Identifying Supply Chain Capabilities of Construction Firms in Industrialised Construction

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Abstract

The heightened risk exposure of construction supply chains calls for greater resilience. Focusing on Industrialised Construction (IC), this study examines how Supply Chain Resilience (SCR) can be boosted through clear identification of the relevant and appropriate Supply Chain Capabilities (SCC) that construction firms would then need to nurture and/or develop further. This study conducted a systematic review of SCC related literature, followed by an in-depth analysis and consolidation of the findings which enabled the development of a proposed action framework for achieving SCR in IC. The results revealed 58 SCC related to IC and mapped the yearly publication trend, publications by country and methodological approaches followed in previous research. Thematic analysis was conducted to categorise the identified SCC into 12 newly formulated constructs. Further, the findings help to identify a suite of capabilities (SCC) to develop value enhanced resilient supply chains in IC and provide a foundation for further research in SCR in the construction industry.

Keywords: Industrialised Construction; Supply Chain Capabilities (SCC); Supply Chain Resilience (SCR)

Research Background

Global supply chains are susceptible to a wide array of disruptions (Oehmen et al. 2009; Zavala et al. 2018) not only due to the external environmental forces but also due to the strategic and managerial decisions made by the organisations (Vecchi and Vallisi 2016). This highlights the need for strategies and practices which mitigate the effects of diverse disruptions that adversely affect global supply chains and calls for supply chain resilience (SCR) (Colicchia et al. 2010; Zavala et al. 2018). Resilience is a horizontal concept applied in diverse disciplines (Ali et al. 2017a) and, SCR is one of the clusters explored in the discipline of management and engineering. Explicating the concept further, SCR is the 'adaptive capability of the supply chain (SC) to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function' (Ponomarov and Holcomb 2009). Therefore, the concept of SCR has been used as a strategy to firstly examine the continuity of SC networks and secondly, to make the operational changes in the processes to reduce their vulnerability to disturbances (Zavala et al. 2018).

SCs are allied with numerous risks and hence, vulnerable to frequent SC failures (Blaikie et al. 2004). The exposure of supply chains to vulnerability can apply to just a part of the supply chain (atomistic vulnerability) or to the entire supply chain (holistic vulnerability) as described by Svensson (2000). These vulnerabilities include project organisational, procedural, supplier/customer, technological, external environmental and financial factors. Due to the uncertain nature of these vulnerabilities, organisations need to strengthen their SCR using flexibility, redundancy and corporate cultural change before the vulnerability events occur, to mitigate the impact of the disruption (Zavala et al. 2018). According to the empirical study findings of Pettit et al. (2013), SCR increases as capabilities increase and vulnerabilities decrease. Ponis and Koronis (2012) also studied how SC capabilities could mitigate the presence of disruptions and how it affects the SCR.

The construction industry is not exempted from being affected by the interconnected risks associated with global supply chains (Zainal Abidin and Ingirige 2018). Indeed, the SC of a construction project is clearly vulnerable to these disruptions, which lead to significant cost impacts and subsequent losses due to the downtime (Wedawatta et al. 2010). New initiatives in construction supply chain management (SCM) have been launched from1980 (Vrijhoef and Koskela 2000; Akintoye and Main 2007; Eriksson and Laan 2007). These initiatives targeted improving the SC efficiency, waste reduction, and SC value additions by discarding the adversarial SC relationships and fragmented business processes (Saad et al. 2002; Gadde and

Dubois 2010). Further, members of the construction SC, especially the main contractor and the sub-contractors deal appropriately with organisational, managerial, technological and relational SC issues to apply SC initiatives effectively (Palaneeswaran et al. 2003). However, SCM practices in the construction industry are ad-hoc and scattered (Gadde and Dubois 2010).

Under these circumstances, Industrialised Construction (IC) as an increasingly attractive approach that emerged in the construction industry to improve the efficiency, flow and the quality of construction SCs (Gibb 1999; Lawson et al. 2011). Manufactured construction, offsite manufacturing, offsite production, offsite construction, modern methods of construction, pre-fabricated construction and the industrialized construction are used interchangeably in the literature to describe similar approaches (Goulding et al. 2015) and all these terms share a common standpoint in production methods and prefabrication (Lessing et al. 2015). Primarily, the focus of IC is associated with manufacturing or factory-based production, which creates a controlled environment in the onsite assembly (Arif and Egbu 2010). The IC process consists of three phases: prefabrication; logistics; and on-site assembly (Zhai and Huang 2017), each of which is serviced by its SC. The foregoing researchers found that each phase of IC SCs is vulnerable to the disruptions such as machine breakdowns, traffic jams, issues related to the customs clearance and damages to equipment. Therefore, it is essential to minimize and/or manage these potential disruptions effectively to elicit the potential benefits of IC. In such circumstances, the first attempt should be preventive risk management, that make the SC robust and risk resilient (Cui 2018). According to the findings of Vecchi and Vallisi (2016), being resilient is the answer to countering the negative impacts and subsequent losses associated with the SC disruptions.

Besides, the literature findings suggest that Supply Chain Capabilities (SCC) should help to withstand SC vulnerabilities since SCC denotes the resilience capability (Chowdhury et al. 2012). Indeed the ‘supply chain capabilities’ theme has motivated research over recent years

(Cui 2018). However, insufficient attention has been paid to researching SCC in the construction industry (Zainal Abidin and Ingirige 2018). Therefore, it is worthwhile to consider SCC to be an emerging research area in the construction industry. Indeed, the research gap is highly significant in IC. This study, therefore, attempts to fill the current knowledge gap and contribute to the existing body of literature by conducting a systematic analysis of literature of the SCC needed in IC for resilient SCs. Also, in this study, the primary consideration was given to the SCR capabilities since the study targets achieving resilient SCs in IC. Hence, the findings of this study could underpin a robust platform to generate greater resilience in IC SCs.

As a result, this study is designed to identify SCC in IC for resilient SCs through the lens of a systematic review which includes; Phase 1: searching for and identifying papers to target, and Phase 2: Examining and analysing the targeted papers. In Phase 1, the authors set out to assess: (a) the annual publication trend on the SCC for SCR; and (b) SCC that are required to achieve SCR in IC. In Phase 2, the authors focused on: the categorisation of the identified SCC under different constructs to develop an envisaged action framework for achieving SCR in IC. This Phase 2 focus was triggered by the observation that IC has obtained broader market expansion and the attention of practitioners and researchers, multiple stakeholders of the global community would be benefited by the study results in such an envisaged action framework for achieving SCR in IC. Indeed, the findings generated from the analysis justify this approach. The remainder of this paper is structured to explicate further the research methodology used, review of the results and, the conclusions reached based on the developed envisaged action framework for achieving SCR in IC.

Literature on SCR, SC Risk Management and SCC

SCR vs SC Risk Management

Organisations adopt numerous Risk Management (RM) strategies to reduce the level of vulnerability to SC disruptions (Zavala et al. 2018). RM is regarded as the traditional way of dealing with disruptions, and it employs empirical data, mathematical modelling and probability distributions in identifying risks and making future predictions (Van Der Vegt et al. 2015). A typical RM process involves hazard identification, risk assessment, controls implementation and review (Pettit et al. 2010). However, it is very difficult to identify all potential risks to conduct adequate risk assessments (Van Der Vegt et al. 2015). Indeed it would be onerous to apply traditional RM approaches to every possible SC disruptive cause (Pettit et al. 2010) and these RM practices are inadequate to facilitate the required protection against potential disruptions since these uncertainties trigger potential disruptions whose root causes are difficult to be understood (Van Der Vegt et al. 2015). These researchers also found that most of the disruptions emerged as a set of joint events and generated cascading impacts which are hard to anticipate and predict. Besides, traditional RM is unable to respond to the low-probability, high impact disruptive events adequately, as it cannot deal well with the enforceable events (Pettit et al. 2010). To cope with these circumstances, the attention of academic researchers and the industry practitioners has increasingly shifted towards resilience (Van Der Vegt et al. 2015), which goes beyond mitigating risk and enables organisations to deal with disruptions more effectively (Fiksel 2015). SCR also goes beyond the traditional SC RM approaches (Zavala et al. 2018) and enable handling the disruptions, which cannot be handled within the RM framework. Hence, resilient SCs develops adaptive capabilities in SCs to deal with vulnerabilities and enhance recoverability in the presence of a disruption. Moreover, resilience is defined as 'the ability to react proactively to disturbances and to return to its original state or a more desirable one after being disturbed' (Christopher and Peck 2004). Adding further to the concept of resilience, Sheffi and Rice (2005) defined SCR as the ability of an organisation to recover from a large disruption or a supply chain's ability to react to unexpected disruptions and restore quickly to normal supply network operations. Therefore, Ponomarov and Holcomb (2009) viewed SCR as the adjustment capacity of a SC to balance changing circumstances and restore operations to normality or to a steady state after facing a disruption.

Supply Chain Capabilities

Supply chain capabilities can be considered as a source for firms' success and as the building blocks for supply chain strategy that includes operational excellence and customer closeness (Morash 2001). However, relating to the SCR, Pettit et al. (2013) identified SCR as derived from an appropriate balance between the associated vulnerabilities and capabilities in the SCs. As previously explained in this paper, vulnerabilities are the key disruptions that disturb the normal construction process and are unanticipated and unplanned (Zavala et al. 2018). These vulnerabilities can be counterbalanced by implementing appropriate managerial controls through Supply Chain Capabilities (SCC) (Pettit et al. 2013). Therefore, these SCR capabilities are distinguished from the general SCC and, these are the 'attributes that enable an enterprise to anticipate and overcome supply chain disruptions' (Pettit 2008). Therefore, some researchers conducted studies on SCR capabilities and suggested several approaches that could be followed.

Accordingly, Christopher and Peck (2004), suggested several SCC approaches, including transshipping, dual sourcing and, improved visibility of the SCs. Tomlin (2006) proposed flexibility as a SCC to deal with SC disruptions. Purvis et al. (2015) highlighted robustness, agility, leanness and flexibility as relevant management capacities for resilient supply chains. Based on the empirical findings, Pettit et al. (2013) developed 13-factor capability assessment tool. Also, Chowdhury and Quaddus (2015) proposed resilient SCC based on three case studies of Bangladesh garment industry. Considering the dynamics of SC vulnerabilities and capabilities, Zainal Abidin and Ingirige (2018) proposed 12 capability factors to improve SCR in Malaysian public construction projects. Therefore, research findings indicate that it is essential to consider the SCC in designing the SC networks since it denotes the resilience capability which mitigates the vulnerabilities and contributes to sustainable SCM (Chowdhury et al. 2012). However, there is no known research on determining SCC in IC, although this is now necessary to meet the emerging needs outlined in this paper. Therefore, the aim of this study was derived to bridge this research gap and thereby address the related knowledge lacuna, as presented in the forthcoming sections of this paper.

Methodology

In-depth and systematic analysis of published literature is required to conduct a comprehensive literature review and deep analysis on a particular topic (Tsai and Lydia Wen 2005; Thome et al. 2016; Durach et al. 2017; Bellisario and Pavlov 2018). Therefore, this study adopted a methodical approach on the lines of that successfully used by Osei-Kyei and Chan (2015); Owusu et al. (2017) and Batista et al. (2018) to identify, retrieve and examine the extensive literature on capabilities in IC supply chains. This approach is the systematic review of literature through meta-analysis and consists of two phases, namely: searching for and identifying the targeted papers and examining and analysing the selected papers.

Phase 1: Searching for and identifying the targeted papers

In phase 1, a broad preparatory desktop search was conducted across Scopus, Web of Science, Google Scholar, ASCE library, Taylor and Francis, and Emerald Insight, to identify the research papers on the subject of capabilities in SCR. This phase of the study initially identified that the majority of the retrieved articles are published in all these databases and libraries. Therefore to reduce upfront overlaps, the Scopus search engine was first used in this study since this database covers most of the publications in different related research fields such as management, engineering, business, and accounting (Hong and Chan 2014) and it is recognised for its wide coverage and accuracy (Falagas et al. 2008). In addition, the same methodology was followed and accepted by similar review studies in the construction management and engineering field (Hong and Chan 2014; Osei-Kyei and Chan 2015; Owusu et al. 2017; Yi and Wang, 2013). Further, a comprehensive Scopus search was carried out to retrieve the research papers using the title/abstract /keyword search option with the keywords; 'supply chain capabilities,' 'supply chain capacities,' 'supply chain competencies', 'supply chain abilities', and 'resilience.' Papers with these specific terms in their title, abstract or the keywords were considered as appropriate and relevant for further consideration in this study. The search was not restricted to any specific year of publication since the study aimed to retrieve as much of the research publications as possible to date. However, the language was set to the English, and document type was limited to articles. With these limits applied to the search, 167 articles were retrieved as the preliminary data set. Following the initial selection and use of Scopus, the search was next expanded to also cover the other databases and the libraries. Thereby, 184 articles were considered (avoiding the repetitions in the databases and the libraries) to be appropriate for the further analysis.

After retrieving the 184 articles, a preliminary screening was conducted to identify publications specifically related to supply chain capabilities for SCR, this being the scope covered in this study. Therefore, an in-depth scanning of title/abstract/keywords was carried out to aid the appropriate retrieval of the articles. Thereby, 50 articles were retrieved and the details of these publications are listed in Table 1. Further, by identifying the importance of including highly cited highly relevant publications within the scope of the study, albeit not highlighting the term SCC, 5 more papers were also selected for the next phase of this study. These added up to 55 articles. Furthermore, most of these articles were published in the journals which are ranked as the top journals in their respective fields.

After the above secondary screening and adjustment process, a more comprehensive visual examination of the articles was conducted to identify highly relevant articles on capabilities in IC supply chains. Therefore, the articles were thoroughly studied to identify their relevance to the subject matter. In particular, the articles which include SCC that can be incorporated to achieve resilient SCs in IC were selected for the further content analysis in this screening out process. Although the publications were not directly addressing IC, they were selected considering their potential/apparent relevancy in determining SCC for IC. The publications belong to the broad categories of 'articles in press,' 'editorial,' 'letter to the editor,' 'discussions and closures,' and 'briefing sheet' in the selected journals were also excluded from the analysis. The results of the selection are presented in Table 1. Therefore, 44 out of 55 articles were selected for examining in the next phase of this study.

Table 1: Search results of papers on capabilities in SCR in selected journals

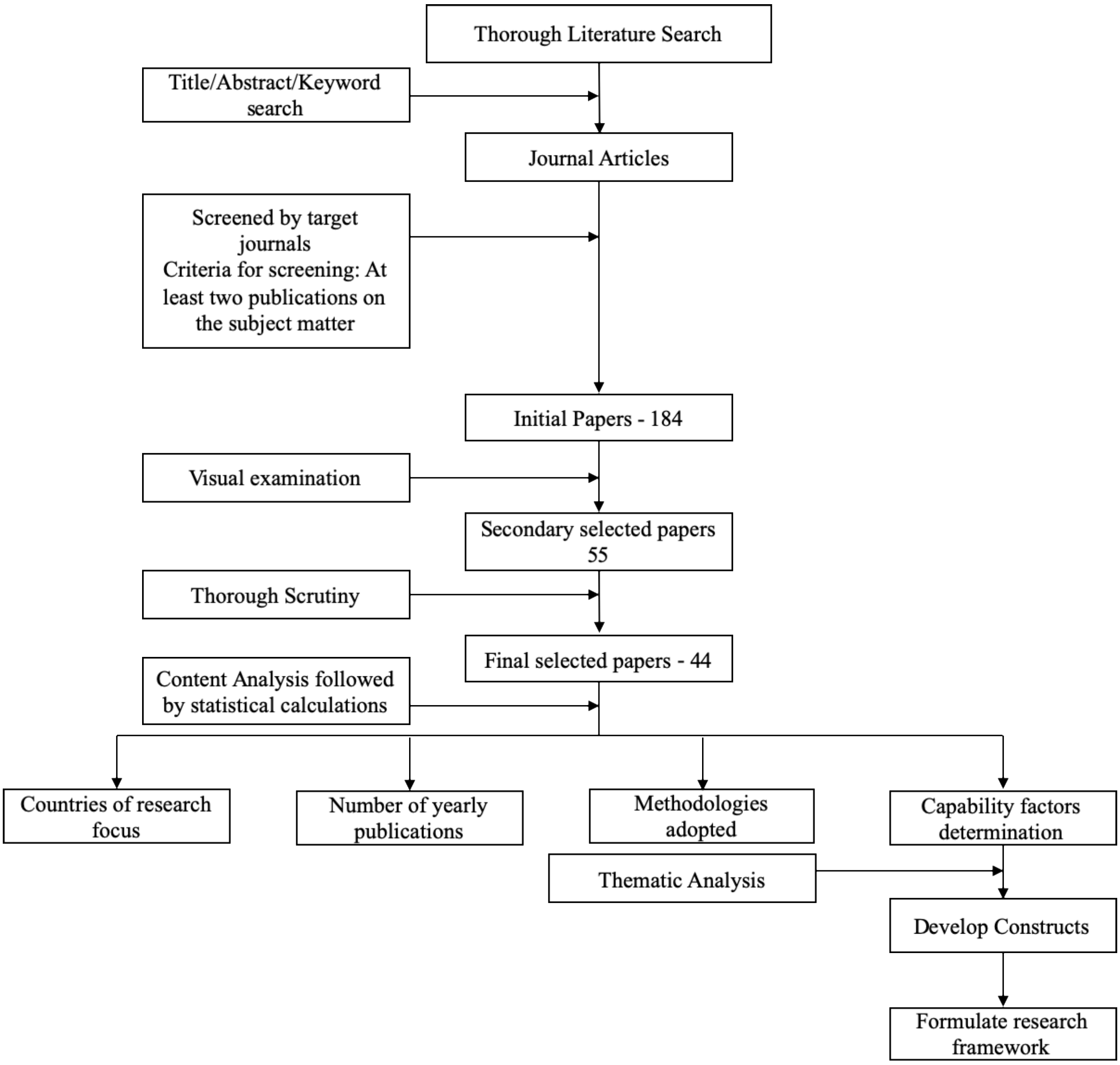
Name of the journal	Number of papers retrieved in final search	Number of papers retrieved in initial search
Construction Innovation	1	1
Journal of Business Logistics	1	1
Procedia-Social and behavioral sciences	1	1
Computers and Industrial Engineering	1	2
International Journal of Logistics: Research and Applications	1	1
Transportation Research Part E: Logistics and Transportation Review	1	2
International Journal of Logistics Management	2	4
Supply Chain Management an International Journal	5	10
Human Resource Management Review	1	1
Expert systems with applications	1	1
Production Planning and Control	4	4
International Journal of Production Research	2	2
International Journal of Production Economics	2	4
Journal of Construction Engineering and Management	1	1
Towards a Vision for Information Technology in Civil Engineering	1	1
MIT Sloan Management Review	1	1
International Journal of Physical Distribution & Logistics Management	4	4
Management Science	3	3
Manufacturing and Service Operations Management	1	1
Industrial Management and Data Systems	1	1
International Journal of Strategic Property Management	1	1

Journal of Risk and Reliability	1	1
Uncertain Supply Chain Management	1	1
Journal of Operations Management	1	1
Omega	1	1
Benchmarking: An International Journal	1	1
Civil Engineering Journal	1	1
Sustainable Production and Consumption	1	1
International Journal of Disaster Resilience in the Built Environment	1	1
Total	**44**	**55**

However, the review study is limited to the selected articles on capabilities in SCR related to IC arena rather than conducting an exhaustive and all-inclusive search in the area of study such as SCR and supply chain vulnerabilities. Therefore, it should be emphasised that the analysis is solely based on the specific data collection method adopted in this study, which is shown in Figure 1 and serves the study purpose as well and ensures its rigour. Indeed, this study does not intend to examine the entire population of the SCR related papers but to review the research trend on capabilities in SCR especially to identify the capabilities in IC SCs for future research and development. In addition, the study first limited the search to SCR in IC, but no publications emerged. After expanding the search to the construction industry, 3 articles were found. This also highlighted the research gap in this important area in construction and IC, which reinforces the need for the current study. Therefore, the search was expanded without limiting the capabilities to a specific field in order to gather a higher number of potential capability factors. This enabled learning lessons from and building on, as well as drawing on cross-references to adopt and/or adapt relevant findings that can be applied to IC supply chains.

Figure 1: The methodological process followed in the study.

Adapted from Osei-Kyei and Chan (2015), Owusu et al. (2018)



Phase 2: Examining and analysing the targeted papers

In phase 2, the articles retrieved after the screening process were subjected to content analysis to examine and analyse the capabilities in SCR related publications based on countries of research focus, number of yearly publications, methodologies adopted and explaining the variables identified as capability factors. An exhaustive summary of the selected articles is presented in Table 2. Following from that exercise, a thematic analysis was employed in this study to develop the constructs and to formulate the research framework. The forthcoming sections of this paper discuss the results derived and the conclusions reached while suggesting useful future research directions.

Table 2: Targeted publications in this study

Paper No	Year	Citation count	Authors	Principal Research Methods used	Source	Country
1	2018	-	Zainal Abidin, N.A., Ingirige, B.	A comprehensive questionnaire survey	Construction Innovation	United Kingdom
2	2013	102	Pettit, T.J., Croxton, K.L., Fiksel, J.	Empirical Study and focus group interviews	Journal of Business Logistics	United States
3	2014	44	Mensah, P. & Merkuryev, Y.	A review	Procedia-Social and behavioral sciences	Latvia, Italy
4	2014	67	Soni, U., Jain, V. & Kumar, S.	Interpretive Structural Modeling approach, Graph Theory	Computers and Industrial Engineering	India, United Arab Emirates, United States
5	2006	880	Tang, C. S.	A review	International Journal of Logistics: Research and Applications	United States
6	2014	27	Bueno-Solano, A., Cedillo-Campos, M.G.	System dynamics model	Transportation Research Part E: Logistics and Transportation Review	Chile
7	2004	760	Christopher, M., Peck, H.	Empirical Study	The International Journal of Logistics Management	United Kingdom
8	2011	194	Jüttner, U. & Maklan, S.	Empirical Study	Supply Chain Management an International Journal	United Kingdom
9	2014	75	Scholten, K., Scott, P.S., Fynes, B.	Case study	Supply Chain Management an International Journal	Netherlands Irelands
10	2013	60	Johnson, N., Elliott, D. & Drake	Social constructionist approach	Supply Chain Management an International Journal	United Kingdom
11	2011	165	Lengnick-Hall, C. A., Beck, T. E. & Lengnick-Hall, M. L.	Review based study	Human Resource Management Review	United States
12	2014	48	Kristianto, Y., Gunasekaran, A., Helo, P. & Hao, Y	Fuzzy analysis	Expert systems with applications	Finland, United States
13	2015	54	Scholten, K. & Schilder, S.	Case study	Supply Chain Management an	Netherlands

					International Journal	
14	2017	1	Ali, I., Nagalingam, S., Gurd, B.	Semi-structured interviews	Production Planning and Control	Australia
15	2017	36	Ivanov, D., Dolgui, A., Sokolov, B. & Ivanova, M.	Literature review	Journal of Production Research	France, Russia, Germany
16	2017	14	Brusset, X. & Teller, C.	Variance-based structural equation modeling	International Journal of Production Economics	France, United Kingdom
17	2011	35	Lim, B. T. H., Ling, F. Y. Y., Ibbs, C. W., Raphael, B. & Ofori, G.	Empirical study	Journal of Construction Engineering and Management	Singapore, United States
18	2003	6	Vaidyanathan, K. & O'brien, W.	A review	Towards a Vision for Information Technology in Civil Engineering	United States
19	2005	499	Sheffi, Y., Rice Jr., J.B.	Literature review and case study	MIT Sloan Management Review	United States
20	2005	274	Peck, H.	In-depth exploratory case study	International Journal of Physical Distribution & Logistics Management	United Kingdom
21	2006	726	Tomlin, B.	Mathematical modelling	Management Science	United States
22	2012	62	Dong, L. & Tomlin, B.	Mathematical modelling	Management Science	United States
23	2010	127	Wang, Y., Gilland, W. & Tomlin, B.	Mathematical modelling	Manufacturing and Service Operations Management	United States
24	2013	31	Kim, S.-H. & Tomlin, B.	Mathematical modelling	Management Science	United States
25	2018	1	Panova, Y. & Hilletofth, P	Simulation and modelling	Industrial Management and Data Systems	China, Russia, Sweden
26	2010	20	Wedawatta, G., Ingirige, B., Amaratunga, D.	Literature review and synthesis of a doctoral research study	International Journal of Strategic Property Management	United Kingdom
27	2018	-	Zavala, A., Nowicki, D., Ramirez-Marquez, J.E.	Literature Review and mathematical modelling	Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability	United States Mexico

28	2018	-	Chaghooshi, A.J., Momeni, M., Abdollahi, B., Safari, H., Kamalabadi, I.N.	Literature review, Questionnare survey, Interpretative Structural Modeling (ISM) and Fuzzy MICMAC	Uncertain Supply Chain Management	Iran
29	2017	22	Chowdhury, M. H., and Quaddus, M	Empirical Study	International Journal of Production Economics	Australia
30	2016	12	Chowdhury, M. H., and Quaddus, M	Field Study Questionnaire Survey and Structural Equation Modelling	Supply Chain Management: An International Journal	Australia
31	2015	112	Ambulkar S., blackhurst, J., and Grawe, S.	Empirical Study	Journal of Operations Management	United States
32	2015	27	Chowdhury, M. H., and Quaddus, M	QFD Methodology	Omega	Australia
33	2013	158	Wieland, A., and Wallenburg, C. M.	Empirical Study with Structural Equation Modelling	International Journal of Physical Distribution and Logistics Management	Germany
34	2010	149	Colicchia, C., Dallari, F. And Melacini, M.	Simulation based framework	Production planning & control	Italy
35	2016	22	Purvis, L., Spall, S., Naim, M. and Spiegler, V.	Case Study	Production planning & control	United Kingdom
36	2019	-	Singh, N.P. and Singh, S.	Survey based study	Benchmarking: An International Journal	United States
37	2019	1	Shahbaz, M.S., Soomro, M.A., Bhatti, N.U.K., Soomro, Z. and Jamali, M.Z.	Questionnaire Survey	Civil Engineering Journal	Malaysia
38	2019	4	Rajesh, R.	Fuzzy approach	Sustainable Production and Consumption	India
39	2013	47	Gosling, J., Naim, M. and Towill, D.	Empirical research based on a case study	Production Planning & Control	United Kingdom
40	2018	37	Namdar, J., Li, X., Sawhney,	Numerical Study	International Journal of	United States

			R. and Pradhan, N.		Production Research	
41	2016	37	Riley, J.M., Klein, R., Miller, J. and Sridharan, V	Questionnaire Survey	International Journal of Physical Distribution & Logistics Management	United States
42	2016	19	Mandal, S., Sarathy, R., Korasiga, V.R., Bhattacharya, S. and Dastidar, S.G.	Questionnaire Survey	International Journal of Disaster Resilience in the Built Environment	India
43	2018	10	Machado, S.M., Paiva, E.L. and Da Silva, E.M.,	Interviews based study	International Journal of Physical Distribution & Logistics Management	Brazil
44	2018	7	Treiblmaier, H	Contingency Theory and Grounded Theory approach	The International Journal of Logistics Management	Austria

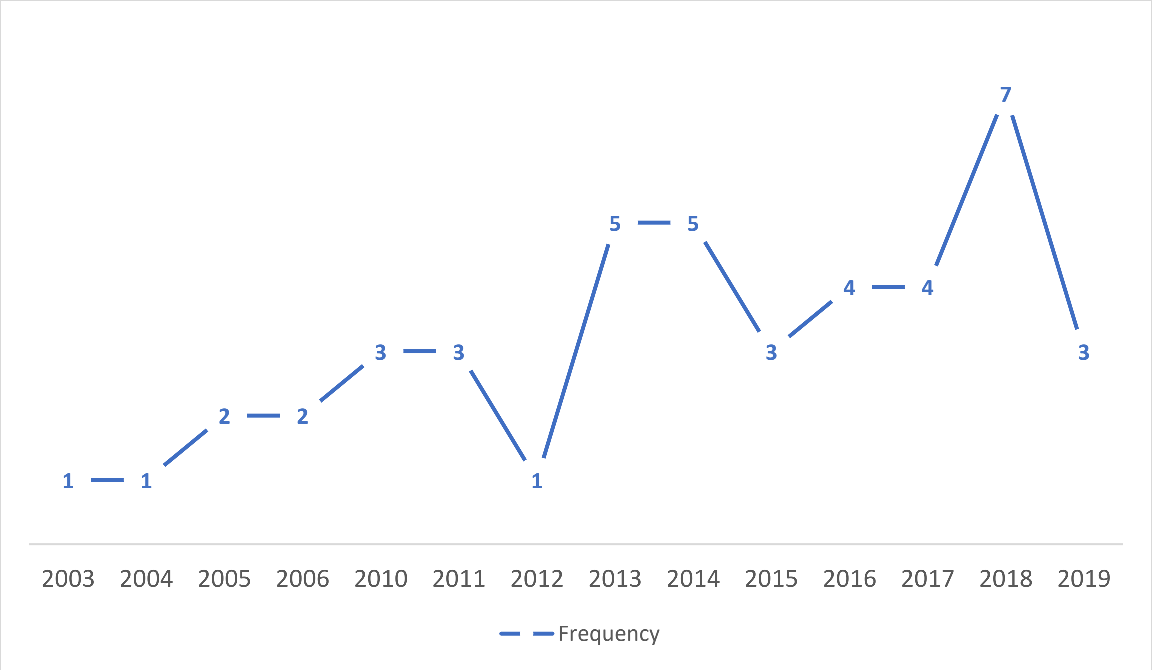
Results and Discussions

As explained in the previous section of the paper, 44 articles were finally selected as relevant for deeper examination after a two-phase systematic selection process. Thereafter the selected articles were examined as explained in more detail in the preceding section to achieve the aim of the study. Results generated from the content analysis process assisted to identify 58 capabilities for SCR in IC. During the thematic analysis of the variables, the authors categorised these capabilities under 12 identified constructs. These constructs include the capability factors which have identical relationships with the constructs by being part of common themes. This laid the basis for developing the conceptual framework of the capabilities in IC SCs. The articles were further analysed to determine the annual number of publications on the subject, publications based on countries of research focus, methodologies adopted and explications to the developed constructs including their constituent variables as explained in the succeeding sections of this article.

Trend of Publications on SCC Targeting Resilience

Figure 2 denotes the number of yearly publications on the subject matter researched in this study, namely SCC for resilient SCs from 2003 to 2019. Although the number of yearly publications remained steady from 2005-2010, the figures indicate a somewhat sporadic publication trend ranging from 1 (minimum) to 5 (maximum) after 2010. Therefore, it is noteworthy to state that less attention has been paid to the SCC related research studies over the past two decades, hence, these low numbers call for critical attention, research and development on SCC as well as highlight the need for more innovative research frameworks to achieve SCR.

Figure 2: Yearly research publications on capabilities in SCR from 2003 to 2019

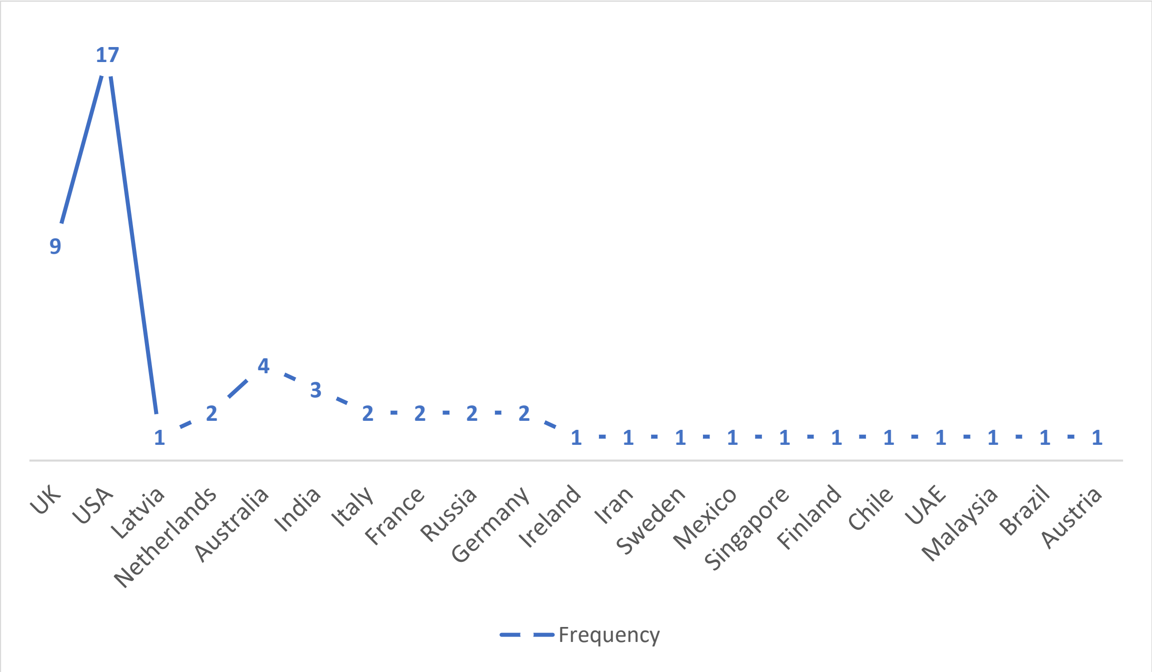


The maximum number of publications (7) were reported in 2018. Also, moving from the literature review and empirical studies, the research interests have broadened towards structural modelling, graph theory, system dynamics modelling, QFD modelling and fuzzy analysis. This may be because of the awareness gained by the academic researchers with the set of SCR related publications made by Pettit (2008); Pettit et al. (2010) and Pettit et al. (2013). After 2014, the researchers have focused more on mathematical modelling and simulation in SCC research by maintaining a similar research pattern. In fact, this pattern depicts the growing interest in exploring better approaches to deliver SCR related research for further knowledge development. However, there is a sudden drop in publications in the year 2015, and thereafter again the figures show a gradual increment in the number of publications. Hence, the results agree with the research findings of Bevilacqua et al. (2018), that is that the concept of SCR was broadly studied during the last few decades evidencing its importance towards the organisational performance. This is clearly evident in the management researches (Ali et al. 2017a), while the trend has been explored in the construction industry recently as well (Cui 2018) recently as well. However, only three articles which discuss SCC in the construction industry were found within the selected list of publications (Shahbaz et al. (2019); Zainal and Ingirige (2018) and Lim et al. (2011)). Therefore, the construction industry appears to be still lacking innovative practices in dealing with SC vulnerabilities despite a few ground-breaking advancements. Besides, there was no publication found on SCC in IC, hence spotlighting the long-neglected research gap that this study aims to fill. Although it appears that a specific research interest has not been previously triggered in IC itself that is until the present study that addresses this identified lacuna, all these 58 capabilities are more or less important in IC SCs over time and are therefore 'ripe' for appropriate application to improve SCR in IC.

Each selected paper in this study has explained the different research methodologies that the researchers followed in their respective studies when deriving the findings. These methods comprised empirical studies (19), literature reviews (6), case studies (4), and mathematical modelling and simulation (14). Empirical studies and the case studies were predominantly used in research studies targeting adequate and reliable data collection. Further, case studies have facilitated detailed contextual analysis of SCC by being specific to the special cases studied. Mathematical modelling and simulation were used in the studies to analyse these systems in a controlled environment to optimise their performance by means of SCR. Notwithstanding these published papers, the other papers were the literature reviews that have analysed the existing knowledge base of SCR.

From 2003-2010, the SCC concept was at its 'infancy' stage, and only two countries viz., the United States (USA) and United Kingdom (UK) paid attention to researching SCC. After 2010, the concept broadened its horizons and was applied in research studies conducted in many developed countries such as UAE, Singapore, Australia and many more as shown in Figure 3.

Figure 3: 'Capabilities in SCR' related research publications by country from 2003 to 2019



However, USA (17) and the UK (9) accounted for the highest number of publications in the SCC knowledge domain within the selected publications. This may indicate that developed countries have already launched some exercises if not initiatives, to develop SCC targeting resilience since these countries apparently value SCR and its associated benefits. Moreover, the emerging attention paid to SCC worldwide can be identified in Figure 3. This, obviously fosters more research studies on SCC and strengthens them in uplifting SCR. The primary lesson to draw from this analysis is that more research studies on SCC should be encouraged with the objective of developing pragmatic and innovative SCC to successfully deal with the alarming rate of SC vulnerabilities.

Identifying the research trend revealed in this study, it is expedient and encouraging to research on SCC in IC due to the following reasons; (a) IC supply chains are complex and vulnerable to a number of unforeseeable disruptions (Luo et al. 2018); (b) the IC SC is relatively fixed and unchangeable once setup (Zhai et al. 2015) hence the disruptions may generate the cascading impacts; (c) although the industry practises traditional RM approaches, they are unable to assess the SC complexities, and prepare the SC for future unknowns including black swan events and (d) there is, therefore, a need to determine the appropriate SCC to successfully withstand all these SC disruptions in IC. These reasons provide the basis for exploring the SCC associated with IC for enhanced SCR in a value-added supply chain.

Analysis of the SCC in IC

All the SCC identified from the 33 publications following the systematic analysis of the literature are presented in Table 3. 58 SCC were identified in total in the study. After a comprehensive screening out process, the authors identified 58 SCC which are relevant to the IC in total and excluded some of the capabilities such as part commonality, asset utilization, product variability reduction, deviation, near-miss analysis, and layered defences that are specifically relevant to the manufacturing industry.

Table 3: Citation frequency analysis of general capability variables for SCR

Nr	Capabilities	References	Frequency	Mean	COV	Rank
1	**Flexibility: Ability to quickly mobilise resources when required**		**85**	**9.44**	**0.68**	
	Multiple sources	[1] [2] [4] [7] [8] [10] [11] [14] [15] [19] [20] [21] [22] [23] [29] [30] [35] [37] [38] [39] [40] [42]	22			1

	Supplier contract flexibility	[1] [2] [5] [17] [19] [20] [28] [29] [30] [32] [35] [37] [39] [40] [42] [43]	16			2
	Alternate distribution channels/multimodal transportation	[1] [2] [5] [20] [28] [29] [30] [35] [37] [38] [39] [42]	12			5
	Risk pooling/sharing	[1] [2] [4] [7] [8] [10] [16] [20] [28] [30]	10			7
	Integrating inventory management with SCM tools	[1] [2] [16] [18] [27] [28] [33] [35] [37]	9			8
	Vertical integration	[14] [28] [33] [39] [41]	5			12
	Multiple uses	[1] [2] [5] [19]	4			13
	Production postponement	[1] [2] [28] [38]	4			13
	Modular product design	[1] [2] [37]	3			14
2	**Capacity: Availability of resources to enable continuous production**		**44**	**11.00**	**0.43**	
	Reserves capacity/inventory buffers	[1] [2] [7] [15] [23] [20] [21] [28] [29] [30] [32] [34] [35] [37] [38] [43]	16			2
	Backup facilities	[1] [2] [5] [15] [16] [19] [24] [27] [30] [32] [35] [40] [43]	13			4
	Redundancy	[1] [2] [7] [9] [14] [19] [20] [21] [35] [43]	10			7
	Backup energy sources	[1] [2] [29] [30] [32]	5			12
3	**Efficiency: Capability to produce outputs with minimum resources**		**22**	**5.50**	**0.79**	
	Waste elimination	[1] [2] [3] [4] [19] [25] [26] [28] [29] [32] [38]	11			6
	Labour productivity	[1] [2] [5] [19] [28] [29] [32]	7			10
	Product variability reduction	[1] [2]	2			15
	Failure prevention	[1] [2]	2			15
4	**Visibility: Knowledge of the status of current operating resources and the environment**		**28**	**7.00**	**0.76**	
	Products, assets, people visibility	[1] [2] [4] [7] [8] [9] [10] [30] [33] [38] [40] [42] [43]	13			4
	Efficient IT system & information exchange	[1] [2] [29] [30] [32] [33] [36] [38] [41] [43]	10			7
	Business intelligence gathering	[1] [2] [38]	3			14
	Finite capacity scheduling tools with procurement visibility/e-procurement	[18] [38]	2			15
5	**Adaptability: Ability to modify operations in response to disruptions or opportunities**		**35**	**4.38**	**0.52**	
	Fast rerouting of requirements	[1] [2] [5] [20] [29] [30] [33] [44]	8			9
	Learning from experience	[1] [2] [5] [12] [19] [20]	6			11
	Alternative technology development	[1] [2] [13] [16] [29] [43]	6			11
	Deploying IT based reporting tools	[16] [29] [30] [32] [33]	5			12

	Conducting parallel processes instead of series processes	[7] [19] [28] [38]	4			13
	Lead time reduction	[1] [2]	2			15
	Strategic gaming and simulation	[1] [2]	2			15
	Maintaining buffer time	[27] [34]	2			
6	**Anticipation: Ability to detect potential future disruptive events**		**43**	**6.14**	**0.51**	
	Risk management	[1] [2] [4] [5] [6] [7] [9] [30] [31] [34] [38] [43]	12			5
	Monitoring early warning signals	[1] [2] [19] [20] [29] [30] [43]	7			10
	Forecasting/predictive analysis	[1] [2] [19] [20] [29] [32] [37] [43]	8			9
	Quality control and checking defection	[1] [2] [29] [32]	4			13
	Cross training/intensive training	[14] [29] [30] [41] [43]	5			12
	Deploying tracking and tracing tools	[16] [30] [32] [43]	4			13
	Business intelligence and disruption management research	[10] [19] [30]	3			14
7	**Recovery: Ability to return to normal operational state promptly**		**18**	**6.00**	**0.17**	
	Consequence mitigation	[1] [2] [29] [30] [34] [43] [44]	7			10
	Communications strategy	[1] [2] [28] [29] [30] [43]	6			11
	Crisis management	[1] [2] [29] [30] [43]	5			12
8	**Dispersion: Decentralisation of resources and clients**		**10**	**3.33**	**0.17**	
	Distributed decision making	[1] [2] [33] [44]	4			13
	Distributed capacity and assets	[1] [2] [44]	3			14
	Decentralization of key resources	[1] [2] [44]	3			14
9	**Collaboration: Ability to work effectively with other parties for mutual benefit**		**24**	**4.80**	**1.23**	
	Collaborative information exchange & decision making	[1] [2] [13] [18] [20] [28] [29] [30] [32] [33] [37] [38] [40] [42] [43]	15			2
	Collaborative forecasting	[1] [2] [30] [38] [43]	5			12
	Public–private collaboration	[14] [43]	2			15
	Obtain more competitive price from suppliers and subcontractors	[17]	1			16
	Procure materials globally	[17]	1			16
10	**Market position: Status of an organisation or its services/ products in specific markets**		**32**	**6.40**	**0.45**	
	Close and healthy client-contractor relationships	[1] [2] [6] [14] [17] [28] [29] [32] [33] [37]	10			7
	Improve the quality of SC process	[5] [14] [17] [19] [20] [22] [23] [28]	8			9

	Improve delivery speed	[5] [17] [19] [20] [22] [23] [28]	7			10
	Brand equity of the organisations	[1] [2] [14] [29]	4			13
	Market share of the organisations	[1] [2] [5]	3			14
11	**Security: Defence against deliberate intrusions**		**8**	**4.00**	**0.00**	
	Cyber-security	[1] [2] [29] [32]	4			13
	Personnel security	[1] [2] [29] [32]	4			13
12	**Financial strength: Capacity to absorb fluctuations in cash flow**		**23**	**5.75**	**0.09**	
	Insurance	[1] [2] [22] [23] [29] [32]	6			11
	Financial reserves and funds	[1] [2] [17] [29] [30] [32]	6			11
	Price margin	[1] [2] [29] [32] [38] [43]	6			11
	Portfolio diversification	[1] [2] [28] [29] [32]	5			12

1=(Zainal and Ingirige 2018); 2=(Pettit et al. 2013); 3=(Mensah and Merkuryev 2014); 4=(Soni et al. 2014); 5=(Tang 2006); 6=(Bueno-Solano and Cedillo-Campos 2014); 7=(Christopher and Peck 2004); 8=(Jüttner and Maklan 2011); 9=(Scholten et al. 2014); 10=(Johnson et al. 2013); 11=(Lengnick-Hall et al. 2011); 12=(Kristianto et al. 2014); 13=(Scholten and Schilder 2015); 14=(Ali et al. 2017); 15=(Ivanov et al. 2017); 16=(Brusset and Telle, 2017); 17=(Lim et al. 2011); 18=(Vaidyanathan and O'Brien 2004); 19=(Sheffi and Rice Jr 2005); 20=(Peck 2005); 21=(Tomlin 2006); 22=(Dong and Tomlin 2012); 23=(Wang et al. 2010); 24=(Kim and Tomlin 2013); 25=(Panova and Hilletofth 2018); 26=(Wedawatta et al. 2010); 27=(Zavala et al. 2018); 28=(Chaghooshi et al. 2018); 29=(Chowdhury and Quaddus 2017); 30=(Chowdhury and Quaddus 2016); 31=(Ambulkar et al. 2015); 32=(Chowdhury and Quaddus 2015); 33=(Wieland and Wallenburg 2013); 34=(Colicchia et al. 2010); 35=(Purvis et al. 2016); 36=(Singh and Singh 2019); 37=(Shahbaz et al. 2019); 38=(Rajesh 2019); 39=(Gosling et al. 2013); 40=(Namdar et al. 2018); 41=(Riley et al. 2016); 42=(Mandal et al. 2016); 43=(Machado et al. 2018); 44=(Treiblmaier 2018)

In addition, Table 3 presents the relationship between SCC and the cited frequency of relevant citations in the selected papers. For instance, 'Multiple Sources' was the first ranking SCC factor as cited by the papers which includes 22 citation counts ([1] [2] [4] [7] [8] [10] [11] [14] [15] [19] [20] [21] [22] [23] [29] [30] [35] [37] [38] [39] [40] [42]). Similarly, all the relevant citations are stated in front of each capability in Table 3. The authors conducted thematic analysis as demonstrated by Owusu et al. (2017); Chan and Owusu (2017) and Owusu et al. (2018) to categorise all the identified SCC into 12 constructs namely; Flexibility, Capacity, Efficiency, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Market

Position, Security and Financial Strength. The results generated from the thematic analysis are further elaborated as follows.

Categorisation and Explanation of the SCC

The authors categorised all the 58 SCC into the aforementioned 12 constructs based on the study protocols and developments by Pettit (2008); Pettit et al. (2010); Pettit et al. (2013) and Zainal and Ingirige (2018) during their thematic analysis process. Pettit et al. (2010) identified 14 categories of SCC related to the limited brands in the manufacturing industry. Zainal and Ingirige (2018) developed 12 constructs by making the categorisation more specific to the construction industry, which also laid the basis for this current study. Both the previous studies have shared in common, the following capability constructs in their studies namely Flexibility, Capacity, Efficiency, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Market Position, Security and Financial Strength in their studies. This highlights the vitality of each construct considered in this study as the capability constructs. However, the study expanded the search limits targeting the IC SC and gathered 58 SCC for the new categorisation using a thematic analysis approach. Therefore, these SCC will now be addressing the SCR in industrialised construction, which is not explored in the previous studies. Therefore, this study specifically facilitates a significant contribution to the IC knowledge domain. A thorough analysis of each SCC was triggered, developing the main constructs, and these specifically formulated constructs along with SCC factors, serve as the extension to the body of knowledge specific to the SCC in IC.

Citation frequency analysis was conducted to indicate the relative importance of each construct (Chan & Owusu 2017 and Owusu et al., 2018). Hence, the total cited Frequency (F), Mean Score (MS), and Coefficient of Variation (COV) of each construct was calculated and presented in Table 3. The total of the frequencies of all the SCC within each construct was added together and divided by the corresponding number of variables – n, in deriving the MS of each construct. For instance, the MS of the 'security' construct was calculated as follows. Further, the construct which received the highest total frequency was considered as the most frequently cited SCC in the previous literature.

$$MS\ of\ 'Security' = \sum_{i=1}^{n} (fSecurityi)\ /n$$

i=1,2

Therefore, MS = (2+2)/2=2.00

Flexibility

Flexibility is the construct that denotes the ability to quickly mobilise resources when required. This construct was the most highly cited construct in the literature with 85 citation counts and 9.44 MS. Although this belongs to the highest total frequency, the construct reserves the second highest MS value due to the citation counts spread (from 22 to 3 with 0.68 COV) within the construct. According to Pettit et al. (2010), flexibility can be in sourcing or order fulfilment. Multiple sources, multiple uses, and supplier flexibility belong to the first category, whereas the other SCC in the constructs belong to the flexibility in the order fulfilment. According to the study findings of Badir et al. (2002), the delays in IC SC are due to the supply delays and shortage of raw materials. Having alternative suppliers/sources may be effective in dealing with such issues in IC. Most of the materials in IC systems in Malaysia are imported from developed countries and cause increased construction costs (Thanoon et al. 2003) hence calls for multiple sources of supply. In the context of SC flexibility, risk sharing, and pooling is also vital in IC supply chains as it is cited as the second highest ranking factor in this analysis. It is evident that some of the project teams used to share inventory holding costs (Zhai et al. 2018) as a result of risk impact sharing in IC. Lim et al. (2011) also highlighted some of the SCC relating to the flexibility that should be adopted in the construction firms to realise the benefits.

Supplier contract flexibility is also vital in construction projects (Zainal and Ingirige 2018) since there are many uncertainties associated with the supply and demand. This will avoid the unnecessary cost and time implications with the availability of easy modifications to specifications, quantities, and terms. However, decision parameters of supplier selection and employment of multi-supplier configurations are still needed to be formulated and analytically solved in the context of IC (Arashpour et al. 2017). Integrating inventory management with SCM was also considered as a SCC in the studies of Zainal and Ingirige (2018); Brusset and Teller (2017) Zavala et al. (2018) and Chaghooshi et al. (2018). Identifying the benefits allied with Zhong et al. (2017) suggested the possible integration of Building Information Modelling (BIM) and Radio Frequency Identification (RFID) in IC projects to manage IC SC effectively and efficiently. As vertical transportation has been identified as an issue in IC due to the transportation of heavy and bulky prefabricated units, the need for having alternative/multi-modal transportation is urged.

Further, since the IC SCs are highly vulnerable to transportation disruptions (Wang et al. 2018), this capability factor may be in high demand in IC. Having multiple capabilities at each location also adds flexibility to the SCs (Sheffi and Rice Jr 2005). Postponement of the production is also essential for a flexible SC (Chaghooshi et al. 2018) and it is even vital in the IC SC since on-site disruptions such as tower crane breakdowns (Blismas and Wakefield 2009) may lead to requests to postpone the delivery of prefabricated units to the site to mitigate the potential associated costs. In addition, modular product design with appropriate production plans and with the optimum outsourcing quantities is value added in IC (Hsu et al. 2017). Also, it is worth proposing vertical integration of supply chain configuration between logistics, on-site assembly, and outsourcing manufacturer under such circumstances (Hsu et al. 2017).

Capacity

Capacity is the availability of resources in the SC to enable continuous output in IC. This construct includes 4 SCC such as redundancy, backup facilities, reserves capacity/inventory buffers, and backup energy sources. This is the second highest frequency construct with an MS of 11.00, and 0.43 COV indicating the higher internal consistency of citation counts within the construct. One of the factors within the construct is ranked as the second in the overall analysis, which justifies the emerging attention of the researchers towards this construct. An organisation's ability to quickly recover from a disruption can be enhanced by achieving redundancy (Sheffi and Rice Jr 2005). According to the authors, it is important to maintain additional resources in reserve to be used during a disruption (Shahbaz et al. 2019). However, it is extremely important to determine the correct level of redundancy to avoid unnecessary cost implications. Since IC SCs are commonly vulnerable to tower crane breakdowns, transportation disruptions, low tolerance-linked problems in assembly and limited supply capacities (Blismas and Wakefield 2009), it is vital to maintain back-up facilities, safety stocks, and reserves. Besides, it has been evident that labor force on site spends considerable time waiting for prefabricated units, and the allied benefits of IC will wither away as a result (Zhai et al. 2018). If it can maintain adequate inventory buffers to hedge against SC uncertainty, profitable SCs can be realised by mitigating rearrangement cost and the tardiness penalty (Zhai et al. 2018). Further, standard operational research methods such as linear programming have been widely employed to optimise the size of the inventory buffers in IC since it is essential to avoid maintaining wasteful stocks (Arashpour et al. 2017). Maintaining adequate energy source backups is also suggested as SCC in the studies of Zainal and Ingirige (2018) and Pettit et al. (2013).

Efficiency

Efficiency depicts the SC capability to produce more outputs with less resources. Therefore, the construct includes the SCC of waste elimination, labour productivity, product variable reduction, and failure prevention. This construct belongs to the 22-citation frequency with 5.50 MS, and 0.79 COV. It also signifies the less frequent appearance of these capabilities in the literature and highlights the relative importance of conducting the research studies on these capabilities in future. According to the findings of Wong et al. (2003), IC enables lesser waste generation at the site. Also, the rate of reusability and the recyclability of wastage is higher in the IC (Begum et al. 2010). However, targeting these benefits in IC, it is vital to reduce the waste in IC SCs. Just-in-time management, adhering to lean construction principles, and the planning of industrial plants play a major role in such circumstances (Li et al. 2011). Improving labour productivity helps to improve the SC efficiency (Tang 2006). This is evident in Japanese and Swedish IC projects (Thanoon et al. 2003). However, low labor productivity and associated high costs have negatively impacted industrialised building production in Malaysia (Thanoon et al. 2003), hence the need for efficiency in resilient IC SCs. Product variability reduction and failure prevention are another two important SCC and come under the main construct of efficiency as cited by Zainal and Ingirige (2018) and Pettit et al. (2013).

Visibility

Visibility is referred to as having knowledge of the status of current operating resources in the SC and the SC environment. The construct consists of 4 factors with 28 citations frequency. By stressing the need for visibility in IC SCs, Zhong et al. (2017) proposed BIM and RFID enabled platform to achieve traceability and real-time visibility in IC. Besides, business intelligence gathering is another important parameter that asserts the visibility in SCs (Pettit et al. 2010). Further, it is vital to have an efficient IT system in IC SCs to bridge the existing gap between these IT systems used in design, prefabrication and on-site assembly processes (Čuš-Babič et al. 2014). Further, the integration of information flows and information mapping is possible with BIM-based construction (Čuš-Babič et al. 2014). In addition, paper-based documentation at the site is usually ineffective and difficult in terms of receiving quick responses, therefore, integrating promising IT namely bar code scanning, personal digital assistants (PDA), and data entry mechanisms are critical in improving the convenience and the effectiveness of construction SC visibility (Tserng et al. 2005). RFID and bar code reading facilitate promising visibility, via increased speed and accuracy of data entry in IC (Li et al. 2011). Hence, SCs of construction projects attempt to achieve efficient real-time data and information sharing by adhering to these techniques (Wang et al. 2007). Indeed, adapting BIM-based tools is extremely useful in achieving procurement visibility in construction projects whereas integrating BIM with Geo-Information Systems (GIS) is useful for logistical purposes in IC SCs (Irizarry et al. 2013). Also, Singh and Singh (2019) suggested big data analytics as a technique for building SCR. Therefore, this 'visibility' construct provides numerous advantages for improved resilience in dealing with disruptions.

Adaptability

Adaptability is the ability to modify operations in response to disruptions or opportunities. The construct received 35 total citations count with 4.38 MS, and 0.52 COV. This shows that less attention is paid on the SC adaptability in the literature. As the SCC can be for any kind of a project and/or organisation, it is beneficial to deploy lessons learnt to manage SCR (Peck 2005), develop alternative strategies/innovations to enhance the capability of dealing with SC vulnerabilities (Brusset and Teller 2017; Scholten and Schilder, 2015), employ fast rerouting of requirements (Peck 2005), conduct parallel processes instead of series processes as much as possible (Chaghooshi et al. 2018), and reduce the lead time of the activities and the processes (Zainal and Ingirige 2018). On the other hand, in IC, transportation and installation of the prefabricated units are risky. Unavailability of clear instructions for transportation and installation may cause SC disruptions, and therefore, the trials or simulation need to be conducted in a virtual environment prior to commencing the activities, so as to save costs and time (Li et al. 2011). These researchers also suggested that virtual prototyping helps mitigate the rework cost and time delays under these circumstances. In addition, to effectively dealing with disruptions, optimisation of precast production scheduling is extremely important. Therefore, the industry utilises advanced programming techniques such as constraint programming-based production scheduling and genetic algorithm-based production scheduling (Chan and Hu 2002). Deploying IT-based reporting tools also enables efficient information sharing between the supply chain members (Tserng et al. 2005) and can be a precursor to the resilient SCs in IC. Maintaining adequate buffer time between prefabrication and on-site assembly are beneficial in enhancing the adaptability of IC SCs (Arashpour et al. 2017). To derive the appropriate advantage over mitigating tardiness during delivery to the site, the contractor would request the order at an earlier due date from the prefabrication factory in IC (Zhai et al. 2018). Production lead time hedging, operational lead time hedging (keeping safety lead-time) were considered as effective ways to improve SC adaptability (Zhai et al. 2018; Zhai and Huang 2017). Also, transportation lead-time hedging is particularly required in IC SCs to mitigate the impact of transportation disruptions while contributing to win-win coordination between the SC members (Zhai et al. 2018).

Anticipation

Anticipation is the ability to detect potential future disruptive events in the SCs, and it is vital to enhance the preparedness to the enforceable disruptions. This construct consisted of 7 SCC with 43 total frequency and 6.14 MS. Industries including IC follow various RM practices in order to identify and contain SC disruptions since IC supply chains are vulnerable to the numerous risks throughout the prefabrication supply chain, from design, manufacturing, and logistics, to on-site assembly (Li et al. 2016). Further, IC SC risks are closely associated with the stakeholders involved in the SC. Therefore, it is necessary to identify the risks based on stakeholders in order to address these risks successfully (Luo et al. 2018). By identifying the importance of predictive analysis, many studies, including Hsu et al. (2017) attempted to predict the best production quantity and the schedule before the construction under demand uncertainty of IC. Further, Ambulkar et al. (2015) highlighted the importance of establishing a risk management infrastructure that manage both high and low impact SC disruptions. In addition, there is a tremendous need for intensive training of the SC members of IC to prepare for potential uncertainties, since a disruption at one point can trigger the failure of the entire SC. Besides, quality control and checking for defects also play a major role in anticipating the disruptions for SCR (Zainal and Ingirige 2018). However, very little attention has been paid in the construction industry to gather business intelligence via disruption management research to achieve SCR (Zainal and Ingirige 2018), whereas this is an imperative in IC, hence addressed in this study. RFID, as an automated data collection technology is a promising technology to efficiently track and trace the components in prefabricated construction SC (Demiralp et al. 2012). However, it is vital to apply a proper cost-sharing ratio that can be calculated based on the benefits received prior to enabling the RFID on-site (Demiralp et al. 2012). Moving ahead of the RFID technology, Irizarry et al. (2013) suggested integrated BIM and GIS tool, which tracks the status of the SC and provides warning signals to ensure the adequate delivery of materials.

Recovery

Recovery is another SC capability which can be considered as the ability to promptly return to a normal operational state. This construct includes 3 SCC, namely; communications strategy, consequence mitigation, and crisis management. Comparatively low citations frequency (18) in this category depicts the need for future research and development of the knowledge concerned. Maintaining a proper communication strategy during a disruption is highly significant to respond promptly to the situation, and it will assist in the prompt recovery from the disruption and the possible reduction of the impact (Zainal and Ingirige 2018). As a technique for 'consequence mitigation', the IC SCs currently follow the traditional RM strategies, which enables risk reduction based on the likelihood and impact (Li et al. 2016). This evokes and highlights the need for a proper consequence mitigation strategy specifically targeting resilience in IC that is based on the particular context, constraints and priorities in IC. As a suggestion for crisis and emergency response management in IC SCs, Irizarry et al. (2013) suggests employing IT technologies such as GIS and digital building information technologies.

Dispersion

Dispersion is the SCC which enables decentralisation of resources and clients. This construct has received the least attention among the academic researchers in focusing SCR and hence received the least citation count of 10 with 3.33 MS and 0.17 COV. However, Arashpour et al. (2017) asserted robust decision making to be critical in the advanced manufacturing of prefabricated products. Therefore, distributed decision making is essential in making optimised and timely purchasing decisions in IC SCs (Arashpour et al. 2017). Dispersion of the facilities at various locations is also significant in dealing with disruptions since they enable prompt availability of the facilities right after the disruption. Performance of a decentralised resources system is also needed in IC since the SC is usually hampered by supply chain uncertainties (Zhai et al. 2018) and the system could be further improved through coordinating the logistics processes which are operated by separated entities in the SC (Vrijhoef and Koskela 2000).

Collaboration

Collaboration is the ability to work effectively with the other parties for mutual benefit and considered as one of the important SCC measures in SCR (Pettit et al. 2013; Shahbaz et al. 2019). The total citation frequency of 24 along with the MS of 4.80 depicts the low attention paid towards the construct within the literature, although the construct is vital. Multi-party collaboration is vital in the SC of IC (Thanoon et al. 2003) during design, production, logistics, and the assembly and its absence may cause design errors and construction problems as usual disruptions (Arashpour et al. 2017). Therefore, Li et al. (2011) proposed virtual prototyping as effective and efficient collaboration and communication platform in IC SCs. Indeed, Zhong et al. (2017) presented an internet of things enabled BIM platform in their research to improve the collaborative data interoperability in the IC SCs. Therefore, these developments can be considered as the precursors to SCR. Apart from these considerations collaborative forecasting of the SC uncertainties (Pettit et al. 2013) and obtaining more competitive prices from suppliers and subcontractors (Lim et al. 2011) are also the SCC where the focus should be placed. Although globalised broader-based material procurement may be helpful in dealing with supply shortages in construction (Zainal and Ingirige 2018), it can generate additional cost implications as materialised in Malaysian IC (Thanoon et al. 2003). Therefore, the SC members should be careful in implementing this SCC measure in the projects. As the last SCC in this construct, public–private collaboration is essential for sharing disruption risks effectively in withstanding risk impacts as witnessed in Hong Kong prefabricated housing project developments (Li et al. 2018; Luo et al. 2015).

Market Position

Market position is the status of an organisation or its products/services in specific markets. The construct consisted of 5 SCC, and the total citation count of the construct was 32 with 6.40 MS and 0.45 COV. This signifies the relatively higher importance assigned to these SCC in the previous literature. Improving the quality of SC processes ranked as the 9th highly cited factor with 8 citation counts ([5] [14] [17] [19] [20] [22] [23] [28]) and highlighted the relative importance of the factor. Improving the quality of SC facilitates positive outcomes during uncertainties, and it is quite evident in the prefabricated homes constructed in Japan (Noguchi 2003). Maintaining close and healthy client-contractor, sub-contractor, supplier relationship is very important in avoiding the SC stakeholder associated risks (Lim et al. 2011) and hence, Xue et al. (2005) proposed an agent-based multi-attribute negotiation system to coordinate contractors in a construction SC. In addition, the brand-equity of an organisation resembles its reputation among the stakeholders. Having good brand equity helps to resist any market pressures and market competition. Therefore, Ali et al. (2017) identified brand equity of the organisation as a SCC towards resilience. As the market share increases, a higher level of profits is achievable in IC SC and facilitate adequate competency to resist market competition and withstand SC risks (Han et al. 2017). Therefore, achieving a good market position by an organisation in the construction industry should contribute to the capacity to successfully withstand market pressure, economical vulnerabilities and market competition.

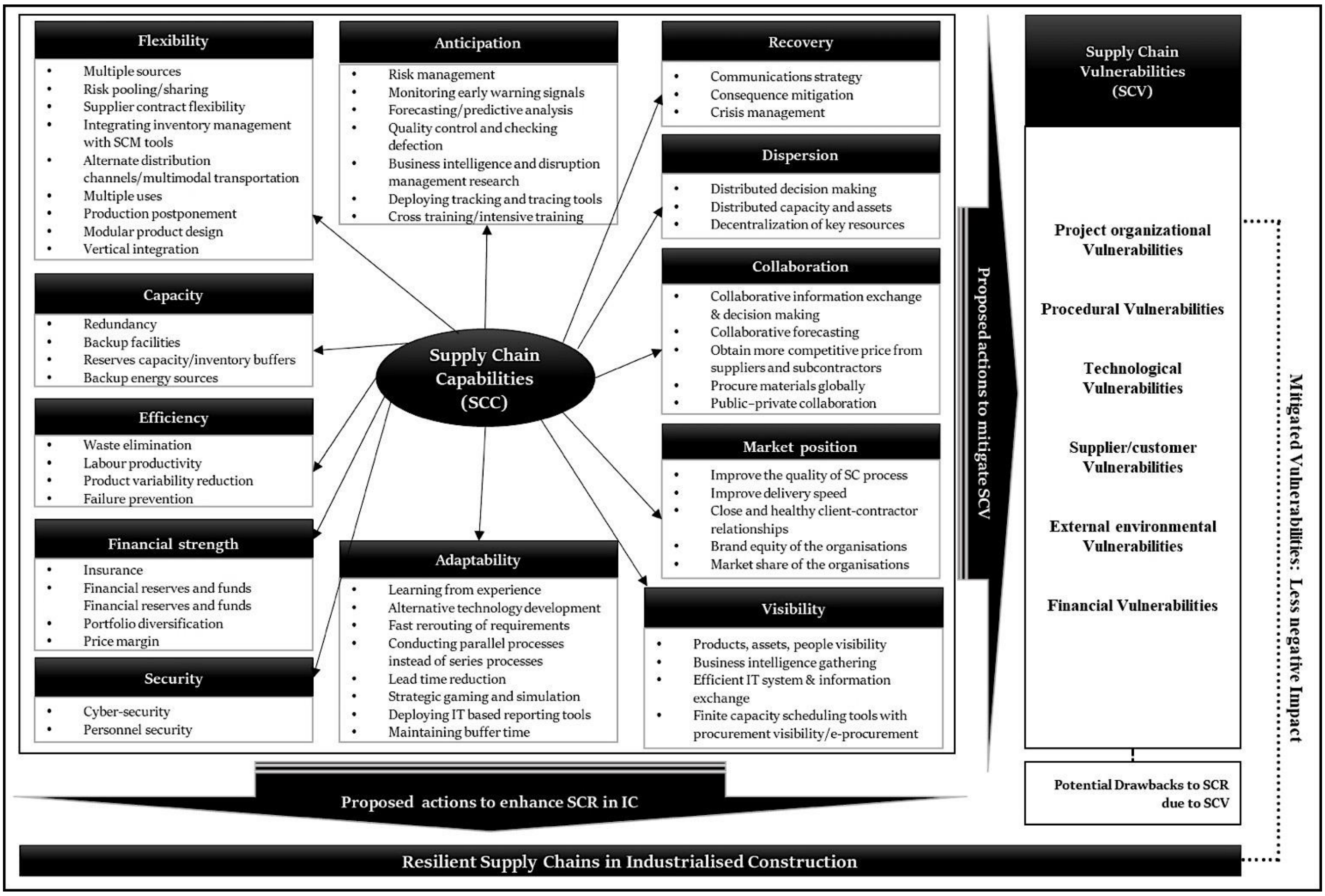
Security

Security is the SC ability to defend against deliberate intrusions. The category includes 2 relevant capability measures such as cybersecurity and personnel security, with the least citation frequency of 8 and highlights the long-neglected gap of research in the knowledge area. Although BIM is suggested to be used as a method to enhance information sharing, visibility and traceability of the IC as SCC, one of the main challenges faced here is enabling cybersecurity (Ghaffarianhoseini et al. 2017). However, in order to avoid the risks of unauthorised access to the data and copyright infringement, it is extremely important to apply appropriate cybersecurity to the SC information, data sharing and use. Taken as a safe construction method, IC facilitates improved safety (Wong et al. 2003). However, IC SCs become vulnerable to personal safety hazards when installing prefabricated components (Li et al. 2011). Since most of the precast members are heavy and bulky, special attention is required during the installation. The workers cannot fully understand the process if the installation programme is not clear, and hence, accidents such as collisions are likely to occur. Further to the findings of Li et al. (2011), the most common type of injury in IC is a fracture, and the most common cause of hazard is fall due to the unstable structure. Therefore, providing adequate personal security such as securing fall protection systems during on-site assembly of components, and developing training programmes and standards focused on IC will be extremely important significant in mitigating safety-related risks and withstanding related disruptive situations (Fard et al. 2017).

Financial Strength

Financial strength is also another required SCC to withstand SC vulnerabilities. It represents the capacity to absorb fluctuations in the cash flow. This construct includes 4 SCC with a total of 23 citations count. This SCC area is also another less explored area in research where greater attention is required. Insurance and contingencies (price margin) are the assurance and other techniques used to recover and absorb losses after any disruption, also considered as the SC capabilities (Dong and Tomlin 2012 and Wang et al. 2010). Therefore, these aspects are considered in the sustainability decision making criteria of construction projects as well (Sharafi et al. 2018). Indeed, standard protocols in contracts require insurance coverage of items in storage on and offsite including during the transit journeys to the site in IC SCs as a mechanism for timely and assured delivery of construction outputs while minimising and containing disturbances (Fateh and Mohammad 2017). As further explained by these researchers, 'all the unfixed material offsite should be insured against loss or damages to their full value starting from the fabrication process, storing period, and until delivering it to the site' according to the JCT 2011. On the other hand, maintaining a healthy cash flow by keeping financial reserves and funds is important to improve the maturity of the IC market (Hong et al. 2018) and will result in improved SC performance despite uncertainties (Zhai et al. 2018). In addition, implementing strategic partnerships can support portfolio diversification in construction SCs (Said 2015), and it will lead to the SCR (Chaghooshi et al. 2018).

Figure 4: Proposed Action Framework for achieving SCR in IC



Envisaged Action Framework for Achieving SCR in IC

The results derived from the systematic analysis of literature on SCC were drawn upon to develop the proposed framework in Figure 4. As identified in the previous literature (Ekanayake et al. 2019), there are numerous vulnerabilities namely Project Organizational; Procedural; Supplier/customer; Technological; External Environmental; and Financial Vulnerabilities that retard the performance of IC SCs. In order to successfully withstand these vulnerabilities, there is a dire need for 'counteractive' capabilities (Kurniawan and Zailani 2010). The literature review presented in the current paper identifies a suite of SCC. Therefore, it is proposed as timely to investigate the dynamics of SCC that can address the vulnerabilities in IC SCs through a suite of counteractive capabilities as proactive initiatives to reduce any negative impacts from the corresponding vulnerabilities as illustrated in Figure 4. In this respect, the envisaged action framework to achieve SCR in IC was carefully developed by consolidating and generalising the current literature findings accordingly. This proposed framework would provide pointers and add value to IC SC stakeholders in formulating a set of capability initiatives to boost SCR, hence enhancing SC performance and productivity.

Future Directions

Apart from identifying a suite of SC capabilities to enhance SCR in IC, as well as a proposed framework highlighting the different constructs of capabilities in IC, this study also lays the foundation for future empirical research and development of a more stringent framework of capabilities and initiatives. The variables within each construct should be evaluated and validated for IC using subject matter expert surveys and case studies. It is also proposed to conduct deep investigations of the developed constructs across IC to identify project specific capabilities based on the precise strength and the intensity of each construct. To academic researchers, although the developed constructs can be considered as the core categorisation of capabilities relating to the IC, more specific findings can be elicited by conducting empirical surveys covering different cultural dimensions. Industry practitioners can consider this as a basic guideline for enhancing appropriate capability measures in their organisational capacities. The findings can be mapped with the organisational vulnerabilities, and an appropriate ‘targeting’ of vulnerabilities through corresponding capabilities could be investigated in a future research exercise. Further, this serves as a basis for the later development of a detailed SCR framework in IC.

Research Limitations

This study was limited to identifying capabilities under the main knowledge domain of SCR. Therefore, it is difficult to make strong empirical justifications in this stage of the study except as reported in the articles that were taken into consideration in this study, although all possible efforts were made to achieve full relevant coverage. Therefore, this study identifies capabilities and elicits capability constructs based on their categorical strength with the allied capability factors and then necessarily generalises the findings to provide a broad foundation for supporting future developments. It also suggests some scientifically derived basic capability constructs, although these are not yet verified. Moreover, the study facilitates an important over-arching overview of the knowledge domain and serves a valuable contribution.

Conclusions

Having noted a gap in research and shortfalls in practice in identifying specific SCC in IC SCs, this study attempted to review and draw on relevant examples of SCC that have been previously pursued in different industries to withstand numerous SC vulnerabilities. Given the increasing use of IC worldwide e.g. the surge of 'modular' construction in many countries, this study set out to cross-refer relevant identified general SCC with IC SCs and IC SCV, and hence, provide both academic researchers and industry practitioners with a comprehensive list of potentially useful SCC to be incorporated into their future studies and practices that target enhanced SCR. Global SCs have been disrupted by several high-profile events over the recent years and have generated severe impacts on SC performance of many industries. Although organisations adopt numerous RM strategies to reduce the level of vulnerability to SC disruptions, the approach is not effective in withstanding all the potential risks. Therefore, the construction industry was looking for a mechanism to withstand these disruptions successfully, and the emerging concept of resilience and SCR suggested an appropriate direction. SCR targets identifying and overcoming SC vulnerabilities with appropriate capabilities. IC, as an increasingly appealing technology, has re-emerged in the construction industry recently, targeting improved efficiency, flow and the quality of construction SCs. Nevertheless, IC SCs are also vulnerable to numerous types of disruptions. However, previous research focusing on handling these disruptions in IC is very limited, and only a few publications were found to support even the SCM in IC. Therefore, to bridge this long-neglected research gap, this study was designed to conduct a systematic review of the various identified SCC over the past few decades. 58 SCC were identified by analysing 44 selected articles in this study. These articles were comprehensively analysed to determine the number of publications annually, publications by country, methodological approaches followed in the previous research studies, and thematic categorisation of SCC. The results found 2018 to be the year with the highest related publications, while the USA was the country that contributed to the highest number of relevant publications. Following the thematic categorisation process, a proposed framework for targeting SCR in IC was developed, including 12 SCC constructs. Both the identified SCC and the developed constructs facilitate an overview of SCC to enhance possible future developments of SCR in IC and provide a platform for further empirical studies. Finally, this study unearths and provides a useful body of conceptual and experiential knowledge for academia and industry to instigate deeper research and development on SCR in IC, in order to achieve enhanced SC performance that can reasonably withstand potential disruptions.

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