four pathways to each of the outcomes where stability was reached, Table 6-12 presents the coefficient of concordance (W) and significance of the results based on the chi-square test. Further analyses of the results are presented in Appendix F (see Tables F-1 to F-6) for each individual outcome at the final third round, where stability in responses was present. Each of the six outcomes has demonstrated a high level of consensus (W>0.7) signifying the high internal validity of the findings.

Table 6-10: Kendall's W and p values at third round of the Delphi stage 'Execute'

SCI Outcome	Kendall's W	W > 0.7	p value	p < 0.05	Consensus
Compete through superior value	0.8025	Yes	0.0001	Yes	Yes
Define client values	0.7688	Yes	0.0004	Yes	Yes
Integrate project activities	0.7938	Yes	0.0003	Yes	Yes
Develop continuous improvement	0.8188	Yes	0.0002	Yes	Yes
Establish supplier relationships	0.7938	Yes	0.0003	Yes	Yes
Manage costs collaboratively	No further analyses of results as no stability was reached				
Mobilise and develop people	0.7813	Yes	0.0003	Yes	Yes

Table 6-13, presents an overview of the results in this stage of the Delphi investigation in terms of each pathway's overall effectiveness to the investigated outcomes.

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Table 6-11: Overview of results of the Delphi investigation at round 3 of the Execute stage

SCI Outcome	Number of respondents	Perspective	Mean	Mode
Compete through superior value	9	Actors	1.11	1
		Flows	2.22	2
		Processes	2.78	3
		Technologies	3.89	4
Define client values	8	Actors	1.00	1
		Flows	2.62	3
		Processes	2.62	2
		Technologies	3.75	4
Integrate project activities	8	Actors	1.37	1
		Flows	2.75	3
		Processes	1.87	2
		Technologies	4.00	4
Develop continuous improvement	8	Actors	1.87	2
		Flows	3.00	3
		Processes	1.25	1
		Technologies	3.87	4
Establish supplier relationships	8	Actors	1.00	1
		Flows	2.37	2
		Processes	2.87	3
		Technologies	3.75	4
Manage costs collaboratively	8	Actors	Results are not meaningful as no stability was reached at round three of this outcome.	
		Flows		
		Processes		
		Technologies		
Mobilise and develop people	8	Actors	1.12	1
		Flows	2.75	3
		Processes	2.25	2
		Technologies	3.87	4

Lastly, similarly to the analysis in the 'Define' stage, in Appendix F, Table F-7, reports the aggregated results based on mean values and Table F-8 based on mode values. These tables present the overall aggregated results of the four pathways' effectiveness to achieving the outcomes investigated in the Delphi study in line with the 'Execute' stage of the research design. In both analytical approaches to the analysis the overall effectiveness positions actors as the most effective archetype, followed by processes, flows as third and technologies as last in effectiveness.

6.5 Chapter Summary

This chapter has analysed the assembled data of this research project. The analyses presented in the chapter have followed the Delphi study research design applied to this thesis. The main findings of this chapter are listed in the following:

- In accordance with the 'Assess' stage of the Delphi study design, seven practical examples and commentary were analysed as relevant to the six potential transformation areas from traditional SCM in construction towards an SCI approach, as identified in the literature review chapter.
- Following the 'Select' stage of the Delphi study design, six SCI management practices were empirically validated as significant to improving SCI in construction
- Following the 'Define' stage of the Delphi study design, each of the SCI management practices from 'Select' were analysed and validated by the effectiveness of the four pathways of SCI to achieving each. The overall effectiveness of the four pathways to SCI practices was presented.
- In accordance with the 'Execute' stage of the Delphi research design the results of the Delphi panel were analysed to validate the 'major' outcomes in the construction context.
- In accordance with the 'Execute' stage, each of the SCI outcomes was analysed and validated by the effectiveness of the four pathways to achieving each of them. The overall effectiveness of the four pathways to SCI outcomes was presented.

Chapter 7 : Discussion

7.1 Chapter Introduction

Beyond this introductory section, the discussion chapter is split into four sections. Initially, Section 7.2 ‘Insights to Adoption of SCI in Construction’ encapsulates and discusses the results of the qualitative part of the Delphi study, drawing on the commentary and examples provided by the panel members in accordance with the insights for transitioning to an SCI approach, as generated in the literature review section. This is followed by Section 7.3, ‘Management Practices Towards Improved SCI in Construction’ which discusses the results from the Delphi investigation in light of the proposed synthesised conceptual framework. It is demonstrated how the empirical results of this research support some assumptions of the existing literature while refuting others. Afterwards, Section 7.4, ‘Pathways to Improving SCI in Construction’ focuses on discussing the findings related to the effectiveness of the four pathways identified in the literature to improving SCI. This is then followed by Section 7.5 ‘Outcomes from Improved SCI in Construction’ which discusses the findings in relation to the outcomes of SCI in construction and the effectiveness of the four pathways to each of them. In Section 7.6, ‘Revised Conceptual Framework’ the discussed results of the study are presented in a revised conceptual framework. Lastly, the main points of this chapter are summarised in Section 7.7, ‘Chapter Summary’. The structure of this discussion chapter also follows the set of RQs presented in the introduction, discussing the findings for each in turn. The structure of this chapter is illustrated in Figure 7-1.

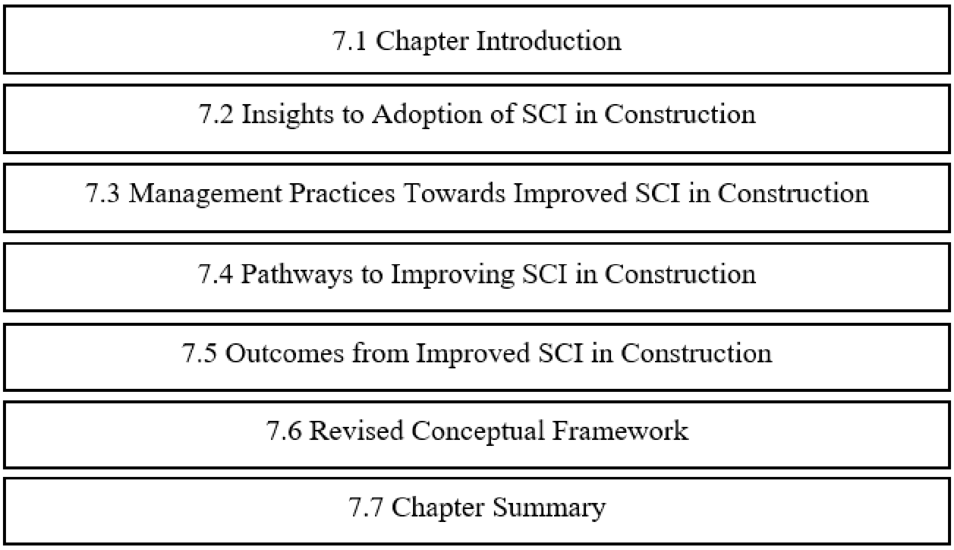

Figure 7-1: Structure of Chapter 7

7.2 Insights to Adoption of SCI in Construction

This section reviews the insights generated from the Delphi investigation through the aggregated qualitative results in the form of discussion points and examples provided in the ‘Assess’ stage.

The discussion is focused on the research question:

> RQ1: What is the current understanding of SCI in construction?

The qualitative part of the study provides relevant examples and commentary to the pre-identified six areas of transformation in construction SCs. These transformation areas were developed in the literature review chapter, and represented as the oppositions of current reality of traditional SCM in construction versus desired state of SCI. The six areas frame the current understanding of what SCI aims to achieve, supplemented by examples and commentary towards realisation of such a potential transformation in construction. The aim of this section is to frame SCI improvement efforts in the construction context based on the qualitative findings, rather than give concrete prescriptions for transformation in construction SCs.

7.2.1 Short-term vs. Long-term Relationships

In the literature review section, a notable area of transformation towards a SCI approach in construction was framed through the need for developing long-term relationships, as opposed to the discontinuous relationships currently characterising the sector (Dainty et al., 2001a; Briscoe and Dainty, 2005; Xue et al., 2005) . In this transformational area the expert panel highlighted that to develop such relationships, there is a need for investment in them. This investment can be justified by the potential benefits of the relationship 'across time, across phases of a project and across projects'. The key message here is that developing long-term relationships requires clearly defined benefits in the form of 'sufficient return' from investing in such and that building long-term relationships is 'not something you can do quickly or easily'. Contributing further to this point, an example of this investment in relationships was formulated as the insight that less spent on procurement does not equal profitability. It appears that forming long-term relationships is characterised by moving away from low cost-driven agendas and squeezing suppliers, but instead focusing on 'relational contracting' through long-term relationships with 'architects, engineers, professional services providers and key enabling organisations within the SC'. One of the experts in the panel provided an example of how such transition meant spending more on a facility in a year, but resulted in significantly higher profitability based on the strong relationships formed in that facility compared to others.

7.2.2 Functional Siloes vs. Outcome-based Approach

An area illuminated by the literature review is that taking an SCI approach to construction SCs involves moving away from functional siloes and instead focusing the SC towards developing value-based outcomes (Pero et al., 2015; Broft et al.,2016). Supporting this transformation area, one of the panel members highlighted that in his experience with a major public construction client, taking an outcome-based approach has actually resulted in large savings. A critical point in the example provided is that value outcomes 'relate to the core business of the client and the partnering organisations' signifying the importance of leveraging the specialism of integrated actors towards 'directing the integration process based on higher productivity'. This example supports the notion of taking an inter-organisational approach to aggregating value in construction. In the words of the expert in the panel, an ‘outcome-based approach to SCI is essential’.

7.2.3 Decentralised Planning vs. Integrated Planning Across the Supply Chain

Another area of transformation generated from the literature review relates to the need to transition from decentralised functional planning based on projects to integrated planning across the SC (Godsell et al., 2018). A key commentary provided here that characterises this transformation is that SCI requires the ‘right conditions to take place’. More specifically, the panel recognised that SCI is not a ‘one size fit all’ approach and establishing the right conditions for SCI requires ‘long-term conditions’ to be present. This involves ‘integrating planning of the supply base with the customer base’. It appears that achieving SC alignment between the demand side and the supply side for construction is the essential activity in integrated planning across the SC and determines the desired level of SCI.

7.2.4 Discrete Work Packages vs. Continuous Repeated Work

As highlighted in the literature review section, a category of issues faced in the construction sector relates to the sporadic engagement of construction organisations on individual work packages, rather than continuous involvement in repeated work packages (Eriksson, 2015; Nikolov and Harpum, 2023). Here one of the members in the expert panel highlighted that such transition may rely on ‘thinking about different contract types and more about the demand type of whether it could be repeatable or it is something that is one-off’. More specifically, by recognising ‘the demand patterns that are repeatable, integration can help us set up continuous repeated work and drive productivity’. A key inhibitor to such transition was recognised by the panel member as the ‘procurement mindset’ in construction, highlighting that this often involves project-buying rather than following commercial and procurement strategy at the SCI level.

7.2.5 Ad hoc Supply Chain vs. SCI Scope

Traditionally, construction SCs are formed on the basis of projects, which is often characterised by 'ad hoc' processes of forming an SC fulfilling function based on a given project's requirements and disbanding at the end of the project (Nikolov and Harpum, 2023; Crespin-Mazet and Portier, 2010; Bagchi et al., 2015). It is suggested that taking an SCI approach can transform the construction SC towards continuous repeated involvement of integrated organisations, forming an encompassing SCI scope that enables delivery of multiple projects with degrees of difference in project requirements. One of the panel members commented that one of the main areas for this transformation is within 'behavioural contracting' and specifically 'many of the clients still favour the traditional contracts, so most of the contracts are set with penalties not incentive mechanisms'. Furthermore, a 'common misconception is that contracting with another organisation means that you get the same results as the last project, while the reality is that you do not, because they are different individuals, therefore the behaviours and the dynamics that you get are totally different'. It appears that the intention of having an SCI scope serving multiple projects can lead to standardisation in performance on projects as it involves the same organisations continuously. To develop SCI scope, the panel member suggested that it is necessary to 'narrow the number and types of variables in construction projects' as 'there are very different practices involved in each and every one of these'. Accordingly a critical first step identified here is to 'define the scope of integration'.

7.2.6 Function-based Organisational Structure vs. Structure Based on SC Flows

The last area generated in the literature review relates to moving from function-based organisational structure to structure based on SC flows (Godsell et al. 2018; Sacks, 2016; Andalib et al., 2018). Here, one of the panel members highlighted the need for establishing the right context and type of integration. Specifically, 'in some cases, integration is not desirable at all for the contractors, because if we assume it is a one-off transaction for the project it is likely that it will not happen again'. In this context, integration can be better managed through a function-based organisational structure. In contrast, if the context to which SCI is applied is a continuous stream of construction projects, it is 'critical to focus on the shared flows between construction organisations taking part in integration, rather than on individual functions'. The underlying message in this transformational area is that applying SCI requires the right context as determined by the desired level of integration, as such 'can take a lot of time to be implemented in practice'.

7.2.7 Section Summary

In this section the six transformational areas generated in the literature review of this thesis were reviewed by supplementing them with commentary and examples provided by the expert panel. The section aimed at framing SCI improvement efforts in the construction context based on the qualitative findings, observing current understanding on the topic, as some of the main approaches taken by practitioners were highlighted. In this section, critical analyses were applied to highlight some of the trends in SCI in construction, rather than giving concrete prescriptions for transformation. Overall, it appears that construction SC professionals have experienced different facets of transition from traditional SCM to an SCI approach in construction, even if such may have been developed intuitively. In other cases, such transitions were supplemented by real-life examples leading to measurable improvement outcomes. To sum up, the qualitative analyses show that there is dispersed understanding of what SCI involves, often positioned in different facets of SCI, but overall a systematic approach to SCI has not been developed. In essence, up to now, it appears that the reason for not developing an SCI approach to construction in practice, is the lack of a systematic approach to SCI. Instead, top-level management has predominantly developed individual insights that have resulted in sporadic SCI initiatives.

7.3 Management Practices Towards Improved SCI in Construction

As summarised in the conceptual framework (Section 4.4), the analysis of management practices for SCI by pathway, identified categories of practices that were generic, prevalent, focused and specific. These categories were reviewed in further detail, suggesting the management practices form a distinct sequence towards improving SCI in construction. Based on the developed conceptual framework, some preliminary insights were then developed. These suggest that there is a foundation of management practices common to all pathways, and this is an essential ‘prerequisite’ to improving SCI in construction. With the prerequisites in place, the next level of common management practices required relates to ‘planning’, both strategic and operational. With a solid and co-ordinated approach to planning, the focal construction firm is in a position to co-ordinate the ‘execution and delivery’ of the project. Lastly, the synthesised conceptual model suggests that either or the pathways for execution can be ‘technology enabled’. This section discusses the empirical findings in light of the synthesised framework for improving SCI in construction.

The discussion is focused on the research question:

RQ2: What are the most significant SCI practices to improve SCI?

7.3.1 Prerequisite practices

The conceptual framework developed through the systematic review of the literature suggests there is a foundation of management practices that are common to all pathways. This set of management practices are characteristic to developing SCI in construction in various contexts and thus are categorised as ‘prerequisite’ for integration to take place. The synthesis of the literature points to these practices as ‘top management commitment’ (TMC), ‘customer involvement’ (CI), ‘long-term orientation’ (LTO) and ‘commitment’ (CM); out of these practices, the experts identified LTO and CM as significant to improving SCI in construction.

Focusing on the practice of ‘top management commitment’ the Delphi experts in the investigation did not recognise this management practice as essential to improving SCI in construction. Based on the Delphi results, it must be concluded that this management practice, assumed to be critical by other authors, seemingly does not characterise as a prerequisite to SCI in construction. This in itself is not surprising, given the rationale that TMC relates to the dimension of depth of SCI. In other words, a starting point of establishing SCI is not determined by the depth of integrative activities of involved partners as there may not be any existing level of integration to begin with. Construction is often referred to as a highly transactional sector with high fragmentation between the different actors in the SC (client, main contractor and suppliers). However, this also means that this finding should be considered within the limits of the study design and the current construction reality. It is likely that TMC can have significant impact as a prerequisite practice, provided SCI maturity in construction increases in the future. As such, it should be assumed that TMC is an impactful practice but can only be recognised as a prerequisite if there is an existing level of SCI between the different SC partners at the outset.

Focusing on the practice of ‘customer involvement’ (CI), the Delphi expert panel did not recognise this management practice as significant and as such it is not determined as a ‘prerequisite’ practice to SCI. Although the role of the customer in SCI was highlighted in the introductory chapter as essential in ‘value identification’ and thus establishing the necessary conditions for improved effectiveness and efficiency in delivery, this management practice concerns the actual integration of the end-users of engineering projects upstream in the SC. This notion was refuted by the empirical results, suggesting that the role of the customer in SCI, is limited to strategic planning activities of construction projects and establishing demand patterns, so that the SC can serve in the most efficient and effective way. Given construction companies work under different types of contracts (i.e., Design and build (DB), Construction excellence (CE), Construction management contracts (CMC) and customer involvement (CI) may not necessarily be a viable option. Furthermore, some construction projects delivered can be highly routine in nature and CI may not be needed. It appears that the type of SC activities in the project determine the need for CI, not the opposite. This assertion is not surprising, given that CI is related to the depth dimension of SCI. In other words, CI can necessitate involvement not from the standpoint of the customer towards the SC, but from the SC towards the customer. Based on the empirical results it is thus suggested highly likely that the practice of ‘customer involvement’ can be beneficial to SCI in more complex and high value projects, but is not classified as a prerequisite practice, given its contextual nature.

Focusing on the practice of 'Commitment' (CM) the Delphi panel members identified this management practice as significant to improving SCI. CM can be classified as a prerequisite management practice as it relates to the type of contract that underpins SCI, risk allocation and alignment in interest and objectives between the members of the SC. These three areas characterising CM serve as a foundation from which SCI in construction can be improved. Given the contract-based nature of the industry, this finding from the empirical results does not come as highly surprising. For instance, in relation to setting the right type of contract, use of Framework Agreements (Fas) is well documented in the industry, but so is risk transfer upstream in the SC. However, what stands out is the need for alignment of interest and objectives as a critical foundational step for developing SCI in construction. The results highlight that alignment in the level of commitment between different construction organisations needs to be directed towards establishing long-term mutual objectives first and then the right contract type and risk allowances used to facilitate capturing associated benefits (win-win in the long-term) and continuity of work (towards guaranteed future work). As outlined in the introduction, such alignment of interest and developing mutual objectives is asserted here as based on the demand profile in 'value identification' of the strategic planning process. Furthermore, establishing alignment in CM points to the necessity for developing strong relational integration between integrated organisations, which is associated with this management practice. These findings point to developing relational strength in SCI, through CM as a prerequisite practice.

The next practise identified in the synthesised model as a prerequisite to SCI in construction is 'long-term orientation' (LTO). The Delphi panel identified this management practice as significant. The key characteristic of LTO is in developing recurring arrangements and supplier involvement, as opposed to competitive bidding and arm's length relationships. This involves procurement practices based not solely on price, but multi criteria from a long-term perspective. The findings highlight that the practice of commitment, aimed at alignment of construction partners and developing long-term mutual objectives, is complemented by LTO. LTO is also a management practice related to the strength of SCI through better relational integration.

The findings assessing CM and LTO as prerequisites to SCI, highlight that a necessary condition for developing SCI is strong relational integration between partners. The practices that build such integration are commitment (CM) and long-term orientation (LTO) and serve as a foundation for improving SCI. The practices of top management commitment (TMC) and customer involvement (CI) relate to the depth of integration and are context-specific, but do not constitute foundational prerequisite practices.

7.3.2 Planning practices

Following on with the synthesis of the conceptual framework developed, the insights from the CF suggest there is a set of planning practices that are prevalent to three of the four pathways. These are 'timing of involvement' (TI) related to integration of actors, flows and processes and 'joint strategic planning', 'joint operational planning' (JSP)(JOP) and trust (T) related to integration of flows, processes and technologies. This in itself poses a noteworthy suggestion that building trust (T) is not caused by integration of actors, but instead is built in conjunction with planning activities and through integration of flows, processes and technologies. Furthermore, the synthesis of the literature suggests that in improving SCI in construction 'timing of involvement' (TI) is a function of integrating actors, flows and processes. It appears that the successful development of relational integration as a prerequisite to SCI, translates into effectiveness in planning. This in turn, can develop higher levels of trust (T) and appropriate timing of involvement (TI) of subcontractors and suppliers.

Starting with the practices of 'joint strategic planning' (JSP) and 'joint operational planning' (JOP), SC planning is a critical activity in any SC, but in construction is often overlooked, as construction partners often focus on project management capabilities instead. The findings of the Delphi investigation did not identify these two practices as significant to SCI. That being said, the role of developing strategic plans and then translating them into operational plans that align demand and supply across the supporting SC is not in question. What the study investigates is whether these practices are a differentiator to improved SCI. The results point to the notion that SC planning is not a differentiator for improved SCI. This finding may appear surprising, but essentially, the planning practices are done regardless of developing SCI. The effectiveness of planning relates to informational integration in the SC, starting with customer demand. In the construction context, the main contractors are often associated with withholding information from SC partners, which results in poor levels of trust, causing limited integration of flows and processes. The results point to effective planning, which translates into customer demand across the SC, serving as a proxy for developing 'trust' (T) in SCI as a prevalent practice.

The management practice of building 'trust' (T) was identified as significant by the expert panel. The role of trust as a prevalent practice is explained first, by the type of trust that partners exhibit. With effective planning in place, the integrated organisations can shift the level of shared trust from simply contractual to long-term goodwill trust. Importantly, higher levels of trust developed through effective planning improve the confidence in others' behaviour in integration and limit the inhibiting effects of any situational trust influencing factors that may arise in different projects. Furthermore, the findings indicate trust as a significant differentiating practice to improving SCI, which appears as a rational next step, given that partners have developed strength in relational integration through commitment (CM) and long-term orientation (LTO) as prerequisite practices. The role of the management practice of 'trust' serves as an important prevalent practice to further focus on integration.

The management practice of 'timing of involvement' (TI) was not identified as overall significant by experts in the panel, although the practice is highlighted in the literature on SCI. TI relates to the duration of integration as it can allow stronger integration within a single project, especially if partners collaborate over many project stages. In this practice, the importance of timing relates to procuring contractors and suppliers early, in order to contribute to collaborative and customised design. In addition, from initiation to later phases of a construction project, actors are known to change their views on desired partnering characteristics (e.g. cost, cooperation and teamwork), so TI can play a crucial role in tuning in to the desired SCI behaviours. The findings indicate that although TI can be considered an impactful practice for improved SCI, it is not significant in construction due to the mainly transactional and arm's length relationships that currently characterise the sector. At least initially, it appears that the most important prevalent practice for diffusion of SCI relates to planning underpinned by building trust. The right TI can be introduced as an effect of improved trust, but not as a prevalent practice in its own right.

To sum up, at this stage of the conceptual framework, the strength of relationships developed through relational integration is of note here. This study demonstrates the eminence of this aspect in developing further SCI, beyond all other measured management practices. Trust appears as most important management practice with regard to planning, serving as a key prevalent practice unlocking further SCI improvement efforts.

7.3.3 Execution practices

Focusing on the first set of execution practices, 'behaviour' (B) and 'joint work processes' (JWP) related to the integration of actors and processes. These two management practices are viewed as a set because they appear to complement each other. Behaviour involves demonstrating the right attitudes and patterns in SCI activities by the integrated organisations (van der Vaart and Van Donk, 2008; Wagner and Johnson, 2004; Leuschner et al., 2013). In a project-based construction context, behaviour can be guided by common antecedents in construction projects (e.g., design class, value engineering, concept select planning, and availability assurance and reliability). These antecedents can invoke different behaviours amongst SC partners and as such relate to the integration of actors (optimum set of integrated organisations) for a given demand profile and the integration of processes (characterising clear overriding SC processes) that converge behaviours within the relevant project types or groupings. As demonstrating the right behaviour in SCI is related to the dimension of the scope of SCI, this clearly outlines the underpinning importance of clarity in project requirements and an integrated SC that is effective in coordinating decisions in these requirements. The second management practice in this set of focused practices is 'joint work processes' (JWP). The practice of JWP compliments B as it enables the intention of firms within the SC to integrate their actions and inter-actively adjust their behaviour while pursuing opportunities over time. Practical examples of JWP in construction include both short-term actions, such as improved supplier scheduling, resource visibility and capacity planning, as well as long-term actions, such as developing joint flexibility and SC adaptability (Ireland and Webb, 2007). JWP relates to operational integration in SCI. Evidently, this set of management practices is suggested to align the scope of the integrated SC with the operational integration that can be developed. This involves translating SC intentions and behaviours amongst the integrated organisations into sets of SC operational actions.

Some of the experts in the panel recognised the impact of both practices, but out of the two, only JWP was identified as significant to improving SCI in construction. These findings indicate that in construction, a sector known for its one-off project-based procurement, developing JWP can play a significant role in the operational integration necessary for improving the responsiveness of an integrated SC, serving demand for construction projects continuously. The results confirm that developing operational integration, based on SC characteristics by types or groups of projects, is essential to the improved responsiveness of the integrated SC and can be achieved by sets of actions, explicated by the focused practice of JWP.

In addition, although the empirical findings show support for the focused practice of 'behaviour' (B), the practice is not determined as significant. This may be explained as the academic disciplines and theoretical approaches of scholars have engendered a focus on the socially-constructed aspects of SCI and behavioural responses to integrative activities. This is instead of adopting frameworks from the area of manufacturing focusing on practical approaches, such as SC segmentation, and differentiating base and surge demand in requirements on various projects. Nevertheless, this set of practices outlines a focused approach towards achieving the higher level of integration required in the context of more complex construction project.

Focusing on the second set of execution practices: ‘resource sharing’ (RS), ‘length of relationship over series of projects’ (LR) and ‘types of SC interdependencies’ (TSI), developing this set of practices relates to the integration of the pathways of actors and flows. These practices outlined from the synthesis of the literature are represented as a set, indicating they complement each other. The first two practices, RS and LR characterise developing SCI through stable demand for construction projects, which is served by an SC that has already identified and coordinated shared resources between involved actors. A key perspective to this link is the integration of flows. These focused practices are aimed at developing stable productivity through one SC with shared resources, the ability to serve multiple projects continuously, and predisposed to collaboration rather than opportunism. The underlying notion is that as actors develop relational integration through longer-term view and a vested interest in a series of projects, this minimises interruptions in flows and maximises opportunities to aggregate value. The additional practice identified from the literature is types of SC interdependencies (TSI) that are specific to integrating actors. This practice suggests that main contractors are able to identify the project interfaces that require close attention and can distinguish the types of SC interdependencies between the different partners (pooled, sequential, reciprocal and synchronic) that address these interfaces (Bankvall et al., 2010). This involves creating clusters of SC organisations able to develop optimum SC responsiveness to project demand without causing inefficiency.

The empirical results from the expert panel enquiry did not identify the management practice of ‘resource sharing’ (RS) as significant. This could be explained by the reluctance of construction firms to tie in resources within the SC, given the uncertainty in project demand over longer time periods. RS is a management practice related to the scope of SCI, which is, as argued in this thesis, a function of multiple projects rather than a single engagement. Having pointed this out, it is noted that RS can be an effective practice in large-scale, single construction projects. However, in reality, large-scale construction work is usually executed through programmes comprising multiple projects. This reinforces further the argument of the importance of RS in construction SCI, but points to developing RS as an effect of larger-scale demand for construction work, rather than the cause of it. The findings identified RS as not significant to improving SCI. This is explained by the dependency of the practice on a continuous stream of construction projects of sufficient size and already existing length of relationships over a series of projects for integrated actors.

The focused practice of ‘length of relationship over series of projects’ (LR) (e.g. Eriksson, 2015) was identified as significant by the expert panel. In essence, establishing a longer duration span of SCI over a series of projects strengthens integration, as partners become familiar with one another and develop mutual trust and attitudes of collaboration, rather than opportunism. A key integration pathway to developing a longer duration span is the stable and predictable recurring flows (of information, material and finance) that maintain the relationship over a series of projects. It is noteworthy however, that this management practice assumes a continuous client demand for construction projects. The significance of this management practice is a finding that corroborates studies by Crespin-Mazet and Portier (2010), Martinsuo and Ahola (2010) and Eriksson (2015). The presence of LR does not necessarily translate into intentions of developing SCI on its own; however, it does confirm the notion of relational integration that has been observed previously. LR is a critical practice as it develops the right conditions and stimuli for integrative activities to take place. It appears that it is the longer duration span of integration through LR that provides the necessary assurance and focus for integrated organisations to look into developing the scope of SCI.

The last practice in this set is ‘types of SC interdependencies’ (TSI) (Segerstedt and Olofsson, 2010). Although TSI appears in the literature as a specific practice to the pathway of actors, it is impactful in relation to project execution and is thus reviewed in this section. Some of the experts in the panel recognised the impact of this management practice for improving SCI, but the practice was confirmed as significant. This could be explained by the project-uniqueness bias that has long served main contractors in construction. Forming integrated construction organisations into clusters based on their interdependencies in projects can be a valuable approach in reducing project complexity from an SC perspective. Practical examples of initiatives that underpin the practice of identifying the TSI in construction are modular designs (e.g.

Doran and Giannakis, 2011) and building a proportion of assets offsite (Pero et al., 2015). Such initiatives highlight the applicability of a manufacturing approach to construction and the need for a clear distinction in how the competencies of different actors in construction relate to one another from a systemic perspective. Nevertheless, construction is a project-based sector and, at this point, it would be beneficial to depart from the assumption that simply identifying the involved TSI will play a major role in adopting an SCI approach. Rather, as discussed, the focus should be placed on the longevity of relationships over a series of projects, establishing the required duration of integration. Similarly to RS, the management practice of TSI plays an enabling role for an improved SCI in the execution stage, provided the necessary conditions and stimuli are in place.

Overall, it appears that, while numerous practices can be hypothesised to influence improving SCI in construction, only a handful are critical. To sum up to this point, the empirical results showcase that the practices significant to improving SCI start with the generic practices of CM and LTO. This highlights that improving SCI starts with the presence of strong relational integration between construction partners. As integrated construction organisations align in their commitment, this is supported by an articulation of the long-term orientation (LTO) required. In the planning stage, the integrated organisations need to build up higher levels of trust (T) through effectiveness in planning practices. It appears that the link between planning and trust is based on informational integration. In the execution stage, the integrated organisations may focus their efforts on JWP so that they develop SC responsiveness in serving projects with various degrees of complexity through better operational integration. In addition, the construction organisations may develop the longevity of SCI through the duration of their involvement over a series of projects (LR). This is a critical condition to SCI that can enable shaping the scope of the integrated SC through the practices of RS, TSI and B, unlocking more effective and efficient value realisation in construction.

7.3.4 Technology-enabled practices

The synthesised framework of the literature suggests that either or the pathways for execution can be technology enabled. For technology to be an effective enabler, it is important to identify the most appropriate types of 'supporting technology' (ST) that can 'communicate' (C) the real time visibility of information required to effectively deliver the project. Both practices relate to the strength of informational integration, relating the practices to the use of information technologies (IT) and information and communications technology (ICT).

The impact of the practices of both ST and C is, to some extent, supported by the expert panel, but out of the two, only supporting technology (ST) is identified as significant. The specificity of these two practices in the conceptual framework relates them to the pathway of integration of technologies and systems. The CF highlights that for improving SCI it is argued to be necessary to establish clear communication channels between partners. These can facilitate the exchange of knowledge (tacit and explicit) related to specificity of different assets, in-depth information required by the SC, and multi-skilled personnel able to mitigate problems related to customisation and variability in assets. While the findings do not suggest the management practice of communication © as significant to improving SCI, it highlights the ways in which integrated supporting technologies can be utilised towards improved communication. For example, in construction, this may involve the use of digital twin technology for digital representation of the assets, internal company handbooks and technical manuals capturing best practice and the skills required in construction activities, or specific equipment that collects asset data (e.g. LiDAR scanners). Continuing this train of thought, it may be inferred that construction professionals need to establish the necessary communication channels translating the captured data, information and knowledge from relevant technologies for improving SCI. However, in reality, construction is a sector traditionally associated with a relatively low integration of different technologies, their limited use and a reluctance to implement new technologies (Zhai et al., 2009). Furthermore, even if data is captured, it is seldom shared between SC partners. It is thus argued that the differentiating management practice for improved SCI is the actual use of supporting technologies. This is confirmed by the Delphi results, as ‘use of supporting technology’ is identified as a significant practice. These findings highlight that establishing strong communication between different construction organisations first starts with the actual use of supporting technology, which can then facilitate information exchange across firms’ boundaries. To apply this practice, construction organisations need to first improve the compatibility of the Information Systems (IS) shared between them, focus on integration of technologies in customers’ and suppliers’ value chains, and develop appropriate personnel training in the use of the available technologies for SCI.

7.4 Pathways to Improving SCI in Construction

This section focuses on the research question:

RQ3: What is the relative importance of each pathway in improving SCI in construction?

The discussion in this section is structured as follows. First the four pathways identified from the literature for improving the effectiveness of SCI are discussed as a collective based on their relative results, as ranked by the expert panel. Second, the pathways are viewed as groups that characterise the different strategic approaches supported by management practices, that can be followed by construction organisations towards improving SCI. Finally, the findings related to the four pathways to improving SCI in this section, are summarised and discussed.

7.4.1 Overall Effectiveness of the Four SCI Pathways

Integration of actors is the most effective pathway to improving the effectiveness of SCI applied to each of the five practices where consensus in the Delphi was reached. This finding highlights that for improved SCI it is essential to first identify the ‘optimum’ collective of integrated construction organisations and their relevant structure in line with each actor’s competencies and capabilities. Construction supply chains on large projects typically involve hundreds of different companies supplying labour, materials, components, equipment and a wide range of professional services. For example, this can include tools as simple as shovels and as sophisticated as diamond cutting saws (Dwan, 1998). Exemplifying this further, a competency can be steel mechanical structures and capabilities can be formed on the basis of MEICA (Mechanical, Electrical, Instrumentation, Control and Automation) expertise. The findings point to the pathway of integrating actors as most effective, highlighting that for improving SCI in construction it is essential for each construction organisation to take on their respective position in the integrated network of actors. Furthermore, this finding relates to the role construction actors can play in SCI, such as ‘aggregator of value’, ‘change agent towards implementing sophisticated strategy’ and ‘antidote to fragmentation’, corroborating studies by Titus and Bröchner (2005), Wood and Ellis (2005), Davies et al. (2015), Broft et al. (2016), Papadonikolaki et al. (2017), and Pillay and Mafini (2017). The pathway of integrating actors, as most effective to SCI, can be further explained by the necessity for developing strong relational integration between actors in construction, serving continuously various construction projects. This is opposed to the current reality in the sector, characterised by disbanding the SC at the end of a project. Following the empirical findings, it is thus argued that the pathway of integrating actors serves SCI in two ways: it shapes the integrated organisations, structuring them according to their relevant competencies and capabilities, and provides confidence and a long-term view in the selection of partners for continuous delivery of projects.

Following on from actors, the second pathway in effectiveness towards improved SCI, as empirically validated by the expert panel, is integration of flows. This finding relates to maintaining stable productivity throughout the SC based on recurring flows (of information, materials and finance). The key benefits associated with integrating flows are in providing stability in demand for construction work and predictability in the SC over a series of projects. The current reality of subcontractors and suppliers in the construction sector is often associated with high demand uncertainty, exemplified by numerous changes and quotation requests for procurement and the design of components and services. This leads to limited value realisation from suppliers in the SC as it results in disjointed production plans and cost volatility, which can be especially critical for different commodity materials. As opposed to this construction reality, developing recurring flows can minimise spikes in associated costs of material sourcing and related implications, provide job security and opportunities for continuous training in labour personnel, improve equipment utilisation and offer continuous engagement with professional services. In the described context, the effectiveness of the pathway of integration of flows is a notable explanation of how SCI can be improved. Furthermore, the second key benefit to integrated flows is associated with the predictability that this pathway can infuse in construction activities. Predictability is important for successful delivery of a series of construction activities and relates operational plans to strategic plans. However, the construction sector is known to suffer from large functional fragmentation. In relation to this issue, integrating flows between actors can minimise discrepancies over different projects' lifecycles and improve the right timing of involvement of actors in construction activities.

Contrary to popular views of the construction sector's nature being project-based with high uniqueness in each project, the experts in the panel ranked the pathway of integrating processes and activities overall in third place regarding effectiveness to SCI, after integration of flows. The 'uniqueness bias' can be explained by the assertion that at project level, the demand for construction work can show considerable variation due to both the frequency (intermittence) and size (lumpiness) of projects coming out of a client's pipeline (Godsell et al., 2018), while in reality at SC level high commonality in requirements may exist between them. In this context, construction organisations integrating through the pathway of processes and activities need to develop a clear understanding of the types and groups of projects and formalise what these mean from an SCI requirements perspective. This pathway involves the integration of construction work packages into overriding SC processes and activities developed for different types and groups of projects. The construction reality is often associated with a high level of design changes, which can be highly disruptive to SC productivity. Contrary to such instances, the pathway of integrating processes and activities develops integration between different projects, thus improving the certainty (predictability) in related SC requirements, and minimising disruptions. The key benefit of this pathway is in differentiating what SC demand is repeatable over different projects and what is project-specific. Discussing the findings further, the pathway of integrating flows is overall more effective to improved SCI, relative to the integration of processes and activities. This is explained by the primary importance of developing long-term relationships between actors based on demand over a series of projects and maintained by continuous recurring flows. This infuses the necessary stability in the SC, keeping actors integrated. The pathway of processes and activities, ranked third in overall effectiveness, formalises the overriding processes and activities in the SC towards standardisation, and facilitates aggregation of value in requirements through the supply chain echelons.

Lastly, the pathway of integrated technologies and systems' effectiveness to improving SCI was also investigated in this study. The aggregated findings show that the pathway was consistently ranked last in effectiveness to SCI. For construction organisations embarking on the pathway of integrating technologies and systems, this involves integration of various available technologies and systems between SC members into a unified whole (e.g., product platforms) (Jones et al., 2021). Examples include integration of BIM, digital twin solutions, specialist equipment and production technology. The initial literature review suggested that the pathway of integration technologies and systems can have a powerful effect for SCI and as such constitutes a separate pathway. However, the results consistently ranked it last in effectiveness. This can be explained by often applying a specific role and function to technology, focused on enabling the other three pathways. In other words, the pathway of integration of technologies and systems in construction is dependent on the integration of actors, processes and flows, and cannot be separated from these three pathways. This appears as a rational assertion, as without integration in the other three pathways, integration of technologies and systems will be disjointed from efforts of improving SCI and likely to achieve limited benefits. In such cases, this pathway may be applied to resolving specific SC issues, rather than enabling transformational change in the sector. Specific examples of technologies related to the three pathways include: use of digital twin technology to facilitate design changes and offsite modular construction that relates to the integration of processes and activities; use of various IT systems and tools that provide connectivity and synchronisation of activities across the SC, related to improving flows; and the use of product platforms and BIM that can provide space for better collaboration related to integrating actors. Following the discussion further, it can be argued that the more various technologies are adopted in construction, the more challenging integration between these technologies becomes. It appears that the pathway of integration of technologies and systems has an enabling role to SCI in integrating the various technologies utilised between the other three pathways and as such has a moderating effect to improving SCI. These findings are further supported by the fact that the experts in the Delphi panel could not reach consensus in ranking the pathways in relation to the management practice of the use of supporting technology (ST).

7.4.2 Differentiated Strategy Based on the Four SCI Pathways

Following the discussion of the aggregated results from the Delphi in the overall effectiveness of the four pathways, this section dissects the findings of the pathways in accordance with the selection of significant practices.

For all five investigated practices that achieved consensus by the expert panel, the pathway of integrating actors was identified as most effective and as such presents the first strategic step to improving SCI. This is indicative of starting SCI improvement with a collective of optimum integrated construction organisations, in accordance with their respective competencies and capabilities. This approach brings forward the necessary structure and positioning of construction organisations in SCI. The high importance of this pathway is placed on the relational integration that this first step develops, as integrated organisations have the underlying security to shape and reconfigure their involvement continuously, instead of disbanding at the end of projects.

Following this first strategic step, the results highlight that there are two possible pathway sequences to follow. One is on integrating the pathway of flows as a second step and the other is on integrating processes and activities.

Following the first sequence, the pathway of integrating actors is followed by the pathway of integrating flows. The results highlight the management practices of ‘trust’, ‘long-term orientation’, ‘commitment’ and ‘length of relationship over series of projects' as impacted positively by integrating flows. This conventional first sequence in steps exemplifies the strategic orientation in construction organisations towards developing productivity based on stable flows and building relationships that maintain SCI in the long term.

Following the second possible sequence, the pathway of integrating processes and activities comes as a second step to improving SCI. The findings from the Delphi investigation point to the management practice of 'joint work processes' as impacted positively by the pathway of integration of processes and activities. This sequence presents a differentiated strategic approach to SCI, where construction organisations following this pathway can focus on integrative actions that interactively adjust the behaviour of integrated construction organisations towards pursuing opportunities over time. Integration through the pathway of processes and activities makes possible the strategic differentiation between various projects served by the integrated SC, enabling construction organisations following this pathway as a second step to set out such integrative actions.

As a third step, the findings of effectiveness in pathways indicate the reciprocity between the two sequences. In other words, organisations taking on the pathway of processes and activities as a second step can complement SCI efforts by focusing on aligning the management practice of 'joint work processes' to the management practices related to the pathway of integrating flows. For example, construction organisations that have focused on strong relational integration through recurring flows, can be enhanced in their SCI efforts by better identification in project profiles through the pathway of processes and activities. In practice, this will provide long-term interactive actions for stable demand in construction work and short-term interactive actions that address surge and variability in project demand. Putting this perspective in context, construction projects in the public sector are often planned in 5-year AMP (Asset Management Periods) with a relatively large proportion of projects exhibiting high levels of repeatability and predictability, making this approach possible. This suggests that, based on their differentiated pathway strategy, construction organisations can pursue 'economies of repetition' through SCI. This approach can offer convergent thinking over a series of projects and a stimulus to the right type of behaviours in the integrated SC.

On the other hand, organisations that have focused on the pathway of flows as a second step can complement joint SCI efforts by focusing on aligning the stability achieved through recurring flows with expertise from integration of processes and activities, based on a clear view of overriding SC processes. This approach is here suggested as particularly beneficial to large and more complex projects or programmes. Major projects are usually planned well in advance and through management practices such as joint work processes, the integrated construction organisations can set up the necessary long-term interactive actions. Such large-scale projects often include large repeatable work packages. The strategic approach suggested by the findings can harness the established stability in recurring flows and offer opportunities for developing 'economies of recombination' (Grabher, 2004). A practical example documenting this approach is the Heathrow T5 project team being able to reuse and place their project knowledge into 'modules' that comprised components (or elements of sub-projects) of the overall T5 project. These components can be effectively delivered, given the strong relational integration construction organisations have already developed through SC efficiency in routine projects.

As highlighted by the findings, these differentiated pathway strategies can be aligned and further supported by the integration of technologies and systems as a moderating function of SCI. This finding is consistent with many studies, emphasising the role of technology as an enabler of SCI.

7.4.3 Section summary

To sum up, this section critically discussed the findings of the effectiveness of the four integration pathways to improving SCI. Overall, construction companies need to first focus on the pathway of actors, followed by flows as a second step, and processes and activities as a third. The pathway of integration of technologies and systems was identified as enabling overall SC integration and also links to each and between the other three pathways. A closer look into the different sequences in pathways to be followed, revealed that construction organisations can differentiate their SCI strategy. Such differentiation can be executed by prioritising integration of processes and activities as a second step through the management practice of 'joint work processes'. This strategic differentiation suggests better facilitation in developing 'economies of repetition' and 'economies of recombination' through SCI.

7.5 Outcomes from Improved SCI in Construction

This section first discusses the outcomes of SCI that are classified as major and explains why this may be (see Subsection 7.5.1). In the second part of the section, each of the seven outcomes is discussed in line with the relevant pathways that can be followed towards achieving each outcome (see Subsection 7.5.2).

7.5.1 Major Outcomes of SCI in Construction

To start with, the discussion focuses on the following RQ:

RQ4: What are the major outcomes that SCI delivers?

The following outcomes of SCI were classified by the Delphi panel as major outcomes:

- Compete through superior value
- Define client values
- Develop continuous improvement
- Manage costs collaboratively

This section first discusses the findings of the four outcomes listed above to explain why they are identified as major outcomes that SCI enables in construction.

The first major outcome of SCI identified is 'compete through superior value' (CTSV). This outcome involves leveraging SCI for enhancing the value of what is actually delivered by improving quality and cutting underlying costs. As discussed in Section 7.4.2, SCI offers a differentiated strategic approach, through which integrated construction organisations can use one SC serving multiple projects. This differentiated approach can enable the SC in developing strategic fit, translated into developing 'economies of repetition' for routine projects and 'economies of recombination' for more innovative and complex projects that include repeatable work packages. Evidently, it does not come as a surprise that in taking on an integrated approach to construction SCs can offer a wider selection of projects that the integrated collective of organisations can compete on. Without SCI, construction partners are not in a position to aggregate value and develop the long-term orientation that enables organisations to compete as a unit (Nikolov and Harpum, 2023). This ultimately leads to competing on small-in-size projects or dispersed work packages that may not necessarily be aligned with the organisations' value drivers, resulting in loss of commercial position.

The second major outcome of SCI identified is 'defining client values' (DCV). This outcome involves applying a more rigorous way of assessing value in construction projects. This is explained as a major outcome resulting from developing SCI, as organisations are not disbanding at the end of projects, and can develop collaboration rather than opportunism. This facilitates developing clarity in functional requirements, design character, and target through-life cost profile of the delivered assets. As construction actors integrate, this offers the opportunity to apply their competencies and capabilities towards reaching agreement in assessing and selecting asset strategic choices and quick prototyping. In contrast, without integration, actors are predominantly incentivised by self-interest in project-based asset decisions and do not consider such decisions on a strategic SC level. This approach ultimately leads to detachment from customer value, increased complexity, disputes and disagreements, and results in project-based winners and losers.

The third major outcome of SCI identified by the panel is 'develop continuous improvement' (DCI). This outcome aims at a decrease in costs, improved functionality and the realisation of better value in future projects. Such improvement is not achieved over the life of one project, but instead requires a series of projects. Generally, continuous improvement relates to agreed long-term relationships allowing for continuous reduction in component and process costs through systemic planning and process improvement. This is often associated with focusing on close control over the SC and application of lean principles and techniques. In construction, this outcome means paying far greater attention to planning how to do activities in advance with a clear view of how problems can be anticipated and avoided. Furthermore, this approach is in contrast to actual practice in construction, characterised by clients and main contractors setting themselves ambitious programme targets without a clear idea of how exactly the work will be delivered. Thus, the key activity for DCI in construction is in mapping out the detailed work processes or methods, and then improving them so that they are compatible with the client priorities driving the overall project or programme. In practice, this involves mapping the necessary processes and activities related to key project interfaces. In construction, shared formal processes and procedures between different partners are seldom established as organisations disband at the end of projects; however, they may exist with the main contractor. Continuous improvement is thus explained as a major outcome of SCI, as construction organisations can develop integration between themselves based on overriding SC processes by types and groups of projects. SCI plays a key role in distinguishing between the processes and methods' characteristics in different projects served by the SC and improving them in line with different client priorities. This becomes a continuous process, made possible by the involvement of actors over a series of projects. Furthermore, it could be argued that through SCI, this outcome builds a strategic learning competence in the integrated collective of organisations that can comprise a long-term competitive advantage over a series of projects.

The fourth major outcome of SCI identified by the experts in the Delphi is 'manage costs collaboratively' (MCC). Traditionally, construction is regarded as a low-margin sector and cost is always a major issue for the integration of SC members. This outcome is essentially a process that is facilitated by SCI. It utilises a specific approach in optimising costs in construction, referred to as 'target costing'. It allows partners to work backwards from the client's functional requirements and the maximum item prices through ring-fencing, thus allowing security to look at underlying costs. Traditional approaches in construction often develop designs that then prove to be too expensive for the client and can result in profit margins and build quality being eroded, further fragmenting the SC. Instead, collaborative planning with integrated clusters of actors allows many of the construction project risks and associated costs to be managed out. This gives the needed security of reasonable margins for each partner and can allow for looking into how their initial estimate is based on allowances for problems arising elsewhere on the project. This outcome develops greater certainty and predictability for the members of the SC that they will make the profit intended from the project, and brings in security in client and construction contractors so that they do not bargain over margins. Although the Delphi panel of experts could not reach consensus in the most effective pathways to achieving this outcome, the impact of SCI towards this outcome is explained through the higher level of relational integration and visibility in supporting planning activities developed between SC partners. This outcome does not allow problems in one partnering organisation to filter out through the entire SC and thus damage relational integration. Instead, the outcome allows for dealing with any issues separately through a tailored approach to each construction actor or cluster of actors.

7.5.2 Pathways leading to SCI outcomes in construction

This section discusses the findings from the Delphi expert panel regarding the four pathways of SCI (Fabbe-Costes and Jahre, 2008), considering their effectiveness towards achieving each of the seven outcomes identified in the conceptual framework. In this way, the section aims to answer the research question:

> RQ5: What pathways lead to the achievement of SCI outcomes?

The results from the Delphi investigation are discussed in accordance with the rank given for each of the four pathways to each of the seven outcomes, thus comprising three categories. The experts in the panel consistently ranked the pathway of integrating technologies and systems last in effectiveness for each outcome. This finding further confirms the enabling role of integrating technologies and systems in SCI as a pathway providing moderating effects to integration between the other three pathways. For better clarity in the discussion, this pathway is removed from the classification as it does not represent a differentiating pathway to any of the outcomes.

Furthermore, the outcome of 'managing costs collaboratively' (MCC) did not reach stability and thus representative results amongst the Delphi experts in how best to achieve it through the four pathways, and as such is excluded from the discussion. However, the lack of agreement on MCC further exemplifies the mistrust and cost-opportunistic nature of the industry, lacking clear guidelines between SC members on how to develop better value realisation through SCI. The findings of the three categories of pathways are discussed in turn with the relevant outcomes for each.

7.5.2.1 Outcomes as a Result of Integrating Actors, Flows and Processes

Starting with outcomes achieved by prioritising first actors, second flows and third processes and activities, the relevant outcomes achieved through this sequence of pathways are:

(1) Compete through superior value (CTSV)
(2) Establish supplier relationships (ESR)

Compete through superior value (CTSV)

The first outcome identified from the literature is compete through superior value (Dainty et al., 2001; Elliman and Orange, 2003; Briscoe et al., 2004; Broft et al., 2006; Davis and Love, 2011), The expert panel ranked the perspective of integrating actors as most effective towards achieving the outcome of CTSV. The outcome relies on high levels of collaboration between SC actors, each with their respective capabilities in taking the 'right' costs out in order to arrive at competitive prices and mutual benefit. The effectiveness of the pathway of integrating actors is explained, as it allows for involving an 'optimum' number of integrated construction organisations and provides insight into cost components. Integrating actors advances joint understanding of the customer requirements, how such translate in the SC and sets up an appropriate structure for continuous value realisation. Second in effectiveness, the expert panel ranked the pathway of integrating flows. As SC actors develop stability with regard to their respective position in SCI and security through protected cost margins, the integrated organisations can focus on developing recurring flows of materials information and finance as key to improved productivity. The pathway of integrating flows allows for stability and predictability in the SC, installing long-term competitiveness as a unit of organisations. Third in effectiveness, the expert panel ranked the pathway of integrating processes and activities. Provided actors and flows are integrated, the collective of construction organisations can improve their understanding of the complexity in the groups and types of projects delivered. The key to leveraging integration of processes is in addressing client demand by offering problem-specific solutions to the client and at the same time reusing sediment project knowledge of ‘modules’ that can be recombined in related projects. Essentially, this pathway relies on establishing overriding SC processes that guide continuous efficient delivery, but still account for effectiveness through outlining the specific requirements by type and groups of projects. Developing this sequence of pathways allows the integrated organisations to leverage their position as a unit and compete through superior value in a broader selection of project scopes.

Establish supplier relationships (ESR)

The second outcome identified in the literature is establish supplier relationships (e.g. Costa et al., 2009; Xue et al., 2005) The expert panel ranked the perspective of integration actors as most effective towards the outcome of ESR. Working with fewer suppliers (as opposed to a high degree of subcontracting) is increasingly becoming more attractive to main contractors in construction, as it reduces complexity and improves communication on projects. As actors are integrated in one SC, able to serve multiple projects with various degree of complexity, establishing long-term commitment with a small number of specialist suppliers within each supply category becomes an essential first step. The relationships with key suppliers, through the perspective of integrating actors, can be characterised as strategic relationships with major organisations in the SC delivering a large share of the value of any project. Following actors, the expert panel ranked integrating flows second in effectiveness towards this outcome. This is explained by the high value in relationships with major suppliers and the high costs associated with underperformance. Integrating flows strengthens the relationships through recurring flows of information, material and finance, and develops stability and predictability in project phases. As such, the pathway of flows is the necessary step that maintains the strength of the strategic supplier relationships over the long-term. After flows, and third in effectiveness, the expert panel ranked the pathway of integrating processes. This pathway is key in differentiating supplier involvement between projects, based on large levels of repeatability and involvement that is project-specific. This approach offers tailoring of the integrated SC to the right type of underpinning relationships; for example, supplier relationships demonstrating high strength, based on large value in construction projects and stability through recurring flows and relationships with increased depth based on developing clear understanding in the types of projects and what these mean from an SCI requirements perspective. The pathway of processes and activities is key in understanding and addressing such project complexities through establishing encompassing supplier relationships.

7.5.2.2 Outcomes as a Result of Integrating Actors, Processes and Flows

Following on from the discussion on outcomes achieved by prioritising first actors, second processes and third flows, the relevant outcomes achieved through this sequence of pathways are:

(1) Defining client values (DCV)

(2) Integrate project activities (IPA)

(3) Mobilise and develop people (MDP)

Defining client values (DCV)

Following on with the discussion the third outcome is defining client values (e.g. Kanji and Wong, 1998; van Zoest et al., 2002; Chen et al., 2021) The expert panel ranked integration of actors as the first pathway in effectiveness towards the outcome of 'defining client values'. This outcome involves applying a more rigorous way of assessing value, through clarification of functional requirements, design character and target through-life cost profile of the delivered asset. Essentially, the outcome starts with the customer requirements, but uses the integrated state of actors to better define what value means from an SC perspective. The effectiveness of this first outcome is explained by the highly integrated state of actors which allows the collective of actors to quickly provide suggestions in concept-select planning activities (e.g. front-end loading (FEL)) and define their respective involvement in the project functional requirements. This is made possible by the clearly defined respective position of organisations in the integrated SC and the increased awareness of partners to one another with regard to their respective competencies and joint capabilities. Second in effectiveness, the Delphi panel ranked the pathway of integrating processes. This involves defining client value in output terms, which is facilitated by identifying how a given project compares with other types or groups of similar projects. As such, this integration pathway involves understanding what products and services used in a project are repeatable and what are innovative. Through following pre-established overriding processes by groups or type of projects, the integrated organisations can apply predetermined control mechanisms, which better define the project's functional requirements from an execution perspective. Following on from actors and processes, the expert panel ranked the pathway of flows as third in effectiveness. Evidently, this pathway enables better definition of client value in output terms and translates client values from planning to execution, with improved definition in project or programme objectives. This is explained by setting up the SC for recurring flows of information, materials and finance throughout the project, which infuses stability and predictability in construction activities and minimises risk associated with the delivery of project objectives.

Integrate project activities (IPA)

The forth outcome identified in the literature is integrate project activities (e.g. Dainty and Brooke, 2004; Briscoe and Dainty, 2005; Titus and Bröchner, 2005; Kesidou and Sovacool. 2019). The expert panel ranked integration of actors as the first pathway in effectiveness towards the outcome 'integrate project activities'. This outcome utilises SCI as a mechanism for selecting strategic long-term partners best positioned to direct the effective management of partners collaborating on a project. The goal is to create clusters of actors and use concurrent engineering techniques with specialist suppliers, in order to respond at each key project interface and resolve all design-related issues early. Not surprisingly, creating clusters of construction organisations as a first step is dependent on the pathway of integrating actors. This involves recognising which are the key actors in the integrated SC and how they relate to other suppliers and subcontractors in each key project interface. Second in effectiveness, the panel ranked the pathway of processes and activities. This is explained by the rigour overriding SC processes can offer towards identifying where the key project interfaces are located in the SC and developing mechanisms of how to address these in various projects. Practically, this can call for focused effort by selected strategic partners in involving specialist suppliers early on into the work clusters, in order to establish commitment to processes and subsequent phases. Developing such responsiveness through the pathways of actors and processes may also be dependent on the interdependencies between processes. As the expert panel ranked the pathway of flows third in effectiveness, this exemplifies the need for predictability and stability that recurring flows can infuse in integrating one set of project activities with another.

Mobilise and develop people (MDP)

The fifth outcome is mobilise and develop people (Dainty et al., 2001a; Dainty and Brooke, 2004; Wood and Ellis, 2005; Eom et. al., 2008; Meng, 2012). The expert panel ranked the pathway of integration of actors as most effective in achieving the outcome of 'mobilise and develop people'. In the UK construction sector, shortage of skilled labour is often highlighted as a major factor contributing to low productivity and quality issues. Furthermore, the cost-driven agenda of the industry results in cost opportunism and switching between suppliers regardless of actors' good performance. These factors lead to short-term engagements and relatively low levels in development of the right skillsets in people. The expert panel ranked integration of actors as the most effective perspective in mobilising and developing people. Essentially, this pathway allows for stable and secure continuous delivery of work packages by actors. The continuous demand for work aligns each actor's respective position and associated involvement in the SC. As the SC becomes integrated, actors can use the underlying security to focus their competencies and capabilities and develop processes of training and acquisition of new skills in employees. For example, engineers involved in any of the MEICA areas can work in the same teams of people and develop multi-disciplinary skillsets associated with other technical areas outside their specialism. This approach can be enhanced by systematic top-level commitment between actors with the right culture, invoking attitudes of proactiveness, mutual help and collaboration. Following on from actors, second in effectiveness, the expert panel ranked the perspective of integrating processes and activities. Understanding the specifics of individual projects and how they compare with other similar construction projects is key in mobilising and developing people. This enables better project team facilitation and more effective capturing of 'lessons learned' on projects. Furthermore, as the integrated SC is formalised in delivering various projects through overriding processes, this presents structured learning and mobilisation opportunities. Following on from the pathways of actors and processes, the expert panel ranked the perspective of integration of flows third in effectiveness towards better mobilisation and development of people. In line with this outcome, the pathway's applicability is explained by the possibility of offering the provision of economic incentives for recurring flows (e.g., payroll practices encouraging achieving the desired predictability and stability over periods of time) and thus better mobilisation and development of people through the SC echelons.

7.5.2.3 Outcomes dependent on integrating processes, actors and flows

Lastly, the discussion in this section focuses on the outcome of developing continuous improvement. This outcome was ranked as most effective by the pathways of processes and activities as first, actors second and flows third.

Develop continuous improvement (DCI)

The seventh outcome is develop continuous improvement (Denicol et al., 2020; Davis and Love, 2011; Bankvall et al., 2010). The findings show that developing continuous improvement is heavily dependent on integrating processes and activities. This pathway appears as more effective than integrating actors. This signifies the importance of the relationship between project capabilities and SC activities. The results highlight that project expertise is the necessary foundation for continuous improvement in construction, irrespective of whether the actors integrated are always the same. Integration of processes and activities as a first step in developing continuous improvement is explained by the need for better understanding of the types and groups of projects delivered. In practice, such understanding is often translated through the use of various management tools applying project information to decisions. These can include the level of routineness or complexity between partners involved in project interfaces; type of activities in terms of whether they are multidisciplinary and done before, or applying novel techniques or equipment; and the level of brownfield content in projects. The key to this outcome is in preventing activities going wrong rather than identifying subsequently that they were not done properly to begin with. The second pathway in effectiveness to this outcome is integration of actors. This is explained as this step focusing efforts and determination to utilise the contributions of everyone in the business continually to seek better ways of working. Higher levels of integration between actors mean that the specialism (competencies and capabilities) of construction organisations is applied towards paying greater attention to planning how to do construction activities in advance and seeing how problems can be anticipated and avoided. The emphasis is on planning through mapping out the detailed work processes or methods between actors, and then improving them so that they are compatible with whatever genuine client priorities are driving the overall project or programme. Integrating actors has a key role in developing the necessary adaptability to client priorities and addressing such adequately in different projects. Third in effectiveness, the expert panel ranked integration of flows. Traditionally, lean practices associated with higher levels of productivity rely on efficient flows of material, information and finance. This means that higher levels of efficiency, based on recurring flows, can only be applied when processes and actors' integration take place beforehand. It is through the perspectives of integration of actors and processes that risks are identified and effective planning takes place, and through the perspective of flows that efficiency can be improved in actual construction activities. Nevertheless, developing higher levels of efficiency is a key perspective in continuous improvement. Integrating flows offers measurable performance indicators on which the integrated organisations in the SC can benchmark their performance on different projects and identify improvement initiatives.

7.5.3 Section summary

To sum up, first, there is a distinction between outcomes achieved through prioritising integration of flows and integration of processes and activities.

Organisations in the SC focusing on integration of flows can achieve higher levels of efficiency in a series of construction projects and leverage the value of SCI. The stable productivity achieved from recurring flows enables the integrated SC to 'compete through superior value' through 'economies of repetition' in repeatable projects as well as reuse sediment project knowledge of 'modules' that can be recombined in related projects developing 'economies of recombination'. In addition, because of the higher levels of productivity and predictability in flows, the integrated actors can develop strategic, long-term relationships with the major suppliers contributing the large share of materials, components, labour and professional services to any project.

Organisations focusing on integrating processes and activities can develop overriding processes that formulate focused involvement and better control in the SC by types and groups of projects. This approach develops the necessary 'fine-tuning' of the SC in line with different project complexity. The expected outcomes are a better definition of client values, improved integration of project activities and better mobilisation and development of the right people on projects. This pathway to integration is also key in building the competencies and capabilities of the collective of construction organisations as it differentiates the requirements on various projects and what lessons can be learned from each. In addition, by focused integration of processes and activities, construction organisations that stay integrated over a series of projects can develop continuous improvement. This may be particularly appealing to main contractors as they build their project capabilities with an SCI approach. It is the formalisation of overriding processes and activities that this pathway offers that illuminate what the key interfaces and risks in projects are, and setting out appropriate actions to prevent things going wrong in the first place.

Furthermore, the findings exemplify that integrated organisations can develop an outcome-based approach to different projects by recombining their respective strengths through the SCI pathways.

The pathway of integrating technologies and systems was consistently ranked last by effectiveness in achieving any of the outcomes. Integrating technologies and systems is thus asserted to have a moderating role for SCI and can play a key role in linking the pathways of actors, processes and flows. However, it does not present a separate step in improving SCI, but does have an enabling role for SCI.

7.6 Revised Conceptual Framework

In this section the discussed results from the Delphi study are presented as a revised conceptual framework of improving SCI in construction. This is illustrated in Figure 7-2, depicting the identified significant practices, pathways organisations can follow and suggested resultant outcomes. The three areas: (1) practices, (2) pathways and (3) outcomes are addressed in the revised conceptual framework in accordance with the three gaps in the literature identified. In the revised framework, most of the practices under the 'specific' category as originally appearing in Figure 4-6 in the conceptual framework were eliminated with supporting technology identified as an enabling practice between all other practice categories. The revised conceptual framework brings in clarity to how SCI in construction can be improved by signifying the actual relationships explored between pathways, practices and outcomes. These relationships further exemplify that there is more to SCI than what is originally conceptualised, in particular, SCI as a process following generic, prevalent and focused stages of practices. The revised conceptual framework signifies that SCI can be improved by defining the practices within each pathway and how these relationships lead to desired outcomes in construction.

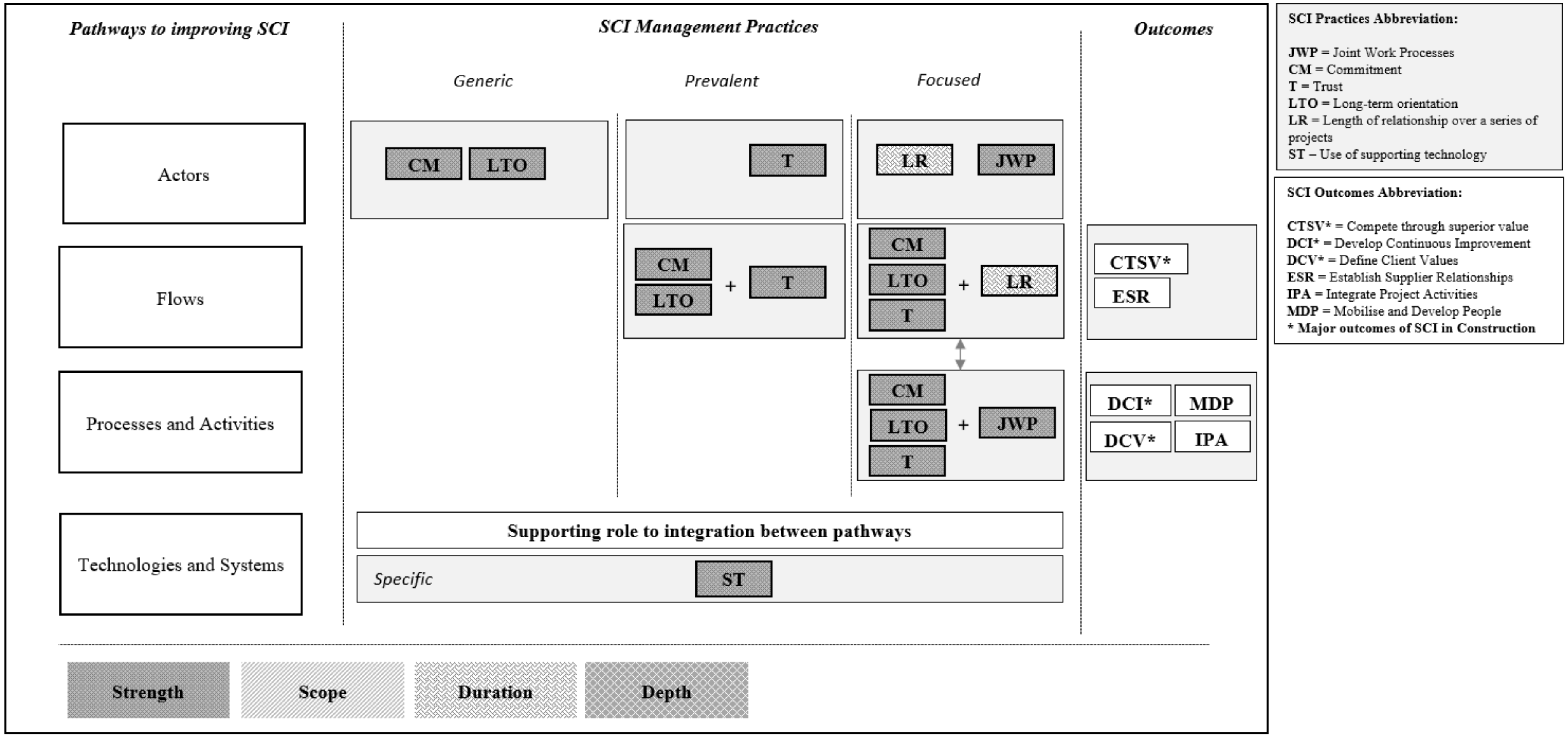

Figure 7-2: Revised Conceptual framework of improving SCI in construction

7.7 Chapter Summary

This chapter has discussed the empirical findings of this research project in accordance with the set of RQs posed. The main findings of this chapter are listed in the following:

- The current understanding of what transforming to an SCI approach from traditional SCM in construction involves was discussed, highlighting that practitioners recognise different facets of SCI, but overall a systematic approach to SCI is currently lacking.
- The findings confirm several SCI management practices previously assumed to improve SCI in construction, while rejecting others.
- The overall effectiveness of the four pathways to improved SCI was discussed, highlighting the distinct steps the construction organisation can take towards improving SCI.
- The chapter offers a distinct sequence of pathways coupled with relevant management practices to improved SCI, as the basis for construction organisations developing a differentiated SCI strategy.
- The major outcomes of SCI were outlined, discussing their importance in construction context
- The relationship between following different sequences of pathways and the outcomes that such can lead to were discussed.
- This indicates that integrated construction organisations can follow an outcome-based approach to value realisation in different projects by recombining their respective strengths through the SCI pathways.
- The pathway of integrating technologies and systems was discussed as having a moderating role for SCI in enabling integration by linking the other three pathways.

Chapter 8 : Conclusions

8.1 Chapter Introduction

Beyond this introductory section, this chapter is divided into four sections. First, the thesis is summarised with the key findings drawn together in Section 8.2 'Key Findings'. Following on, the outputs of the research project will be outlined in Section 8.3 'Thesis Contribution', which is divided into two subsections, one based on contribution to academia, 8.3.1 'Contribution to Theory' and a second section on contribution to practice, 8.3.2 'Contribution to Practice'. These subsections are followed by Section 8.4 'Study Limitations and Further Research' demonstrating the ways in which the findings of this research and the relevant limitations enable further progress in the field through further research opportunities. Lastly, the main points of this chapter are summarised in Section 8.5 'Chapter Summary'. The structure of this chapter is illustrated in Figure 8-1.

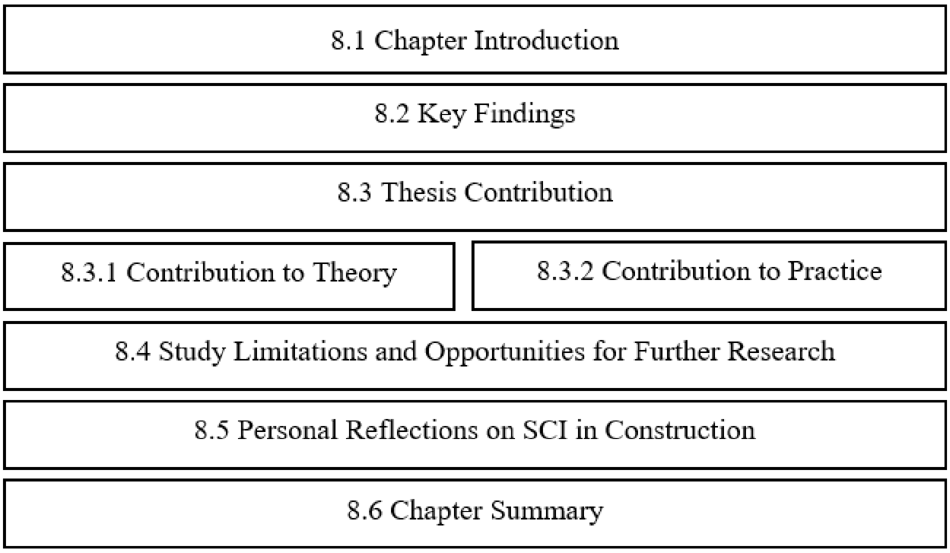

Figure 8-1: Structure of Chapter 8

8.2 Key Findings

This thesis has investigated the adoption of an SCI approach in a project-based context, in particular construction of an infrastructure. The thesis aimed at identifying how SCI can be improved towards better value realisation in construction. Based on the many SC issues faced in the construction sector, there is a general agreement amongst practitioners and academics that the sector is not capturing opportunities in value realisation, calling for an integrated approach to SCM. The initial scoping of the project highlighted that large clients of public infrastructure projects usually work with sufficient scale in the number and size of projects and with relatively high levels of predictability and repeatability in projects. This pointed to alternative ways in value identification through strategic planning processes of projects, taking into account the SC (Godsell et al., 2018; Nikolov and Harpum, 2023). It became evident that value realisation requires an alternative approach to SCM, which was posed and investigated in this thesis as SCI. Through the use of an SLR, the concept of SCI in construction was deconstructed to involve sets of management practices, pathways and outcomes. The relationships between these variables in the construction context were framed through an SCI conceptual framework that was empirically tested with construction experts through a Delphi investigation.

The overarching RQ of the thesis was set as:

RQ: How can SCI in construction be improved?

Focusing on the overarching RQ, five RQs were asked at the outset of the thesis:

RQ1: What is the current understanding of SCI in construction?
RQ2: What are the most significant SCI practices to improve SCI?
RQ3: What is the relative importance of each pathway in improving SCI in construction?
RQ4: What are the major outcomes that SCI delivers?
RQ5: What pathways lead to the achievement of SCI outcomes?

This thesis postulated that the construction industry can benefit from integrating the multiple SCs it forms for different projects through SCI. Little is known at this stage about what SCI entails in construction and how it can be improved.

Through the qualitative part of the investigation, six transformation areas, as generated by the literature review section, were presented. These areas were further discussed with supporting empirical evidence of what resonates with panel members' experience of SCI in construction. The areas included: change towards forming long-lasting relationships between construction partners; focusing the integrated organisations on an outcome-based approach in SCI, rather than individual functional objectives; enabling integrated planning in the SC, as opposed to one-off project-based requirements planning; moving away from the ad hoc approach of forming a new SC for each project and instead developing an SCI scope able to serve multiple types and groups of projects continuously; developing continuous partner engagement based on continuous repeated work, rather than competing on discrete work packages; and forming an organisational structure based on SC flows, rather than based on functions. These transformation areas represent significant change in how the sector operates currently and offer opportunities for developing SCI, as a basis for a different approach to value realisation. Examples and commentary from the experts in the Delphi panel indicated the different insights practitioners have developed though their extensive experience in construction. However, these insights were relatively discrete and not based on a systematic approach to improving SCI in construction. Such a systematic approach is currently lacking both in academia and in practice.

Overall, it appears that, while numerous management practices can be posited to improve SCI, only a handful are critical. It can be concluded that improvement of SCI in construction, as investigated here, hinges on developing strong relational integration between integrated actors through the management practices of commitment and long-term orientation as prerequisite practices for further integration. The relational integration developed is strengthened by the management practice of building trust tied in to the effectiveness of planning activities. Another key finding to improving SCI in construction is in the importance of maintaining the relationship between integrated actors through continuous involvement in a series of projects. Establishing strong relational integration can be coupled with developing joint work processes that fine-tune SCI in better responding to a degree of variability in SC requirements of different projects. Interestingly, the use of supporting technologies in integration was recognised as significant management practice, but is not as untenable to improving SCI, as is assumed in the literature, serving primarily as an enabler of SCI.

This thesis also investigated improvement in SCI from a strategic perspective by focusing SCI efforts through four pathways of integration (actors, flows, processes and technologies). It can be concluded that the first step to improving SCI in construction is integrating actors, establishing strong relational integration with the same construction organisations involved continuously, as opposed to assembling new SCs through tendering and bidding for each project. This pathway underpins all management practices identified as significant in this investigation, confirmed by consensus in the panel on its key importance as a foundational first step. One of the key conclusions of this thesis is that as a second step, it was found that construction organisations developing SCI can differentiate their integration strategy. This can involve focusing on the pathways of integrating processes and activities or integrating flows. Organisations focusing their SCI strategy on integrating flows can maintain the longevity of integration, through stronger relational integration coupled with longer duration by the management practice of length of relationships over a series of projects, serving as an antidote to fragmentation. On the other hand, organisations focusing on the pathway of integrating processes and activities can develop a better awareness of the overriding SC processes underpinning different projects and the specifics in SC requirements to each project. In turn, organisations following this integration pathway can develop joint work processes consisting of integrative short-term and long-term actions to interactively address various projects over time. At the third stage, this thesis postulates that the two integration pathways can be recombined to develop ‘economies of repetition’ and ‘economies of recombination’, making the integrated SC able to better realise value from the construction project pipeline. This thesis also investigated the role of integrating technologies and systems as a separate pathway to integration. The findings regarding this pathway lead to concluding that integration of technologies and systems has primarily an enabling role in SCI with a moderating effect on integration between the other pathways.

This thesis also investigated the relationship between improved SCI and SC performance, pointing out that such a relationship can be explicated through sets of outcomes achieved collectively by the integrated organisations. In relation to the major outcomes out of the set, as relevant to construction, it can be concluded that the sector can benefit from SCI in a number of ways. First, by developing SCI, organisations can become more collaborative, rather than opportunistic and this can result in competing collectively through superior value. This approach predicates overcoming the cost-driven agenda in the industry, leading to adversarial relationships, instead it focuses on continuous value realisation through SCI. Second, well known issues in the sector related to fragmentation and problems associated with translating client demand across the SC are addressed through the major outcome of defining client values. This is concluded to be one of the major outcomes of SCI in construction, as it facilitates integration of suppliers and subcontractors into value creation processes, limits misalignment between partners and develops clarity in projects' functional requirements. It is also concluded that another major outcome in construction is developing continuous improvement, as integrated organisations are in a better position to learn from projects collectively and identify areas for improvement over consistent engagement with one another, rather than sporadic involvement in single projects. Finally, significant inhibitors to construction are associated with problems of cost calculations transparency and applying commercial pressure by the main contractor. In contrast, it is concluded that one of the major outcomes SCI can lead to is in managing costs collaboratively, which allows for security in margins for different supplying organisations.

Following on with the conclusions of this thesis, the set of seven outcomes were also empirically tested by the expert panel in relation to the effectiveness in achieving them through the four pathways. It can be concluded that achieving any of the six outcomes that reached consensus starts with the integration of actors and follows a strategic choice actors can make between the pathways of flows or processes. Construction organisations prioritising the pathway of flows over the pathway of processes are in a better position to lead efforts towards the outcomes of 'competing through superior value' and 'establish supplier relationships'. On the other hand, organisations prioritising the pathway of processes and activities are better positioned to focus efforts towards the outcomes of 'develop continuous improvement', 'define client values', 'integrate project activities' and 'mobilise and develop people'.

8.3 Thesis contribution

The thesis has answered the above RQs and by doing so, can make several contributions to existing knowledge, as well as address practical implications for SCM in the construction sector. These contributions are divided into two categories according to the relevant beneficiaries. First, contributions to academia will be summarised, which can be utilised by other researchers in the domain to further expand understanding in the adoption and improvement of SCI in a project-based context and specifically in construction. Second, contributions to practice show how the findings of this project can enable construction professionals to make better decisions in improving and managing SCI and what benefits this approach can lead to.

8.3.1 Contribution to Theory

The theoretical backdrop of this thesis was outlined in the introductory chapter, highlighting through problematisation, the need for better cohesion between value identification developed through strategic planning of construction projects and value realisation through SCI. Focusing on SCI, three gaps in the literature were identified and consecutively elaborated on, through the use of an SLR in this thesis. First, it was shown how, in studies on SCI in construction, one of the areas that has gained traction in the discourse of adopting an SCI approach is in operationalising the concept through sets of management practices. The research track in this area identified some 'neglect spotting' in current research and consolidated the dispersed and fragmented body of knowledge into concise management practices underpinning SCI. Second, drawing from the broader SCI literature, it was argued that improvement efforts in SCI can be framed through four integration pathways (actors, flows, processes and technologies). In the current literature, these four pathways represent competing explanations for improving SCI and this thesis aimed at testing their effectiveness, thus presenting a structured approach to improving SCI. This approach identified some 'confusion spotting' in the existing literature, enabling the development of a higher level of understanding in the field, by drawing on explanations from the sequences formed by the four investigated pathways. Third, the relationship between SCI and SC performance in construction was investigated to highlight that such a relationship is currently divergent in the literature, but can converge through a set of outcomes that integrated organisations can develop collectively. This area of the thesis was focused through 'application spotting' with the aim of extending and complementing existing literature. These three areas led to the development of a comprehensive conceptual framework, explicating how SCI in construction can be improved and to what benefits, as expected from such efforts. The synthesised framework presented in this study is a forward step in developing the theory base relating to the application of SCI in project-based organisations and specifically in the construction context. It builds a holistic view beyond individual publications, achieved through the SLR methodology.

Initially, the empirical findings of this research will be of interest to researchers working on identifying the mechanisms, as a composite of practices, that can drive SCI in project-based organisations and, more specifically, in construction. Such research can lead towards developing fundamental rule-like research on SCI and/or, on the basis of situational interventions, addressing different industry issues and scenarios. Examples of these researchers include Fabbe-Costes and Jahre (2008), Van der Vaart and Van Donk (2008), Bankvall et al. (2010), Adams et al. (2014), Eriksson (2015), Broft et al. (2016), Papadonikolaki and Wamelink (2017), Godsell et al. (2018), Koolwijk et al. (2018), and Denicol et al. (2020). Both the confirmed and suggested management practices as determinants of improving SCI are of interest here, as they develop robustness in variables and future models' research. The implications of this study regarding the numerous proposed management practices highlight some of the practices as actually highly relevant towards driving integration. This then allows the field to focus academic effort and resources on studies converging in the SCI mechanisms that matter most. For example, based on the results of this study, it should be acknowledged that while SCI is encompassing a multitude of practices, there is a clear priority on developing strength in integration between construction organisations based on their relational integration as a first step. These research findings can supplement studies such as Xue et al. (2007) and Chen et al. (2021), highlighting the need for relational contracts in improving commitment. This, in turn presents implications that can enrich and position research on SC co-ordination in construction as part of SCI. Furthermore, a notable area of construction research is centred around partnerships; however, there is no unified view of what such consist of in the construction industry. This research can provide further focus to studies on partnerships such as Bygballe et al. (2010), offering more depth to these studies from an SCI perspective. In addition, as outlined in the introduction of this thesis, the stream of SC collaboration has also gained continuous research in relation to SCI, albeit with limited clarity in definitions. Exploratory studies, such as Kache and Seuring (2014) review such a relationship broadly in the literature. Aimed at converging these research streams, the implications of this thesis provide a structured space for SC collaboration research within SCI in construction, by designating its role in the pathway of 'integration of actors'. This study also shows that SCI in construction may not be as problematic as previously assumed by Kesidou and Sovacool (2019), further corroborating the direction of their study.

Overall, this thesis aimed at extending previous research in focal studies by Fabbe-Costes and Jahre (2008), Leuschner et al. (2013) Eriksson (2015), and Broft et al. (2016), and follows the trajectory set by these authors. This thesis also contributes to the understanding of improving SCI on a strategic level by exploring the applicability of four pathways of integration as distinct steps that construction organisations can take. The pathways unlock avenues for mapping construction organisations' strategy for SCI towards concrete outcomes set to deliver superior value. Little research has been done to this point on SCI strategy and specifically in a project-based sector such as construction. The explanations of the relative effectiveness of the four pathways offer implications for future research towards demonstrating how the pathways of integration of actors, flows, processes and technologies can formulate a distinct strategy in the construction context, taking a step forward in this direction. This research can be of interest to authors focusing on strategic studies; however, attention should be paid to the relatively nascent stage of current research on SCI in a project-based context. The outcome-based approach demonstrated in this study, as a critical link to what benefits can be expected from SCI in construction, is a research trajectory that has regained momentum in recent studies. This research can also be of value to authors such as Broft et al. (2016), Keung and Shen (2017) and Cigolini et al. (2022) who also corroborate this stream of research. Lastly, a considerable amount of research has recently been conducted on the introduction of various technologies to the construction sector, investigating their applicability through different SCM angles. This project aims to provide focus for such studies through offering a better definition and structure to the relationship of these various technologies and SCI. This study proposes further research can focus on how integrating various technologies affects integration between actors, flows and processes.

Overall, this research has extended the notion that large construction clients can apply different approaches to the strategic planning of their projects, identifying value through taking into account the SCs that serve these projects. SCI was posed in this research as a key approach to realisation of the identified value. The study reviewed SCI in detail by dissecting it and empirically testing what practices, pathways and outcomes constitute improving SCI in construction.

8.3.2 Contribution to Practice

This study suggests several managerial implications for construction firms considering SCI. First, it offers a number of managerial insights applicable to construction clients, main contractors and subcontractors and suppliers wishing to improve their SCI. A number of insights emerge from the qualitative results, explaining the transformation SCI can bring into the construction industry’s current SCM reality. Second, the study outlines some of the most impactful SCI management practices that construction companies can adopt as determinants of success of integration intentions. Third, the study offers insights to construction companies on how they can benefit from developing a differentiated SCI strategy based on the four pathways of SCI. Lastly, the study contributes to current practice in construction through depicting a set of outcomes and explaining how taking a focused approach to SCI can lead to achieving them.

First, it is acknowledged that there is evidence of many SC initiatives in construction that have been undertaken in the past with limited success. The initial qualitative findings form several insights that position the context in which an SCI approach can be adopted in construction. The experts in the Delphi panel provided substantial evidence in support of the different transformational aspects of SCI, signifying that SCI resonates with their experience. These findings can help construction managers in positioning SCI in various transformation programmes or initiatives and serve as valuable guidelines on how change can be managed towards introducing SCI in construction. It is granted that the insights generated could be described as wishful thinking; however, this study also focuses on the practical application of SCI, offering concrete practices, pathways and outcomes that can translate into actions to be taken forward.

An initial finding is the overwhelming importance 193evelopping relational integration through commitment of partners to SCI, based on shared objectives and interest, as described here. As explained in this study, this can be the critical step in linking the demand profiles formulated from the strategic planning process of the client and the integrated construction organisations delivering projects. It appears exceedingly unlikely that construction organisations are willing to transition from the current value realisation paradigm characterised by the creation of a new SC for each project, based on operational or informational integration alone. For SC managers in construction, this study highlights the importance of relational integration in underpinning shared commitment and long-term orientation, as necessary management practices for pulling partners together in objectives stemming from the customer's strategic planning processes over a series of projects. The strength of SCI, developed by relational integration can be supplemented by operational integration in the form of joint work processes and longer duration through relationships spanning a series of projects. These are critical insights for SC managers looking to change current reality and bring together the different SCs into an integrated SC that serves project demand continuously.

While it remains unclear whether the opportunity for value improvement in delivery (i.e. how well owners' objectives are met), presented by value identification in strategic planning will necessarily translate into tangible benefits for the client, it is clear that SCI has transformative potential to value realisation. This transformative power is explained by the dependence organisations share in delivery on the one hand and their commercial position on the other. As explained in this thesis, underperformance in a given demand profile can detach construction partners from the strategic planning process, which in turn can result in loss of future work. SCI requires integrated organisations to think about both how to create long-term win-win relationships and improve their joint performance. As such, it is of interest for construction companies to perform well collectively and compete as an integrated unit of organisations. This is a powerful insight to construction SC managers that can serve as a business case for the acceptance of SCI and provide the impetus for putting into practice a particular philosophical orientation towards SCM in construction.

Following on with the implications to practice from a strategic perspective, the findings of this project demonstrate that SCI can be considered as a means of implementing a sophisticated strategy. First, the study shows that integrated organisations can focus SCI through three pathways (actors, flows and processes) with the integration of technologies and systems as a key enabler between these integration areas. The findings indicate that executing such a strategy, tailored to account for each actor's respective strengths and SC involvement, can lead to improved competitive position for the collective of integrated organisations. Although this study does not confirm or refute this notion explicitly through the findings, it is suggested that as construction organisations integrate, they become more effective and efficient than the sum of their parts. In turn, management can leverage the degree of SCI, towards competing on a wider selection of projects through 'economies of repetition' and 'economies of recombination'. Second, because construction SCs are currently exhibiting large fragmentation, this can lead to commercially opportunistic behaviour by some actors, at the expense of others. Instead, integrated organisations need to think of SCI as an aggregator of value and antidote to fragmentation beyond organisational boundaries. Identifying what pathways can realise most value to different types and groups of projects, can indicate to management what set of initiatives (with regard to the SCI management practices) should be taken forward. This can lead to realising sets of outcomes, not achievable by any single organisation. Following on from this point, it is acknowledged that in value identification, developing a demand profile through the client strategic planning process can still exhibit different requirements in individual projects that need addressing. Taking this notion further, value realisation through SCI, has been presented in this study as a viable approach to collectively achieving outcomes that can provide the flexibility needed for different projects. The practical implications of this thesis, suggest that SC managers can strategically position their organisations, working together in applying SCI to meet down the desired outcomes.

Overall, the main practical contribution of this study is to highlight that construction companies can capture collective opportunities presented, by adopting the right SCI approach. Although described narratively, the investigated systematic approach to SCI in this study presents an opportunity for further value engineering by SCM professionals in construction.

8.4 Study Limitations and Opportunities for Further Research

As is the case in all research, this work has some limitations, which are described in the following. However, these limitations also present opportunities to advance the area of improving SCI in the construction context and will, therefore, be supplemented with ideas for future research.

First, this study has analysed a hypothetical SCI in construction, as a value realisation approach predisposed to value identification from strategic planning conducted by the client organisation. This is not unproblematic, as the study assumes the conditions for SCI are in place, rather than investigating a demand profile of projects based in a real-life application. While this decision was taken out of necessity due to the need for a narrowed scope of the investigation and the resource constraints of the research, this has also allowed for more depth in this study, focusing on describing and testing the applicability of SCI in construction. This has led to explanations producing initial concepts about the context in which SCI is applied and postulating the ones appearing fundamental from the value chain paradigm selected. Nevertheless, the interplay between value identification and value realisation, from an SC perspective, may involve many factors related to projects and SC complexity and not be as straightforward as assumed in this study. This in itself proposes a gap in existing research that can be addressed following studies by Blichfeldt and Eskerod (2008), Patanakul and Milosevic (2009) and Godsell et al. (2018). However, this does not render the findings of this study invalid, as research by Godsell et al. (2018) used demand profiling to empirically validate the significant share of projects of a large infrastructure client to be both predictable and repeatable, outlining a clear opportunity for better value identification through strategic planning, calling for adopting SCI in construction. Nevertheless, it would progress the field to identify more real-life cases where application of value identification can be coupled with an SCI approach in value realisation to bridge this gap effectively.

Second, this study suggests SCI outcomes as an effect of improved SCI, but at the same time can represent a cause for such. While the application of outcomes appears sensible, given that different projects may exhibit different needs from SCI, it may also be argued as a starting point for setting objectives between partners, rather than the end-point of SCI. Nevertheless, while this study has been able to explain improvement to SCI in construction to a significant extent, the fundamental management practices that drive improvement may not be those that lead integrated partners to accept SCI in the long-term. It is suggested here that if not managed closely, the outcomes can shift the focus of SCI from its core function of keeping actors integrated in value realisation and instead lead to sub-optimal results based on pursuing specific outcomes. As such, the interplay between what are fundamental practices to improving SCI and the resultant outcomes in this study is recognised as a limitation and requires more research.

Third, the research has been conducted using a Delphi method applying both qualitative and quantitative enquiry in what can be characterised as a nascent body of knowledge. The method was applied to probe into the application of SCI in specifically project-based organisations, in the specific context of the UK construction infrastructure, and with a specific group of construction SC experts. This method has proven useful in converging dispersed knowledge artefacts to answer the set of RQs with considerable strength in explanatory power. Moreover, while the specifics set in the design of the study increase validity and allow the research to contribute to some of the pronounced threads in SCI research, there is a trade-off with generalisability. It is therefore unknown whether the findings here related to management practices, pathways and outcomes of SCI are the same for other project-based industries, construction sectors, countries or populations. However, on the one hand, this presents further opportunities for research, while on the other hand, this research in itself already presents an encompassing route to testing SCI improvement, indicating by what such generalisability is limited. Ultimately, further research is needed, as the nexus of management practices, pathways and outcomes of SCI has scarcely been explored before in combination and this study shows that SCI can be modelled using these features.

Fourth, although the study follows a clear and logical research design, in line with the SLR and Delphi method applied in this study, a limitation that can be highlighted is that the application of a Delphi method generally lacks clear methodological guidelines.

Fifth, the study applies an SLR methodology, which is conducted at a point in time when research in SCI applied to project-based organisations, and specifically in construction, is fragmented. It can be expected, as bodies of knowledge expand, that parts of the literature review will be contested. This is especially so in the area of duration of SCI, which is required for achieving better SCI, but can also be the result thereof. In addition, it is likely that SCI may acquire better traction within the construction sector, by being labelled differently, in accordance with existing terminology within the industry. This can shift the trajectory of future research towards terms such as partnerships, collaboration and coordination. As presented in this thesis, such terminology constitutes only a partial view of the concept and can result in more disjointed research.

Sixth, the outcomes of SCI are described narratively. The study asserts a relationship exists between improved performance in construction in the form of higher effectiveness and efficiency and each, or a combination of the SCI outcomes. However, while such a relationship seems sensible, it is not explicitly tested. Focusing further research on quantification of performance benefits derived from each outcome is likely to require a longitudinal study; this type of study could adopt the framework constructed in this paper as a starting point in guiding events observation.

Seventh, the SCM discipline has long been recognised in the construction domain and has meaningful discourse in traditional and non-traditional outputs. Although screening the literature using journal papers provides a measure of academic rigour and thus is justified for inclusion, this does not necessarily mean books or chapters are of low quality. Due to the practical orientation and narrative-driven nature of SC studies in conjunction with project-based organisations, some vetted (peer-reviewed) knowledge can disseminate through books. This study uses a proven methodology of SLR based on the repeatability of findings. Including books may not necessarily be a trade-off with the method used, as books can also be rated using the publisher rankings. It is thus worth noting that the exclusion of books and book chapters may be identified as a limitation of this study.

Eighth, sustainability aspects of integration are not explicitly investigated in this study. As the business agenda is shifting towards carbon neutrality, further research can focus on a fifth pathway of integration by capturing sustainability aspects.

Lastly, further research can be directed into building the qualitative and quantitative data required for developing SCI empirical studies. It is worth noting that further development of how the management practices can be measured individually and how they fit collectively in the framework requires further research. The conceptual framework provided is limited to synthesis from SCI studies and may not display all feasible SCI possibilities.

8.5 Personal Reflections on SCI in Construction

This research project has been conducted within the context of the large opportunity for better value realisation in infrastructure projects' construction in the UK. The current reality in the sector is characterised by capital project delivery that is consistently late and overbudget. This represents both a considerable challenge and a paradox, given the low-cost driven agenda characteristic of the sector. Cost opportunism of some construction actors at the expense of others and the discontinuous arm's length relationships resultant from such are well documented in the sector. There is a clear need for introducing alternative approaches to construction SCM, given the importance of the sector in spending UK taxpayers' money. Fortunately, SCI comes in as an alternative approach to current reality, as more stakeholders with institutional power to fund, promote and explore change, and stakeholders with power to introduce widespread sustainable change, realise the transformation needed in the sector. It is acknowledged that research on SCI applied to a project-based context such as construction is in its infancy. Nevertheless, this study has demonstrated that there are feasible alternative approaches in how construction SCs realise value, particularly through improving SCI. I hope this thesis is a step in the right direction and contributes to the further development and implementation of SCI in construction and more broadly in project-based organisations.

8.6 Chapter Summary

This chapter concludes this thesis. Over the course of this chapter, the following points have emerged, as summarised here:

- The key findings of this thesis were summarised by restating the five RQs asked at the start of the research project and providing succinct answers to these RQs towards answering the overarching research question.
- These answers allowed the three areas of oversight (practices, pathways and outcomes) that emerged from SCI literature in construction to be effectively addressed.

- As such, this study can confirm some of the management practices driving improvement in SCI, while refuting others; these findings will allow researchers to redirect their focus towards what practices matter most in construction.
- Furthermore, this study highlights that relational integration needs to be researched in greater detail as a first foundational step to improving SCI in construction.
- The study asserts that construction companies' SC managers can leverage their SCI strategy through the pathways of integration.
- The strategic choice of construction companies between developing the pathways of flows and processes to improved SCI presented in this study enables developing different sets of outcomes.
- Several practice contributions have also been described, which can be of use to construction companies seeking to improve their SCI.
- Several study limitations have been outlined and justified, indicating how the limitations also present opportunities for further research that may complement what has been found here.

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Appendices

Appendix A: List of SLR papers reviewed and their contribution to four SCI pathways

Appendix B-1: SCI pathways and practices' thematic synthesis with literature supporting evidence

Appendix B-2: Supporting evidence on outcomes of SCI from the SLR literature

Appendix C-1: Definitions of SCI management practices in construction

Appendix C-2: Definition of the four pathways to improving integration in construction supply chains

Appendix C-3: Definition of the seven construction outcomes from SCI efforts

Appendix D-1: Overview of different measurement techniques of stability in a Delphi study

Appendix D-2: Overview of different measurement techniques of consensus by qualitative analysis and descriptive statistics

Appendix D-3: Overview of different measurement techniques of consensus by inferential statistics

Appendix D-4: Justification of applicability of consensus measurement techniques for this Delphi study

Appendix E: Analyses of consensus measurement of the four pathways to SCI practices

Appendix F: Analyses of consensus measurement of the four pathways to SCI outcomes

Appendix G: Dataset and analytical instrument for analysis

Appendix H: Research Ethics

Appendix A: List of SLR papers reviewed and their contribution to four SCI pathways

Number	Author(s) (*) not core papers	SCI pathway			
		Actors	Flows	Processes	Technologies
1	Kanji and Wong (1998)	✓	✓		
2	Ofori (2000)		✓	✓	
3	Dainty *et al.* (2001a)	✓	✓	✓	✓
4	Saad *et al.* (2002)*	✓	✓	✓	
5	Elliman and Orange (2003)	✓		✓	✓
6	Briscoe *et al.* (2004)	✓	✓	✓	✓
7	Dainty and Brooke (2004)			✓	✓
8	Pryke (2004)	✓	✓		
9	Briscoe and Dainty (2005)	✓	✓	✓	
10	Titus and Bröchner (2005)	✓	✓	✓	✓
11	Wood and Ellis (2005)	✓	✓		
12	Xue *et al.* (2005)	✓	✓	✓	✓
13	Khalfan and McDermott (2006)*	✓			
14	Xue *et al.* (2007)	✓	✓		
15	Eom *et al.* (2008)	✓	✓		
16	Forgues and Koskela (2009)			✓	✓
17	Cheng *et al.* (2010)*	✓	✓		✓
18	Bankvall *et al.* (2010)	✓	✓	✓	✓
19	Khalfan *et al.* (2010)*	✓			
20	Pan *et al.* (2010)	✓	✓	✓	
21	Davis and Love (2011)	✓			
22	Meng *et al.* (2011)	✓	✓	✓	✓
23	Meng (2012)	✓			
24	Eriksson and Pesämaa (2013)*	✓	✓		✓
25	Davies *et al.* (2015)			✓	✓
26	Gosling *et al.* (2015)	✓	✓		
27	Van Lith *et al.* (2015)	✓	✓		
28	Manu *et al.* (2015)	✓	✓	✓	✓
29	Eriksson (2015)	✓	✓	✓	✓
30	Pero *et al.* (2015)	✓	✓		
31	Mesa *et al.* (2016)	✓		✓	
32	Broft *et al.* (2016)	✓	✓	✓	✓
33	Pillay and Mafini (2017)	✓		✓	
34	Liu *et al.* (2017)	✓	✓		
35	Papadonikolaki *et al.* (2017)			✓	✓
36	Demirkesen and Ozorhon (2017a)*	✓		✓	✓

37	Papadonikolaki and Wamelink (2017)*	✓	✓	✓	✓
38	Kim and Nguyen (2018)	✓	✓	✓	✓
39	Godsell *et al.* (2018)	✓	✓	✓	✓
40	Costa *et al.* (2019)	✓	✓		✓
41	Kesidou and Sovacool (2019)*	✓	✓	✓	✓
42	Pattanayak and Punyatoya (2020)*			✓	✓
43	Denicol *et al.* (2020)*			✓	✓
44	van Zoest *et al.* (2020)*	✓	✓	✓	✓
45	Chen *et al.* (2021)*			✓	✓
46	Le *et al.* (2021)*			✓	✓
47	Jones *et al.* (2021)*			✓	✓

Appendix B-1: SCI pathways and practices thematic synthesis with literature supporting evidence

		Pathway to Supply Chain Integration			
Dimension	**SCI Practice**	**Integration of Actors**	**Integration of Flows**	**Integration of Processes and Activities**	**Integration of Technologies and Systems**
Strength	*Joint strategic planning*	(10)(17)(23)(29)(32)(37)(38)(39)(41)	(10)(17)(23)(29)(32)(37)(38)(39)(41)(2)(6)(8)(9)(30)(31)	(4)(5)(10)(16)(17)(18)(20)(23)(27)(29)(32)(35)(37)(38)(39)(41)(9)(21)(31)	(4)(5)(10)(16)(17)(18)(20)(23)(27)(29)(32)(35)(37)(38)(39)(41)
	Joint operational planning	(10)(17)(23)(29)(32)(37)(38) (39)(41)	(10)(17)(23)(29)(32)(37)(38)(39)(41)(2)(6)(8)(9)(30)(31)	(4)(5)(10)(16)(17)(18)(20)(23)(27)(29)(32)(35)(37)(38)(39)(41)(9)(21)(31)	(4)(5)(10)(16)(17)(18)(20)(23)(27)(29)(32)(35)(37)(38)(39)(41)
	Supporting tech ology	(5)(14)(10)(29)(21)(6)(15)(36)(37) (32)	(5)(14)(10)(29)(6)(17)(37)(32)(30)	(5)(14)(10)(29)(21)(6)(35)(37)(32)(30)	(5)(14)(10)(29)(17)(35)(36)(37)(32)
	Communication	(10)(29)(6)(19)(36)(13)(39)(14)(41)	(10)(29)(6)(39)(30)(14)(17)(41)	(10)(29)(6)(39)(30)(14)(41)	(10)(29)(36)(39)(14)(17)(41)
	Co-ordinated decision making	(8)(14)(21)(29)(25)(33)(39)(40)(41)(37)	(8)(14)(29)(39)(40)(17)(41)(37)	(14)(21)(29)(25)(33)(35)(39)(40)(41) (37)	(29)(35)(40)(17)(41)(37)
	Joint work processes	(29)(38)(41)(1)(17)(31)(32)(37)(15)(23)(24)	(29)(38)(41)(31)(17)	(29)(38)(1)(41)(31)(32)(37)(23)(24)	(29)(38)(41)(32)(37)
	Developmental activities	(9)(6)(33)(29)(28)(39)(13)(37)(22)(19)(41)(24)(26)	(9)(2)(6)(29)(39)(37)(30)(41)(24)(26)	(9)(2)(6)(33)(29)(39)(37)(30)(41)	(29)(39)(37)(41)
	Commitment	(1)(3)(31)(38)(39)(37)(40)(41)(14)(12)(7)(15)(22)(33)(20)(36)(6)(13)	(1)(3)(31)(38)(39)(37)(40)(41)(14)(12)(6)	(1)(3)(31)(38)(39)(37)(40)(41)(14)(12) (33)(35)(20)(6)	(1)(3)(31)(38)(39)(37)(40)(41)(14)(12)(35)(36)
	Trust	(23)(38)(39)(41)(6)(9)(22)	(23)(30)(38)(39)(41)(6)(9)(22)(28)(19)	(17)(23)(30)(31)(37)(38)(39)(41)(6)(9)	(17)(23)(30)(31)(37)(38)(39)(41)
	Long-term orientation	(1)(9)(8)(10)(32)(31)(38)(39)(37)(41)(40)(18)(11)(22)(19)(13)(26)(27)(6)	(1)(9)(8)(10)(32)(31)(38)(39)(37)(41)(40)(18)(11)(17)(26)(6)(30)	(1)(9)(8)(10)(32)(31)(38)(39)(37)(41)(40)(18)(21)(27)(6)(35)(30)	(1)(9)(8)(10)(32)(31)(38)(39)(37)(41)(40)(18) (17)(27)(35)
Scope	*Configuration of supply base*	(24)(29)(26)(34)(39)(40)	(2)(24)(29)(26)(34)(39)(40)	(2)(29)(39)(40)	(29)(39)(40)
	Behaviour of SC actors	(4)(8)(9)(12)(10)(16)(21)(24)(29)(28)(38)(39)	(10)(24)(29)(38)(39)	(2)(4)(9)(10)(16)(21)(28)(29)(38)(39)	(4)(10)(29)(38)(39)
	Power position of firm in SC	(4)(9)(28)(26)(27)(29)(39)	(2)(9)(26)(29)(39)	(4)(9)(27)(29)(39)	(4)(27)(29)
	Resource sharing	(1)(10)(16)(24)(27)(29)(26)(30)(39)(21)(25)	(1)(10)(16)(24)(27)(29)(26)(30)(39)	(10)(29)(27)(39)(21)(25)	(10)(29)(27)(39)
	Types of SC inter-dependencies	(1)(8)(21)(29)(32)(36)(39)(13)(41)(37)	(1)(8)(29)(32)(39)(30)(41)(37)	(1)(21)(29)(32)(35)(39)(30)(41)(37)	(29)(32)(35)(36)(39)
	Interdependent networks	(4)(8)(10)(29)(39)(6)(37)	(8)(10)(29)(39)(6)(30)(37)	(4)(10)(29)(35)(39)(6)(30)(37)	(4)(10)(29)(35)(39)(37)
Duration	*Length of relationship over a series of projects*	(3)(25)(29)(26)(32)(39)(22)	(3)(25)(29)(26)(32)(39)	(3)(29)(32)(39)	(29)(32)(39)
	The timing of the involvement in a single project	(5)(3)(29)(32)(39)(41)(2)(31)(26)(6)(28)(30)(11)(16)(25)	(5)(3)(29)(32)(39)(41)(2)(31)(26)(6)(28)(30)	(3)(29)(32)(39)(41)(6)(16)(35)	(3)(29)(32)(41)(35)
Depth	*Customer involvement*	(3)(5)(10)(8)(12)(29)(32)(40)(39)(2)(6)(7)(11)(13)(15)(16)(21)(22)(24)(28)	(3)(5)(10)(8)(12)(29)(32)(40)(39)(2)(24)(6)(30)	(3)(5)(10)(8)(12)(29)(32)(40)(39)(6)(16)(21)(30)(35)	(3)(5)(10)(8)(12)(29)(32)(40)(39)(35)
	Top management commitment	(3)(15)(16)(29)(32)(38)(39)(1)(6)(21)(25)(33)	(3)(15)(16)(29)(32)(38)(39)(1)(2)(6)(30)	(3)(15)(16)(29)(32)(38)(39)(1)(2)(6)(21)(25)(30)(33)	(3)(15)(16)(29)(32)(38)(39)

Table B-1: SCI pathways and practices thematic synthesis with literature supporting evidence deducted by setting apart unique references to each practice and pathway

Appendix B-2: Supporting evidence on outcomes of SCI from the SLR literature

Outcome	***Supporting evidence from the literature***
Compete through superior underlying value	(1)(3)(4)(5)(9)(20)(26)(29)(32)(33)(35)(36)(38)(39)(40)(41)(42)(47)
Define client values	(1)(3)(5)(7)(9)(10)(12)(14)(22)(29)(31)(32)(38)(39)(40)(41)(44)(45)
Establish supplier relationships	(3)(4)(7)(9)(10)(12)(14)(21)(28)(29)(32)(38)(39)(40)(41)(45)(46)
Integrate project activities	(1)(2)(3)(4)(5)(7)(9)(10)(14)(16)(18)(21)(22)(27)(29)(31)(32)(35)(38)(39)(40)(41)(42)(43) (44)(45)(47)
Manage costs collaboratively	(2)(5)(8)(9)(10)(15)(16)(21)(24)(25)(27)(28)(32)(33)(38)(39)(41)(42)(43)(44)(46)(47)
Develop continuous improvement	(3)(7)(9)(14)(18)(22)(23)(29)(31)(32)(34)(38)(39)(40)(41)(44)(47)
Mobilise and develop people	(3)(4)(5)(7)(10)(11)(14)(15)(22)(23)(27)(29)(31)(32)(38)(39)(40)(41)(44)

Table B-2: Supporting evidence on outcomes of SCI from the SLR literature

Appendix C-1: Definition of SCI management practices in construction

Abbreviation	**Management Practice**	**Definition**
JSP	*Joint Strategic Planning*	Joint strategic planning refers to the extent to which SC partners actually forecast demand and plan business activities jointly while taking into account each other's long-term success. Joint strategic planning defines an advanced level of inter-firm interaction that leverages the coordination of information to develop informed, inter-firm and long-term SCI decisions.
JOP	*Joint Operational Planning*	Joint operational planning enables partners to undertake inter-firm forecasting and planning at a tactical level, building on the consolidated and routine electronic transactions and information exchanges along the SC.
ST	*Use of Supporting Technology*	Use of supporting technologies for SCI facilitates information exchange across firms' boundaries. To enable this, supporting technology requires establishing the compatibility of Information Systems (IS) between construction partners and backward integration in suppliers' value chains. Supporting technology enables project-based SC efficiency and relies on appropriate personnel training for SCI.
C	*Communication*	Communication in SCI refers to the level of exchange of information, knowledge and skills being provided openly, timely and adequately among the owner, designer, and contractor. In terms of information, this refers to the degree and breadth of exchanging information with SC partners. Exchange of knowledge refers to understanding and translating the level of complexity underlying the integration of differentiated knowledge, such as building offsite a proportion of the assets, modularity or the buildability of design ideas. Communication also refers to exchange of skills, as multi-skilled groups could mitigate problems related to customisation and variability because they make it possible to overcome functional fragmentation and to cope better with unpredictable situations.
CDM	*Coordinated Decision Making*	The demand for construction work can show considerable variation due to both the frequency (intermittence) and size (lumpiness) of projects in a pipeline. This makes projects appear both unpredictable and non-repeatable while, in reality, high commonality in requirements may exist between them. Coordinated decision making refers to the redeployment of decision rights, work and resources to the best positioned SC member. In practice, coordinated decision making in SCI aligns the demand profile (construction projects' characteristics) to the best suited SC configuration, resulting in

		systemic production channels facilitating material, information and finance flows.
JWP	*Joint Work Processes*	Use of joint work processes for SCI is associated with the intention of the firms within the SC to integrate their actions and interactively adjust their behaviours while pursuing opportunities over time. Such integrative actions include both short-term actions, such as improving supplier scheduling, resource visibility and capacity planning, and long-term actions, such as developing joint flexibility and SC adaptability.
DA	*Developmental Activities*	Developmental activities include product and process engineering, joint investment, use of knowledge and capabilities within the strategic SC and supplier development activities. Product and process engineering concerns the integration of products and processes across firms within the strategic SC, assuming responsibility for product engineering development activities, including suppliers' understanding of the complexity and scope of coordinated processes within work packages. Joint investment is the extent to which SC members jointly invest in projects of mutual interest (capital and equipment investments, financial investment, partial ownership or provision of resources). The use of knowledge and capabilities indicates the extent to which members of the integrated SC share knowledge and new ideas towards identifying and implementing improvement initiatives. Supplier development involves developing and shaping the integrated supplier portfolio in accordance with the construction SCI needs.
CM	*Commitment*	Commitment in SCI includes the contractual relationships between partners, risk allocation practices and objectives alignment. SC contractual relationships indicate the level of expected commitment from partners (i.e., normal tendering contract, preferred partners, SC framework agreement and uniform administrative conditions contract). Commitment in SCI also relates to risk allocation, which defines how the risk is allocated and the reward is given. Establishing commitment in SCI also depends on the level of alignment of interest and objectives among the owner, designer, and constructor. The areas of setting objectives in construction are alignment (towards long-term mutual objectives), benefits (towards win-win in the long term) and continuity of work (towards guaranteed future work).
T	*Trust*	Establishing trust in SCI involves the level of trust that exists between partners and manifests through the type of trust exhibited, confidence in others' behaviour, monitoring of others' work, as well as situational trust influencing factors. In increasing levels, the type of trust shared can be contractual, competence-based, short-term

		goodwill and long-term goodwill trust. Regarding confidence in others' behaviour, partners can exhibit from little to full confidence. Trust influencing factors relate to situational expectations and views that influence trustworthiness and trustfulness attitudes. Examples include the perception of future work opportunity, project-specific circumstances, economic climate, payment practices, etc.
LTO	*Long-term orientation*	Long-term orientation refers to supplier relationships based on recurring arrangements and supplier involvement instead of competitive bidding and arm's length relationships. This is established through collaborating with, perceiving and striving for suppliers as long-term partners. The right orientation in SCI relies on establishing and implementing procurement practices based not solely on price, but multi-criteria from a long-term perspective.
CSB	*Configuration of Supply Base*	Configuring the supplier base encompasses a number of sub-activities including reducing the number of suppliers, segmenting the supplier base, and assessing and selecting suppliers. A supply base that is best positioned to realise value from SCI, requires a healthy balance across partnership categories (approved, preferred, strategic) to allow main contractors to effectively configure the SC for different project requirements.
B	*Behaviour of SC actors*	Behaviour of SC actors in integration includes attitudes and patterns of behaviour in SCI. Evident behaviours include joint responsibility, shared planning and flexibility arrangements. In a project-based construction context, behavioural aspects are guided by the role actors play in SCI and a set of common antecedents that can moderate behaviour towards improved value.
PP	*Power Position of firm in SC*	SCI includes assessing partners' power position in the SC. This includes the extent to which the product or service is standardised or commoditised, number of alternative suppliers available to the buyer, number of alternative buyers available to the supplier, switching costs for both buyers and suppliers, and the level of information asymmetry advantage that one party has over the other.
RS	*Resource Sharing*	SCI relates to the extent of resource sharing. This is characterised by the strategic integration of buyer resources with supplier resources and the extension and blending of relevant activities between the buyer and seller firms. Partners with high levels of resource sharing can affect prioritisation in the allocation of resources in the integrated SC. High level of resource sharing can foster value engineering, but also create implications for maximising value and responsiveness with an optimal number of SC actors, to changing customer needs and market dynamics.

TSI	*Types of SC interdependencies*	Involves assessing the types of SC interdependencies between partners. The types of interdependencies between actors in the construction SC are important because difficulties in SCI might relate to how the temporary SCs (for specific projects) meet with the permanent SCs in the production of raw materials and components. A way to understand these challenges is through the different types of interdependencies (pooled, sequential, reciprocal and synchronic) For example, distinguishing pooled interdependence between activities relates different SCs to each other as well as different construction projects to one another.
IDN	*Interdependent networks*	Involves understanding the interdependencies based on the networks (of contractual relationships, performance incentives and information exchange) that may exist between partners. Discrepancies in and between these network categories can shift the point centrality of SCI and form coalitions that can lead to suboptimal results.
LR	*Length of relationship over a series of projects*	Involves establishing a longer duration span of SCI over a series of projects. This strengthens integration, because the partners become familiar with each other, develop mutual trust and enhance possibilities of future work, as they develop collaboration rather than opportunism. This minimises abandoning partnering, sending shocks to the SC and interrupting flows (of information, materials and finance). Longer duration over a series of projects allows for SCI to aggregate value and develop continuous improvements over time.
TI	*Timing of involvement in a single project*	Timing of involvement in engineering projects strengthens SCI within a single project, especially if partners collaborate over many project stages. Timing of involvement relies on procuring contractors and suppliers early in order to contribute to collaborative and customised design, as well as align desired partnering characteristics (e.g. cost, cooperation and teamwork) over the duration of a project.
CI	*Customer involvement*	Customer involvement is characterised by communicating with and integrating clients' end users in engineering projects. This enables SCI, as end users contribute to the design work with valuable insights based on their high level of expertise and infrastructure network intelligence. Through customer involvement the client can commit to the end product before handover, minimising discrepancies between partners' different internal functions involved at different stages of a project. Reciprocally, educating the customer in how SCI realises value can enhance customer involvement in SCI and its practical adoption in construction.
TMC	*Top Management Commitment*	Top management commitment establishes the right number, hierarchical level and function of personnel involved in integrative

		activities. In the context of engineering projects, top management commitment is critical for integration, while mobilising personnel at lower hierarchical levels can strengthen collaboration by increasing behavioural transparency and reducing information asymmetry. In practice, main contractors can increase the depth and strategic importance of their relationships with subcontractors, especially where the majority and complexity of work efforts take place. Top management commitment displays through the way in which a firm organises patterns of contact with its partners, the frequency of contact and the level of personnel involved.

Table C-1: Definitions of SCI management practices in construction

Appendix C-2: Definition of the four pathways to improving integration in construction supply chains

Pathway	**Definition**
Integration of Actors	Integration of actors (structures and organisations) in construction involves integration of any stakeholder involved with the SC or the client organisation. This involves understanding the competencies and capabilities of each actor and the clusters they constitute. This pathway enables an 'optimum' number of organisations to be involved and appropriately structured for value realisation within the integrated SC.
Integration of Flows	Considers the movement of materials, information and money between suppliers, manufacturers, logistics providers, and customers. Integration of flows involves establishing continuous recurring flows (informational, material and financial) between construction partners and is aimed at improved productivity.
Integration of Processes and Activities	Articulates the core processes that link different functions in an SC (i.e. planning, purchasing, manufacturing, logistics and the reverse flow of materials at end of life). Integration of processes and activities in the construction SCs involves the integration of partners into defined overriding SC processes to types or groups of construction projects.
Integration of Technologies and Systems	Integration of technologies and systems involves integration of various available technologies and systems between SC members into a unified whole (e.g., product platforms). Examples include integration of BIM, digital solutions, specialist equipment and production technology.

Table C-2: Definitions of the four pathways to improving integration in construction SCs

Appendix C-3: Definition of the seven construction outcomes resulting from SCI efforts

Abbreviation	Outcome	Definition
CTSV	*Compete through superior value*	Involves leveraging SCI for enhancing the value of what is actually delivered by improving quality and cutting underlying costs. This is achieved by using SCI to allow for collaboration between SC actors, each with their respective capabilities, in taking the "right" costs out in order to arrive at competitive prices and mutual benefit. Practically, this outcome requires a good understanding of the customer's perception of value, insight into cost components, margins protection and taking out inefficiencies and waste in the SC. As the SC becomes integrated, margins are protected and partners have the security and investment to undertake the continuous improvement or innovation required.
DCV	*Defining client values*	Involves applying a more rigorous way of assessing value, through clarification of the functional requirements, design character and target though-life cost profile of the delivered asset. In practice this involves assessing value through: (1) defining client value in output terms, and (2) design of through-life cost performance.
IPA	*Integrate project activities*	Utilises SCI as a mechanism for selecting strategic long-term partners best positioned to direct the effective management of partners collaborating on a project. The goal is to create clusters of actors and use concurrent engineering techniques with specialist suppliers, in order to respond at each key project interface and resolve all design-related issues early. In practice, this also involves focused effort by selected strategic partners in involving specialist suppliers early into the work clusters, in order to establish commitment to processes and subsequent phases.
DCI	*Develop continuous improvement*	The key aspects to achieving continuous improvement are in (1) preventing things going wrong rather than identifying subsequently that they were not done properly to begin with, and (2) a determination to utilise the contributions of everyone in the business continually to seek better ways of doing things. In practice this means paying far greater attention to planning how to do things in advance, and seeing how problems can be anticipated

		and avoided. The emphasis of CI is on planning in the sense of mapping out the detailed work processes or methods, and then improving them so that they are compatible with whatever genuine client priorities are driving the overall project programme.
ESR	*Establish supplier relationships*	Aims at encompassing relationships based on the long-term commitment of a small number of suppliers within each key supply category of the core business. This is done in a way that still allows variety and flexibility for different types of projects in various regions. In practice, arriving at this outcome is based on developing strategic relationships with the major organisations in the SC which deliver approx. 80% of the value of any project.
MCC	*Manage costs collaboratively*	Is essentially a process unlocked by SCI. This outcome utilises a specific approach in optimising costs referred to as "target costing". In practice, SCI allows partners to work backwards from the client's functional requirements and the maximum price for the item. Margins are detached from risk allowances and costs through ring-fencing, which allows security to look at underlying costs.
MDP	*Mobilise and develop people*	Associated with the substantial cultural change necessary in the construction industry. In practice, SCI allows better mobilisation and development of employees through four mechanisms: (1) displayed systematic top-level commitment, (2) focused training and acquisition of new skills, (3) project teams facilitation, and (4) establishing economic incentives.

Table C-3: Definitions of the seven construction outcomes resulting from SCI efforts

Appendix D-1: Overview of different measures of stability in a Delphi study

Measure of stability	Description
Coefficient of variation (CV)	Following English and Kernan (1976), in their Delphi study, the authors suggest the use of the coefficient of variation (standard deviation divided by the mean) of the responses, in conjunction with a decision rule, as the stopping criterion. They selected ranges for the coefficient of variation and associated these ranges with decision rules that defined consensus and determined a strategy for continuation or termination. Following von der Gracht (2012) it is possible, to extend their method and to use the coefficient of variation as a measure of stability. This can be achieved by analysing for changes in the coefficient of variation between two successive rounds and terminating the enquiry when such changes assume a predetermined small value.
Change level of ≤ 15%	Following Scheibe et al. (1975) determining whether stability had been achieved in going from one round to the other, is done by using a 15% change level to represent a state of equilibrium in responses. They considered any two successive rounds that resulted in a marginal change of less than 15% to have reached stability. Successive rounds resulting in a change in excess of 15% were considered to continue to be in an unstable state and were included in subsequent Delphi rounds.
F - test	Jolson and Rossow (1975) suggested that an F-test on two variances be used as the basis of a stopping criterion for Delphi rounds. In a study directed toward the estimation of event probabilities, the variances of the probability estimates obtained in two successive Delphi rounds are compared. In cases where no significant difference is identified the particular question is dropped from further rounds. Only those questions in which a significant between-round difference in variance is found are retained in a subsequent round. It should be noted however, that an F-test on two variances using Delphi data is not an appropriate two-variance test, since one or more of the assumptions underlying such tests may be violated. In particular, this test is viewed as not appropriate since an F-test on two variances assumes that the two sample variances are computed from independent samples. For Delphi data the two samples or rounds are dependent, as the same respondents are enquired for each round, and responses obtained in one round are a function of feedback developed from the previous round. Furthermore, the test assumes that the samples are taken from normal distributions.
F and X^2	Ludlow (1975) has used both the F and X^2 tests to analyse disagreements between subgroups of homogeneous participants. He has not, however, extended his analysis to include stability between successive Delphi rounds.

Table D-1: Overview with references to techniques applied for measuring stability in Delphi studies

Appendix D-2: Overview of consensus measures by qualitative analysis and descriptive statistics

Measure of consensus	Examples of Application
Stipulated number of rounds	Fan and Cheng (2006, p.218) state that "research indicated that three iterations are typically sufficient to identify points of consensus…Thus, three rounds were used in this study."
Subjective analysis	"A consensus…was pursued through a series of personal interviews" (Lundsford and Fussel, 1993, p.15)
Certain level of agreement	"In keeping with most other Delphi studies, consensus was defined as 51% agreement among respondents." (Loughlin and Moore, 1979, p.103) "Consensus was achieved on an item if at least 60% of the respondents were in agreement and the composite score fell in the "agree" or "disagree" range." (on a 5-point Likert scale) (Seagle and Iverson, 2002, p.1) More than 67% agreement among experts on a nominal scale (yes/no) was considered consensus. (Alexandrov et al.,1996; Pasukeviciute and Roe, 2003)
APMO Cut-off Rate (average percent of majority opinions)	Cottam et al. (2004) calculate an APMO Cut-off Rate of 69.7%, thus questions having an agreement level below this rate have not reached consensus and are included in the next round. Islam et al. (2006) calculate APMO Cut-off Rates of 70% (first round) and 83% (second round) for consensus measurement.
Mode, mean/median ratings and rankings, standard deviation	"In our case, mode was used as an enumeration of respondents who had given 75% or more probability for a particular event to happen. If this value was above 50% of the total respondents, then consensus was assumed." (Chakravarti et al., 1998, p.159) Mean responses within acceptable range (mean±0.5) and with an acceptable coefficient of variation (50% variation) were identified as the opinion of firm consensus (Sharma et al., 2003)
Interquartile range (IQR)	Consensus is reached when the IQR is no larger than 2 units on a 10-unit scale (Scheibe et al., 1975). Ray and Sahu (1990) calculate the amount of convergence of group opinions by a formula using the interquartile ranges. A higher value of its outcome near to 1.0 indicates a higher degree of convergence.
Coefficient of variation	Zinn et al. (2001) found the coefficient of variation at or below 0.5, which was to them a cut-off point conventionally accepted as indicating reasonable internal agreement. "A consistent decrease of the coefficients of variation between the first and the second round, indicated an increase in consensus (greater movement toward the mean)." (Buck et al., 1993, p.284)
Post-group consensus	"Post-group consensus concerns the extent to which individuals, after the Delphi process has been completed, individually agree with the final group aggregate, their own final round estimates, or the estimates of other panellists." (Rowe and Wright, 1999, p.363); post-group consensus has also been examined by Rohrbaugh (1979) as well as Erffmeyer and Lane (1984).

Table D-2: Overview with references to techniques applied for measuring consensus by qualitative analyses and descriptive statistics in Delphi studies

Appendix D-3: Overview of consensus measurement by inferential statistics

Measure of consensus	Description
Chi-square test for independence	Ludlow (1975) used Chi-square tests to analyse disagreement between subgroups of homogeneous participants.
McNemar change test	Weir et al. (2006) as well as Rayens and Hahn (2000) used the McNemar test to quantify the degree of shift in responses between Delphi rounds.
Wilcoxon matched-pairs signed-ranks test	Changes in consensus between the second and third rounds were assessed using Wilcoxon signed-rank tests (De Vet et al., 2005)
Intraclass correlation coefficient, kappa statistics	The levels of agreement among participants in the first and second rounds were assessed with intraclass correlation coefficient (Ferri et al., 2005). Overall agreement of importance was measured using interclass correlation coefficients, whereas within-question agreement was measured by Cohen's kappa (Weir et al., 2006). Molnar et al. (1999) used the kappa statistic for measuring agreement level among experts rated on 3-point rating scales. Questions equal to or below a kappa value of 0.74 were reiterated.
Spearman's rank-order correlation coefficient	"A Spearman rank correlation was calculated to reflect the degree of consensus between Round 2 ratings and Round 3 rankings…A high correlation reflected a high degree of consensus." (DeLeo, 2004, p.8)
Kendall's W coefficient of concordance	"A high and significant W means that the participants are applying essentially the same standard in judging the importance of the issues. For the final round W was calculated (W=0.618) and found to be statistically significant (at p 0.001)." (Brancheau and Wetherbe, 1987, p.29). Also applied by Schmidt et al. (2001), Schmidt (1997), Cooper et al. (1995), Doke and Swanson (1995)
t-statistics, F-tests	Hakim and Weinblatt (1993) used t-statistics to test for significant differences between the rounds and also used F-statistics to test whether the variance (or the lack of consensus) within one subgroup was significantly different from the variance within another subgroup.

Table D-3: Overview with references to techniques applied for measuring consensus by inferential statistics in Delphi studies

Appendix D-4: Justification of applicability of consensus measurement techniques for this Delphi study

Measure of consensus	Discussion regarding application
Stipulated number of rounds	Delphi studies usually use three rounds to reach consensus. This approach is adopted in the study due to constraints of available time and attrition of panel members.
Subjective analysis	Subjective analysis was applied through the qualitative 'Assess' stages of the Delphi, drawing on experts' experience.
Certain level of agreement	Certain level of agreement was applied to the selection task of major outcomes in the 'Execute' stage with consensus consisting of more than 51% of respondents selecting an outcome.
APMO Cut-off Rate (average percent of majority opinions)	The 'Average Percent of Majority Opinions' (APMO) Cut-off Rate is a consensus measure that has been sporadically used in Delphi research in the UK. Consensus, which can be either agreement or disagreement with a statement, is defined as a percentage higher than the average percentage of majority opinion. This approach is useful for Delphi investigation of statements, but as such it is not appropriate, considering the design of this Delphi.
Mode, mean/median ratings and rankings, standard deviation	This technique is valid with interval/ratio data. In many Delphi studies, the mean is calculated without considering that the scales used are actually ordinal scales. Mode and mean analysis are used in this Delphi investigation as an approach to analyse the panel members' responses as aggregate results, but not as measures of consensus.
Interquartile range (IQR)	IQR is a useful technique for data in interval scales, which is not the case in this Delphi. As such it is not suitable technique, given the dataset and the type of questions in the Delphi investigation.
Coefficient of variation (CV)	In some Delphi studies CV is suggested as a technique for measuring consensus. It is well known that in Delphi investigations there is a strong link between achieving stability and consensus. However, in this Delphi investigation, CV is applied as a traditional measure of stability, not consensus, as a more robust technique.
Post-group consensus	This is a qualitative technique that can be applied post the Delphi investigation. The technique can be useful; however. It introduces a qualitative approach as an additional analysis layer to an otherwise quantitative enquiry and as such is not adopted.

Table D-4: Overview of measures of consensus by qualitative analysis and descriptive statistics and their application to the Delphi study

Measure of consensus	Discussion regarding application
Chi-square test for independence	The technique is not suitable to be applied to this Delphi as a measure of consensus, as it analyses disagreement between groups of panel members. In this Delphi, the approach taken is a homogeneous panel taken as a group and analysed as a collective. However, the Chi-square test is useful for testing for the statistical significance of results (testing if results are different from what could be expected by chance).
McNemar change test	The test is used for nominal data that can be labelled or classified into mutually exclusive categories within a variable. However, these categories do not lend themselves to be ordered in a meaningful way. In addition, the test uses 2x2 contingency tables with a dichotomous trait, which is not directly applicable to this Delphi investigation. This Delphi tests the rank (i.e. order) between four pathways. As such the technique is regarded as not suitable.
Wilcoxon matched-pairs signed-ranks test	The Wilcoxon test is a non-parametric statistical hypothesis test used either to test the location of a population based on a sample of data, or to compare the locations of two populations using two matched samples. The research design of this Delphi is not intended to test differences between populations and the questions are not aimed at identifying any specific location of a data point making the technique not suitable.
Intraclass correlation coefficient, kappa statistics	The intraclass correlation, or the intraclass correlation coefficient (ICC), is a statistical technique that can be used when quantitative measurements are made of units that are organised into groups. It describes how strongly units in the same group resemble each other. These techniques are not suitable for this Delphi investigation as it does not rely on data points (units) in groups, but relative ranking between groups.
Spearman's rank-order correlation coefficient	The Spearman rank-order correlation coefficient is a nonparametric measure of the strength and direction of association that exists between two variables measured on an ordinal scale. The technique requires many data points and is not particularly useful for this Delphi study which is focused on the relative rank of variables rather than their correlation.
Kendall's W coefficient of concordance	The technique is specifically suitable for application to consensus in ranking questions. As such this technique was selected in analysing level of reached consensus in this Delphi study.
t-statistics, F-tests	The t-statistic and f-statistic can be applied as techniques but are not suitable given the small number of category ranking (four in total) and not taking a subgroup approach to panel members' ranking. These techniques are considered of limited statistical relevance to this study.

Table D-5: Overview of measures of consensus by inferential statistics and their application to the Delphi study

Appendix E: Analyses of consensus measurement of the four pathways to SCI practices

Each participant's rankings in effectiveness of the four perspectives for improving joint work processes				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	1	2	3	4
Participant 3	1	3	2	4
Participant 4	1	3	2	4
Participant 5	2	4	1	3
Participant 6	1	2	3	4
Participant 7	1	3	2	4
Participant 8	1	3	2	4
Total Score:	9	23	17	31
Numerator:	3120			
Denominator:	3840			
W value:	0.8125			
chi-square	19.5			
p value	0.0002			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table E-1: Analysis of consensus at round 3 of the Delphi study for SCI practice JWP

Each participant’s rankings in effectiveness of the four perspectives for improving commitment				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	2	3	4
Participant 2	1	3	2	4
Participant 3	2	3	1	4
Participant 4	1	2	3	4
Participant 5	2	1	3	4
Participant 6	1	2	3	4
Participant 7	2	1	3	4
Participant 8	1	3	2	4
Total Score:	11	17	20	32
Numerator:	2808			
Denominator:	3840			
W value:	0.731			
Chi-square	17.55			
p value	0.0005			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table E-2: Analysis of consensus at round 3 of the Delphi study for SCI practice CM

Each participant's rankings in effectiveness of the four perspectives for improving trust				
n = 4 m = 10	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	2	3	4
Participant 2	1	3	2	4
Participant 3	1	3	2	4
Participant 4	1	2	3	4
Participant 5	1	2	3	4
Participant 6	1	2	3	4
Participant 7	1	3	2	4
Participant 8	1	3	2	4
Participant 9	1	2	3	4
Participant 10	1	2	3	4
Total Score:	10	24	26	40
Numerator:	5424			
Denominator:	6000			
W value:	0.904			
Chi-square	27.12			
p value	0.00001			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table E-3: Analysis of consensus at round 3 of the Delphi study for SCI practice T

Each participant's rankings in effectiveness of the four perspectives for improving long-term orientation				
n = 4 m = 10	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	2	3	4
Participant 2	1	3	2	4
Participant 3	1	2	3	4
Participant 4	2	1	3	4
Participant 5	1	2	3	4
Participant 6	1	2	3	4
Participant 7	1	2	3	4
Participant 8	1	4	2	3
Participant 9	1	3	2	4
Participant 10	1	2	3	4
Total Score:	11	23	27	39
Numerator:	4800			
Denominator:	6000			
W value:	0.800			
Chi-square	24			
p value	0.00002			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table E-4: Analysis of consensus at round 3 of the Delphi study for SCI practice LTO

Each participant's rankings in effectiveness of the four perspectives for improving length of relationships over series of projects				
n = 4 m = 10	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	2	3	4
Participant 2	1	4	2	3
Participant 3	1	2	3	4
Participant 4	1	2	3	4
Participant 5	1	2	3	4
Participant 6	1	3	2	4
Participant 7	1	2	3	4
Participant 8	2	3	1	4
Participant 9	1	3	2	4
Participant 10	1	2	3	4
Total Score:	11	25	25	39
Numerator:	4704			
Denominator:	6000			
W value:	0.784			
Chi-square	23.52			
p value	0.00003			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table E-5: Analysis of consensus at round 3 of the Delphi study for SCI practice LR

	Pathway			
SCI Practice	**Actors**	**Flows**	**Processes**	**Technologies**
Supporting technology	Results are not meaningful as no stability was reached			
Joint work processes	1.125	2.875	2.125	3.875
Commitment	1.38	2.13	2.5	4
Trust	1	2.4	2.6	4
Long-term orientation	1.1	2.3	2.7	3.9
Length of commitment over series of projects	1.1	2.5	2.5	3.9
Mean	1.14	2.44	2.485	3.935
OVERALL EFFECTIVENSS RANKING:				
1 Actors	**1.14**			
2 Flows	**2.44**			
3 Processes	**2.49**			
4 Technologies	**3.94**			

Table E-6: Overall and by practice ranking of effectiveness of the four pathways by mean number of results

	Pathway			
SCI Practice	**Actors**	**Flows**	**Processes**	**Technologies**
Supporting technology	Results are not meaningful as no stability was reached.			
Joint work processes	1	3	2	4
Commitment	1	2	3	4
Trust	1	2	3	4
Long-term orientation	1	2	3	4
Length of commitment over series of projects	1	2	3	4
Mean	1	2.2	2.8	4
OVERALL EFFECTIVENSS RANKING:				
1 Actors	**1.00**			
2 Flows	**2.20**			
3 Processes	**2.80**			
4 Technologies	**4.00**			

Table E-7: Overall and by practice ranking of effectiveness of the four pathways by mode number of results

Appendix F: Analyses of Consensus measurement of the four pathways to SCI outcomes

Each participant's rankings in effectiveness of the four pathways towards the outcome of Compete through superior value				
n = 4 m = 9	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	2	1	3	4
Participant 3	1	2	3	4
Participant 4	1	2	4	3
Participant 5	1	2	3	4
Participant 6	1	3	2	4
Participant 7	1	3	2	4
Participant 8	1	2	3	4
Participant 9	1	2	3	4
Total Score:	10	20	25	35
Numerator:	3900			
Denominator:	4860			
W value:	0.8025			
Chi-square	21.667			
p value	0.0001			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table F-1: Analysis of consensus at round 3 of the Delphi study for SCI outcome CTSV

Each participant's rankings in effectiveness of the four pathways towards the outcome of Defining client values				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	1	3	4	2
Participant 3	1	3	2	4
Participant 4	1	2	3	4
Participant 5	1	2	3	4
Participant 6	1	3	2	4
Participant 7	1	3	2	4
Participant 8	1	2	3	4
Total Score:	8	21	21	30
Numerator:	2952			
Denominator:	3840			
W value:	0.7688			
Chi-square	21.667			
p value	0.0001			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table F-2: Analysis of consensus at round 3 of the Delphi study for SCI outcome DCV

Each participant's rankings in effectiveness of the four pathways towards the outcome of Integrate project activities				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	2	3	1	4
Participant 3	1	3	2	4
Participant 4	2	3	1	4
Participant 5	1	2	3	4
Participant 6	2	3	1	4
Participant 7	1	3	2	4
Participant 8	1	2	3	4
Total Score:	11	22	15	32
Numerator:	3048			
Denominator:	3840			
W value:	0.7938			
Chi-square	19.05			
p value	0.0003			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table F-3: Analysis of consensus at round 3 of the Delphi study for SCI outcome IPA

Each participant’s rankings in effectiveness of the four pathways towards the outcome of Develop continuous improvement				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	2	3	1	4
Participant 3	2	3	1	4
Participant 4	2	3	1	4
Participant 5	1	3	2	4
Participant 6	2	4	1	3
Participant 7	2	3	1	4
Participant 8	3	2	1	4
Total Score:	15	24	10	31
Numerator:	3144			
Denominator:	3840			
W value:	0.8188			
Chi-square	19.65			
p value	0.0002			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table F-4: Analysis of consensus at round 3 of the Delphi study for SCI outcome DCI

Each participant's rankings in effectiveness of the four pathways towards the outcome of Establish supplier relationships				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	1	2	3	4
Participant 3	1	2	4	3
Participant 4	1	2	3	4
Participant 5	1	2	3	4
Participant 6	1	4	2	3
Participant 7	1	2	3	4
Participant 8	1	2	3	4
Total Score:	8	19	23	30
Numerator:	3048			
Denominator:	3840			
W value:	0.7938			
Chi-square	19.05			
p value	0.0003			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table F-5: Analysis of consensus at round 3 of the Delphi study for SCI outcome ESR

Each participant's rankings in effectiveness of the four pathways towards the outcome of Mobilise and develop people				
n = 4 m = 8	Participant Ranking for Actors	Participant Ranking for Flows	Participant Ranking for Processes	Participant ranking for Technologies
Participant 1	1	3	2	4
Participant 2	1	3	2	4
Participant 3	1	3	2	4
Participant 4	1	3	2	4
Participant 5	2	1	3	4
Participant 6	1	4	2	3
Participant 7	1	3	2	4
Participant 8	1	2	3	4
Total Score:	10	24	26	40
Numerator:	3000			
Denominator:	3840			
W value:	0.7813			
Chi-square	18.75			
p value	0.0003			
W Benchmark (0.7)	W is over 0.7 - Indicating high degree of consensus			

Table F-6: Analysis of consensus at round 3 of the Delphi study for SCI outcome MDP

Outcome	Pathway			
	Actors	Flows	Processes	Technologies
Manage costs collaboratively	Results are not meaningful as no stability was reached.			
Compete through superior value	1.11	2.22	2.78	3.89
Defining client values	1.00	2.62	2.62	3.75
Integrate project activities	1.37	2.75	1.87	4.00
Develop continuous improvement	1.87	3.00	1.25	3.87
Establish supplier relationships	1.00	2.37	2.87	3.75
Mobilise and develop people	1.12	2.75	2.25	3.87
Mean	1.25	2.62	2.27	3.86
OVERALL EFFECTIVENSS RANKING:				
1 Actors	**1.25**			
2 Processes	**2.27**			
3 Flows	**2.62**			
4 Technologies	**3.86**			

Table F-7: Overall and by outcome ranking of effectiveness of the four pathways by mean number of results

	Pathway			
Outcome	**Actors**	**Flows**	**Processes**	**Technologies**
Manage costs collaboratively	Results are not meaningful as no stability was reached.			
Compete through superior value	1	2	3	4
Defining client values	1	2	3	4
Integrate project activities	1	3	2	4
Develop continuous improvement	2	3	1	4
Establish supplier relationships	1	2	3	4
Mobilise and develop people	1	3	2	4
Mean	1.17	2.50	2.33	4.00
OVERALL EFFECTIVENSS RANKING:				
1 Actors	**1.17**			
2 Processes	**2.33**			
3 Flows	**2.50**			
4 Technologies	**4.00**			

Table F-8: Overall and by outcome ranking of effectiveness of the four pathways by mode number of results

Appendix G: Dataset and analytical instrument for analysis

The Dataset can be obtained from the following link:

https://files.warwick.ac.uk/anikolov/files/Dataset/DATASET+DELPHI.xlsx

The instrument used for analyses can be obtained from the following link:

https://files.warwick.ac.uk/anikolov/files/Analyses+Instrument/ANALYSES+INSTRUMENT+DELPHI.xlsx

Appendix H: Research Ethics

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Biomedical and Scientific Research Ethics Committee
Kirby Corner Road
Coventry
CV4 8UW

Monday, 20 December 2021

Mr Aleksandar Nikolov
Warwick Manufacturing Group
University of Warwick
Coventry
CV4 7AL

Dear Mr Nikolov,

Application Reference: BSREC: BSREC 31/21-22
Title: Improving Supply Chain Integration in Construction

Thank you for submitting your revisions to the Biomedical and Scientific Research Ethics Committee (BSREC) for consideration. We are pleased to advise you that, under the authority delegated to us by the University of Warwick Research Governance and Ethics Committee, **full ethical approval for your project is hereby granted, subject to the conditions outlined in Appendix 1.**

Any substantial changes to any aspect of the project will require further review by BSREC and the PI is required to notify the BSREC as early as possible should they wish to make any such changes. The BSREC Secretary should be notified of any minor amendments to the study.

Should issues arise during the course of the project that present risks to the safety and wellbeing of participants, these must be reported to BSREC. In such an event, recruitment and research activity must be halted until the appropriate actions have been taken, as agreed in consultation with BSREC.

I would like to take this opportunity to wish you all the best with your study.

Yours sincerely,

Professor David Ellard
Chair, Biomedical and Scientific Research Ethics Committee

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Figure H-1: Ethical approval by BSREC – page 1 of 2

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Appendix 1

- Please also be aware that BSREC grants **ethical approval** for studies. The seeking and obtaining of all other necessary approvals are the responsibility of the Principal/ Chief Investigator, for example that all appropriate risk assessments have been completed. For advice on what additional approvals may be required, please visit the following BSREC Other Approvals page.

- Please ensure that evidence of all necessary local permissions is provided to BSREC prior to commencing your study.

- Before conducting your research, you must complete the online Research Integrity training. As a minimum, the 'Concise' version and the 'Protecting Human Participants' modules must have been completed.

- You must ensure that you are compliant with all necessary data protection legislation. Legal and Compliance guidance can be accessed on their GDPR information pages.

- In undertaking your study, you are required to comply with the University of Warwick's Research Code of Practice.

- You are also required to familiarise yourself with the University of Warwick's Code of Practice for the Investigation of Research Misconduct.

- Further advice and support is available from the BSREC Secretary via BSREC@warwick.ac.uk.

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Figure H-1: Ethical approval by BSREC – page 2 of 2

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Participant Information Leaflet

Study Title: Improving Supply Chain Integration in Construction

Investigator(s):
Mr. Aleksandar Nikolov
Prof Naomi Brookes
Prof Janet Godsell

Introduction

You are invited to take part in a research study. Before you decide, you need to understand why the research is being done and what it would involve for you. Please take the time to read the following information carefully. Talk to others about the study if you wish.

Please ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Who is organising and funding the study?

This study is organised and funded by WMG (Warwick Manufacturing Group) University of Warwick

What is the study about?

The overall aim of the study is to improve UK Supply Chain Integration (SCI) in the construction sector. The research project will identify how SCI in UK construction can be improved by investigating what SCI practices construction companies need to undertake and examine the relationships between them. Specifically, the project seeks to understand the functional role of integrating actors, flows, processes and technologies and systems and how integration practices can lead to enabling SCI outcomes in construction. Enabling specific or sets of outcomes in construction can lead to improved construction value.

What would taking part involve?

You are invited to join an expert panel in a set date and time (online) and fully participate in a Delphi study. In essence the Delphi method uses participants' input to catalyse responses aiming at reaching a form of group consensus around the initial research question. The event will be facilitated by the main investigator on the day. Through email, you will be sent a link to the Delphi study. You will be asked to enter your name, the name of your organisation and your job role (no other personal data will be collected). From that point you are set to take part in the study and are expected to contribute to and submit your answers to the questions on the day following the Delphi procedure. Completing the study will approximately take 2h and will be a facilitated event. While your data will be used as input to an aggregated dataset used for analysis and comparison purposes in the construction sector, your data will be anonymised and will not be traceable back to you or to your organisation.

Figure H-2: Participant Information Leaflet (PIL) – page 1 of 4

The Delphi event will start with a short presentation by the facilitator on the topic and then will follow a predefined 5 stages procedure. This stage-based procedure is summarised here.

Stage 1: Identify
Involves facilitated discussion that will identify the current and most prominent challenges to SCI in the respective workstream and link them to the known SCI practices from research to date.
Stage 2: Assess
Involves facilitated discussion what will introduce other potential areas not initially recognised by the expert panel but relevant from research to date. As an output the panel will develop anecdotal examples based on their experience of SCI.
Stage 3: Select
The panel members will be asked to select the most important SCI practices from a predefined list by distributing a total of 10 points for each participant between practices.
Stage 4: Define
The panel members will be asked to rank the selection of most important practices according to four integration perspectives most effective for improving them (i.e., integration of actors, flows, processes and activities and technologies and systems)
Stage 5: Execute
The panel members will be presented with seven outcomes that can be achieved in construction as a result of better SCI. First, the panel members are asked to rank the three outcomes (out of seven) that can achieve the highest value potential in the construction work stream. Second, the panel members are expected to attribute a maximum of 3 practices (out of the 7 in "select") that are most effective to each of the seven outcomes.

Do I have to take part?

No. Participation in this study is voluntary and anonymous with regards to the consolidated input as part of the Delphi study. Whitin the event, the participant will not be anonymous. Once the Delphi event starts, withdrawal of data will not be possible as the data is not uniquely identifiable and will be swiftly anonymised. Participants are free to discontinue their involvement in the study without giving any specific reason at any stage of the Delphi event. However, once involved in the interactive Delphi event, withdrawal of participant data will not be possible. The reason for this is that throughout the online event, all responses are amalgamated to arrive to a group consensus and it would be impossible to remove any individual contribution. You can also choose to withdraw your participation without giving a reason by contacting one of the research team. Further details about withdrawing from the study are provided later in this document.

What are the possible benefits of taking part in this study?

The findings of this study will be disseminated in various formats such as industry reports, academic publications, workshops and seminars. All materials are available upon request. In addition, by taking part in the Delphi study the participants have the opportunity to contribute to possible wider benefits to society and the UK construction sector. The study draws on participants' experience to answer predetermined questions through testing a typological framework and does not rely on anecdotal examples.

What are the possible disadvantages, side effects or risks, of taking part in this study?

No known side effects. You have the right to withdraw at any time if you feel uncomfortable. However, withdraw of your data is not possible, as the data is not uniquely identifiable and is anonymised. There is no possibility to track any individual data as such capability in the software used to conduct the Delphi is not present. Any data in the form of names of personnel, organisations or projects through the Delphi event is not encouraged. In the event that such

Figure H-2: Participant Information Leaflet (PIL) – page 2 of 4

is shared with other members of the expert panel, the data will not be shared in any way outside the Delphi facilitated event. General data regarding the size (i.e., budget, duration, etc.) of a given project or situational SCI details can be useful in the commentary of the facilitated event. It is entirely up to the participants to share such, should they wish to do so.

Expenses and payments

No expenses or payments will be given.

Will my taking part be kept confidential?

Yes. The information provided by you will be anonymised and all data will be kept confidential and stored on secure University of Warwick servers for 10 years.

What will happen to the data collected about me?

As a publicly-funded organisation, the University of Warwick have to ensure that it is in the public interest when we use personally-identifiable information from people who have agreed to take part in research. This means that when you agree to take part in a research study, such as this, we will use your data in the ways needed to conduct and analyse the research study.

We will be using information from you in order to undertake this study and will act as the data controller for this study. The personal information collected is name, role and affiliated construction company. We are committed to protecting the rights of individuals in line with data protection legislation. The University of Warwick will keep identifiable information about you for 10 years after the study has finished.

Once submitted data cannot be withdrawn as it will be swiftly anonymised.

Data Sharing

Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. The University of Warwick has in place policies and procedures to keep your data safe.

This data may also be used for future research, including impact activities following review and approval by an independent Research Ethics Committee and subject to your consent at the outset of this research project.

For further information, please refer to the University of Warwick Research Privacy Notice which is available here:
https://warwick.ac.uk/services/idc/dataprotection/privacynotices/researchprivacynotice or by contacting the Legal and Compliance Team at GDPR@warwick.ac.uk.

What will happen if I don't want to carry on being part of the study?

Participation is voluntary and anonymous. Participants will be offered to first sign a consent form and then take part in the Delphi event on the pre-communicated date and time. Participant consent (by signing and sending back the consent form) is given prior to the Delphi event commencing.

Withdraw of data will not be possible as the data is not uniquely identifiable and will be swiftly anonymised.

What will happen to the results of the study?

The results will be used and discussed in any journal that the researcher plans to publish, industry reports, and any conferences, seminars and workshops that the researchers plan to

Figure H-2: Participant Information Leaflet (PIL) – page 3 of 4

attend.

Who has reviewed the study?

This study has been reviewed and given favourable opinion by the University of Warwick's Biomedical & Scientific Research Ethics Committee (BSREC)

Who should I contact if I want further information?

Mr. Aleksandar Nikolov: A.Nikolov@warwick.ac.uk
Prof. Naomi Brookes: Naomi.Brookes@warwick.ac.uk

Who should I contact if I wish to make a complaint?

Any complaint about the way you have been dealt with during the study or any possible harm you might have suffered will be addressed. Please address your complaint to the department below, entirely independent of this study:

Head of Research Governance
Research & Impact Services
University House
University of Warwick
Coventry
CV4 8UW
Email: researchgovernance@warwick.ac.uk
Tel: 02476 575733

If you wish to raise a complaint on how we have handled your personal data, you can contact our Data Protection Officer, who will investigate the matter: DPO@warwick.ac.uk.

If you are not satisfied with our response or believe we are processing your personal data in a way that is not lawful you can complain to the Information Commissioner's Office (ICO).

Thank you for taking the time to read this Participant Information Leaflet

Figure H-2: Participant Information Leaflet (PIL) – page 4 of 4