A Decade of Engineering-to-Order (2010-2020): Progress and Emerging Themes

Abstract

In 2009 a literature review on supply chain management in Engineer-to-Order (ETO) situations was published in the International Journal of Production Economics (Gosling and Naim, 2009). The paper has received more than 200 citations from over 100 international journals. The ETO body of knowledge has been particularly relevant to those seeking to mobilise operations and supply chain concepts within the context of complex innovative engineering work. These are all increasingly pressing concerns for many organisations in the contemporary global economy; hence, it is timely to revisit this body of knowledge. Consequently, this study performs a systematic review of the last decade (2010-2020) ETO studies to identify the major advances revealed and develop a future research agenda. The results show that literature, over the last decade, presented new emerging trends related to: (i) ETO definitions through conceptualisation of the engineering flows and integration of engineering/production flows via the two-dimensional decoupling point; (ii) strategies for decoupling positioning, supply chain integration, planning and control, uncertainty/risk management, industry 4.0, exploration of new business models and system design, design automation and engineering management in ETO situations; (iii) applicability of lean within ETO situations. Finally, the paper suggests guiding research questions in relation to linkages between different disciplinary areas, evaluation of the application of new technologies, guidance for managing transitions between decoupling configurations and understanding of the new servitisation trends in ETO situations. In conclusion, the study highlights four research challenges to address: positive science challenge, comparative research challenge, multidisciplinary research challenge, and prescriptive research challenge.

Keywords. Engineer-to-order; Supply chain management; Operations management; Systematic literature review; Content analysis

1 Introduction

Engineer-to-order (ETO) situations relate to all the companies that are involved in the design and production of customised products such as construction projects, shipbuilding, and machine tools. This often results in an environment where there is complex engineering work, novel design work, and new supply chain processes to be established, possibly leading to one-of-a-kind or first-of-a-kind scenarios. The body of knowledge relating to ETO situations has been gathering pace over the last decade (2010-2020), and there has been much interest in the area as project-based firms seek to better understand how mainstream operations and supply chain management concepts can be adapted to better suit their needs, and high value manufacturing firms seek to better understand innovation processes.

It is 10 years since the publication of the Gosling and Naim (2009), a literature review published in the International Journal of Production Economics to define the fundamental characteristics of supply chain management in ETO situations and connect a fragmented knowledge base for use by ETO researchers and practitioners. Since then, there have been a range of PhD projects, university collaborations, funded projects, and published papers and books, building directly on this work and developing our understanding of ETO situations. There have also been multiple special tracks across different conferences, including 'INCOM' 2018 (iFAC proceeding), 'EurOMA' 2014 – 2019, 'Mass Customization and Personalization Conference – MCPC' 2017 (Springer proceeding), 'International Working Seminar on Production Economics' 2020.

Hence, it is timely to revisit the ETO body of knowledge to understand the progress that has been made since Gosling and Naim (2009) and provide future research directions. The main aim of this paper is, therefore, *to present a review, including a descriptive and thematic analysis, of the studies that addressed the supply chain management research area in ETO situations between 2010 and 2020, identifying the main patterns, themes, and major advances in ETO research revealed over the last decade, and to develop an agenda to guide the next decade.*

2 A decade of engineering to order: revisiting the body of knowledge

Gosling and Naim's (2009) review focused on ETO situations for a number of reasons. First, the few authors that had focused on supply chain management had outlined some of the challenges of working in ETO situations, but from very different industrial perspectives, disciplines, and discourses. Hicks et al. (2000) outlined ETO as a strategic manufacturing issue for operations and supply chain scholars to consider, whereas construction management researchers were seeking to establish the right supply chain approach for construction projects (Briscoe and Dainty, 2005). The knowledge base was, therefore, fragmented. Second, building on earlier manufacturing strategy theory (e.g., Hayes and Wheelwright, 1984; Hill, 1993; Skinner, 1974) pointing towards the need for focus and alignment across markets, products and processes, there was much debate about getting the right supply chain for different products and services (Fisher, 1997). It was not clear what was right for ETO situations, or the extent to which assumptions and best practices from more mainstream operations and supply chain (for example, automotive and retail) hold in the ETO situations. Fortunately, decoupling point frameworks had become available to use as a basis to facilitate debate and discussions about what was suitable for different situations (Naylor et al., 1999; Olhager, 2003; Wikner and Rudberg, 2005).

The 2009 review identified 91 papers based on a structured key search approach, identifying a wide range of studies addressing ETO issues. Papers were organised in response to 4 research questions, as per table 1. To answer these questions, papers were categorised across three interconnected literature streams (which we explain in more detail in our method section). The key focus was to establish underlying characteristics and definitions of ETO situations, the strategies that have been employed to improve supply chain management in ETO situations, and the methodological approaches evident in the literature. An additional question, relating to lean and agile, was included as a separate stream, as this was a very topical debate at that time.

Research Question	Key Findings	2009 Call for Future Research	Number of papers
What are the unique characteristics of the ETO?	-Production flow in an ETO supply chains is all driven by actual customer orders. -The decoupling point is located at the design stage. -Several types of ETO supply chain organisation exist	-Research relating potential ETO sectors to the wider ETO body of knowledge. -The application of decoupling strategies in the design phase. -Greater exploration of ETO types	35
What strategies have been proposed to improve performance in the ETO sector?	-Shift between structures -Supply chain integration -Information management -Systems engineering -Flexibility, Time compression -NPD improvement	-Research identifying synergies and trade-offs between different strategies	64
How do lean and agile paradigms relate to the ETO sector?	-Lean, agile and leagile strategies can be mapped onto supply chain structures to help determine their applicability. -Both lean and agile strategies have been proposed but there is no clear answer regarding their applicability.	-More empirical evidence relating to lean and agile paradigms in ETO	45

What methodological approaches have been utilised to study ETO supply chains?	-Dominance of conceptual and case study approaches. -Lack of survey-based research	-Greater large-scale empirical research, and range of methods.	86

[Table 1 near here]

The world has changed significantly over the last decade. Advances in Information Technology have transformed our interactions with each other. This presents challenges and opportunities for interacting with customers, and across the supply chain. The need to innovate has also become more intense, making innovation processes and highly engineered solutions a pressing concern for companies (Tiedemann et al., 2019; Zennaro et al., 2019). Evidence from the machinery industry suggests that global competition has also made competitive trade-offs more difficult to management for different industrial clusters (Cannas et al., 2020a, 2019). As a result, some governments and industry forums have taken strategic initiatives to improve the competitiveness of companies operating in ETO situations and promote best practice. For instance, encouraging engineering work to move away from transactional to more collaborative enterprise models (Source: Institution of Civil Engineers, UK), and boosting digital innovations in the machinery industry through Industry 4.0 national plans (Source: Ministry of Economic Development, Italy). The findings and agenda for future research, as summarised in table 1, give a platform to considering the progress made over the last decade. We are particularly interested in the extent to which the calls for future research have been satisfied, or whether new themes and trends have emerged.

During this time, relevant literature reviews have been published that help inform and give context to the current review. Dekkers et al. (2013) provided a review on the important interface between 'product design and engineering' and manufacturing. Their review focuses on a discussion of several themes, including order entry points and modularity, product life cycle management, sourcing decisions and supplier involvement, integrated processes and coordination, and enabling through information and communication technology. Their review was specifically targeted at better understanding the engineering-production interface across different production situations in general, and not only focused on ETO situations. We agree that this is a critical interface but are more directly concerned with the ETO body of knowledge.

Zennaro et al. (2019) have reviewed the literature relating to ‘big size highly customised products’ in make-to-order and ETO situations, clustering the literature under the topics of specification processes and product design, production planning and control and project portfolio management. Their primary keyword search focused on size and shape, as opposed to ETO, and, hence, their results reflect these physical systems, identifying ergonomics and space (for example) as key considerations. This adds considerably to our understanding of large physical systems, and the space management issues that become a priority, but it is possible that ETO research may relate to many contexts outside of this narrow focus.

Denicol et al. (2020) reviewed the megaprojects literature to study the causes of poor performance and success factors, suggesting five routes for future research: designing the system architecture, bridging the gap with manufacturing, building and leading collaborations, engaging institutions and communities, and decomposing and integrating the supply chain. This provides a useful link with the project management literature, and we return to this link later in the paper. Tomašević et al. (2020) addressed the investigation of the available research on lean in high complex and low volume industries. They are primarily concerned with understanding the application of lean thinking in such environments, which are similar, but defined according to slightly different frame of reference. They underlined that existing studies focused mainly on practice with little attention to theory development, variability management and buffering concepts. This review was particularly useful for revisiting the applicability of lean and agile in ETO situations. Finally, recently, Tiedemann (2020) addressed the study of the relations among different demand-driven supply chain management strategies (segmentation, leagility, customization, transparency, postponement), showing the effects that different decisions have on operational performance.

These reviews have informed our approach, but the key purpose here is to evaluate the progress made since Gosling and Naim (2009) in better understanding supply chain management in ETO situations. Hence, we deploy a systematic review of papers related to this research area, and the method is explained in detail in the following section, to assure transparency and increase the replicability of the research (Thomé et al., 2016).

3 Method

This study systematically reviews the papers that addressed the ETO research area between 2010 and 2020. The systematic literature review (SLR) applies a rigorous and well-defined methodology to the review process of existing studies in literature for answering to specific research questions. As explained by methodological references in the literature (Bearman et al., 2012; Thomé et al., 2016; Tranfield et al., 2003) and done by recent review studies (Noroozi and Wikner, 2017; Pereira et al., 2020), the SLR methodology employed in this study consisted of four different steps: (i) formulating the problem: to plan the review by identifying the current literature needs, the research scope and the research questions; (ii) literature searching and sampling: to select the studies for the review by evaluating the existing contributions through a comprehensive search strategy, the definition of inclusion and exclusion criteria, and the screening of the articles; (iii) data analysis, synthesis and interpretation: to conduct the review by analysing and synthetising the data of the included studies, and making an interpretation that make possible to answer to the research questions; (iv) presenting results: to report the evidence building on the main findings in a way to clearly show what is and what is not known about the topic analysed. The authors paid maximum attention in following these research steps, to ensure reliability and validity of the results. Also, the transparency and replicability of this study is fundamental. Therefore, a careful documentation of each step of the study is provided in the following sub-sections.

3.1 Formulating the problem

Building on the research scope presented in section 1 and the background of this study presented in section 2, the authors defined a set of clearly framed research questions (RQs) to focus the study and guide the review of the literature.

The first research question addresses the understanding of the progress made over the last decade by studies related to supply chain management in ETO situations. Gosling and Naim (2009) categorised the literature into 3 streams: ETO definitions, ETO strategies, and ETO lean and agile paradigms. However, the last decade (2010-2020) has seen many changes to the business environment, and there have been many studies that aimed to expand the ETO body of knowledge. Hence, we frame RQ1 as follows:

RQ1: "What themes, patterns and evidence relating to supply chain management in ETO situations emerge over the last decade (2010-2020)?".

An important role of literature reviews is to develop future areas of research to a specific topic (Hart, 2018). Based on the results of the literature analysis, there is a need to understand the research challenges and future research questions for supply chain management in ETO situations to establish a new research agenda that is suitable for the next decade (2020-2030) and beyond. Hence, we frame RQ2 as follows:

RQ2. "What are the future research challenges and questions regarding supply chain management in ETO situations for the next decade (2020-2030)?".

3.2 Literature searching and sampling

3.2.1 Citing papers

The first step of the literature searching has been performed directly via a link on the paper's URL to the Scopus and Web of Science databases of all the papers making citations. The timeframe within which the literature was selected and analysed has been the last decade 2010-2020, including all the papers that cited Gosling and Naim (2009) to date. In total, 227 citations were identified. The first step of the review was the definition of the criteria for paper inclusion and exclusion, to limit the full-text reading process to a sample of papers linked to the research scope. A comprehensive and unbiased search strategy was applied, based on well-defined selection criteria (Tranfield et al., 2003). The exclusion criteria applied were the followings: (i) the language was limited to English, obtaining 225 papers; (ii) the source type was limited to 'Journal', i.e., peer-reviewed journals, so to narrow the analysis based on the most up-to-date sources of information that assure the quality of the citations (Cronin et al., 2008; Lin et al., 2017), obtaining 130 papers; (iii) titles and abstracts were screened to exclude papers that cite Gosling and Naim (2009) only as a reference for the SLR methodology and were not related to ETO (in total, 19 papers); (iv) full texts were screened to exclude papers that simply give a passing reference to add value to an argument that is not subject of the citing paper (in total, 12 papers). In total, we obtained 99 papers as final sample for the review.

3.2.2 Keywords searching

Additionally, for completeness, it is possible that there are very relevant papers that did not cite Gosling and Naim (2009). Therefore, the second step of the literature searching consisted of a keyword search through Scopus and Web of Science databases. We approached this second step following the methods proposed by recent SLRs published by International Journal of Production Economics (e.g., Masae et al., 2020; Zhang et al., 2020). First, to facilitate the searching for relevant works, the authors defined keywords that describe the subject of this paper, using keywords that expressly denote ETO situations. The final list of keywords included "engineer to order" or "engineering to order" or "ETO". The papers found in the database search were added to the existing citation database if they had one of the keywords selected either in the title or the abstract or the list of keywords. The number of studies identified through this search were 6,452. Then, the authors applied the following exclusion criteria: (i) the language was limited to English, obtaining 5,845 papers; (ii) the source type was limited to 'Journal', i.e., peer-reviewed journals, so to narrow the analysis based on the most up-to-date sources of information that assure the quality of the citations, obtaining 5,025 papers; (iii) publishing year was limited to the time period 2010-2020, in line with this study goal, obtaining 2,314 papers; (iv) titles, abstracts, and full text were screened to exclude papers that were not related to the main scope of this literature review, i.e. papers not contributing to theory and practice in the field of supply chain management in ETO situations. In total, we obtained 110 articles as final sample for the review.

Finally, a merge of the two list of articles obtained in the first searching step, i.e., citing papers, and the second searching step, i.e., keywords searching, has been made, and 52 additional papers were identified as not part of the citing papers and were included to the analysis. Thus, in total, 151 papers were read and analysed.

3.3 Data analysis, synthesis and interpretation

The 151 papers selected were reviewed by the authors, based on their full text, first, through an individual review and analysis, and, secondly, through a group brainstorming, to align the interpretation and avoid possible biases and errors. The methodology applied for the analysis has been the content analysis approach, as suggested by Seuring and Gold (2012). This study followed a two levels analysis: the first level examines the content of texts by conducting a descriptive analysis, to check literature descriptors related to the evolution of literature studies over the years; whereas the second level examines the latent content of the text by means of a thematic analysis, to make a qualitative interpretation of arguments and extract complex information. The descriptive and thematic analyses have been based on a set of analytic categories used for classifying the reviewed papers. The analytic categories, presented in table 2, were defined before to start the analysis, by following a deductive approach that assures the validity of the results, building on the existing theory to identify clear definitions as an aid for the discussion within the research team.

Category	**Subcategory**	**Definition**	**References**
Research methodology	Qualitative field research	Observe social behaviour and understand phenomena through case study or focus group	This category has been labelled, according to the fundamentals of social research (Babbie, 2013; Hays, 2004) and operations and supply chain management research (Bertrand and Fransoo, 2002; Coughlan and Coghlan, 2002; Meredith, 1998; Seuring and Gold, 2012),
	Action research	Participate in social behaviour, be part of the phenomena analysed and learn from it	
	Survey research	Collect data from a sample of competent respondents, and statistically analyse them to generalise results from a population	
	Quantitative data analysis	Develop mathematical models to explain the behaviour of real processes or capture real decision-making problems	
	Evaluation research	Model and understand realities by means of computer simulation	
	Literature review	Map, consolidate and develop theory of a certain research area	
	Conceptual study	Conceptualise models and frameworks by observing and analysing already existing information on a given issue	
Literature stream	ETO definition	Contribute on the understanding of the different types of ETO supply chain organisations based on the study of the decoupling point strategies and the	This category has been labelled according to the Gosling and Naim

		engineering activities performed to order.	(2009) literature streams
	ETO strategies	Focus on strategies or performance improvement techniques specifically for ETO supply chains regarding: (i) shift between supply chain structures; (ii) supply chain integration; (iii) information management; (iv) business systems engineering; (v) flexibility; (vi) time compression; (vii) new product development process improvement.	
	ETO lean and agile	Address the understanding of boundaries, definitions and applicability of lean and agile in ETO supply chains.	

[Table 2 near here]

4 Descriptive analysis

Figure 1 shows the distribution of the 151 papers selected over the period analysed and the research methodologies applied by the studies.

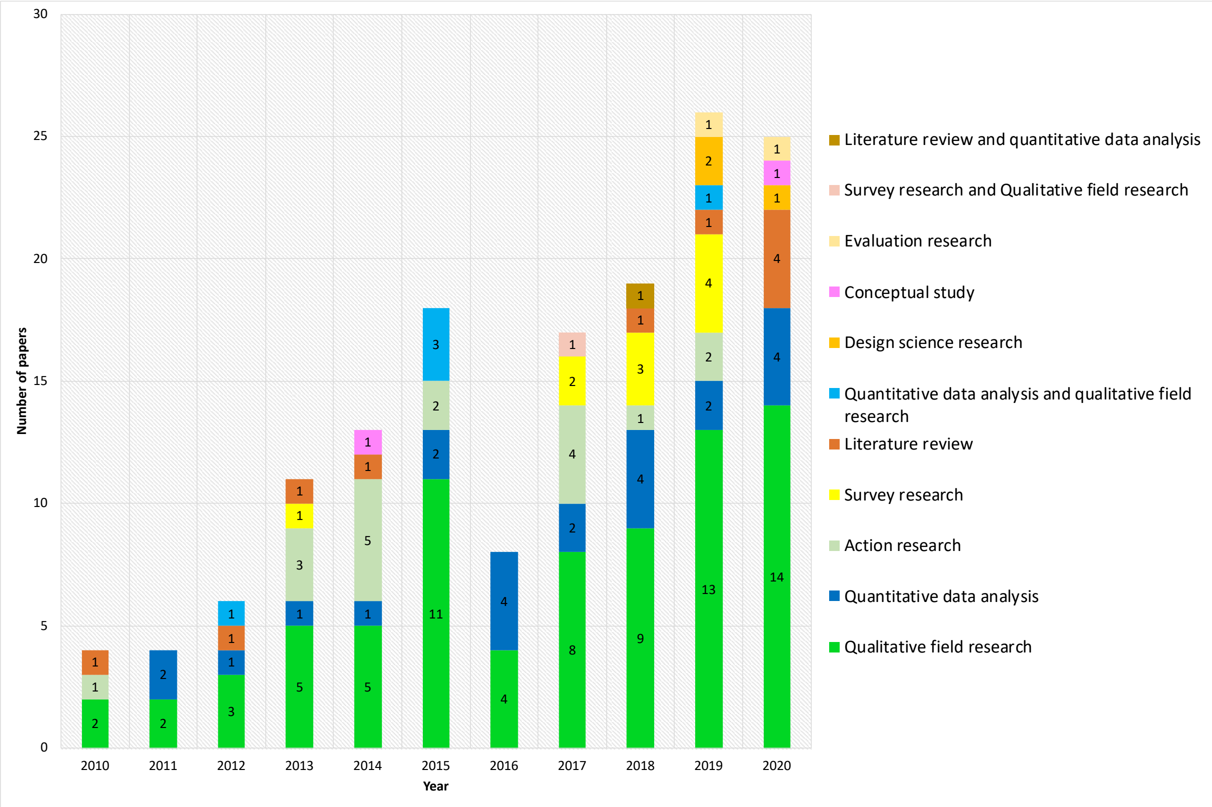

Figure 1. Temporal distribution of the papers divided by research methodology applied

In Gosling and Naim (2009), there was a predominance of conceptual and case research, and a noteworthy lack of survey research. It is possible to see in figure 1, that the most common method applied over the last decade is still qualitative field research (76 papers), followed by an interesting increased number of studies related to quantitative data analysis (23 papers), action research (18 papers), survey research (10 papers), literature review (10 papers), and mixed quantitative and qualitative studies (5 papers). Qualitative field research has been mainly characterised by multiple case study research and single case study research, quantitative data analysis is especially employed with the application of optimization models, and literature review is usually related to systematic literature review methods. Only 2 papers recently conducted a conceptual study. Whereas, recently, some alternatives methods were introduced, such as evaluation research (2 papers), mix of survey and qualitative research (1 paper) and mix of literature review and quantitative analysis (1 paper). Also, through the iterative inductive category refinement, one research methodology category has been added: 'design science research' (3 papers), which aims to prescribe new solutions (e.g., innovative artifacts, models, methods) to empirical problems by implementing changes in close collaboration with an organization (Järvinen, 2007; Sein et al., 2011). It seems that, in more recent years, changes are affecting the ETO research field in terms of research methodologies. Indeed, especially in 2019 and 2020, the number of alternative methodologies applied is increasing, and the distribution is becoming more homogenous compared to the previous years.

For the streams, the one that was major object of interest of the papers selected has been 'ETO strategy', with a total of 119 contributions, whereas the 'ETO definition' stream received 11 contributions and 'ETO lean and agile' received 21 contributions. Figure 2 shows the sector analysis across the three streams.

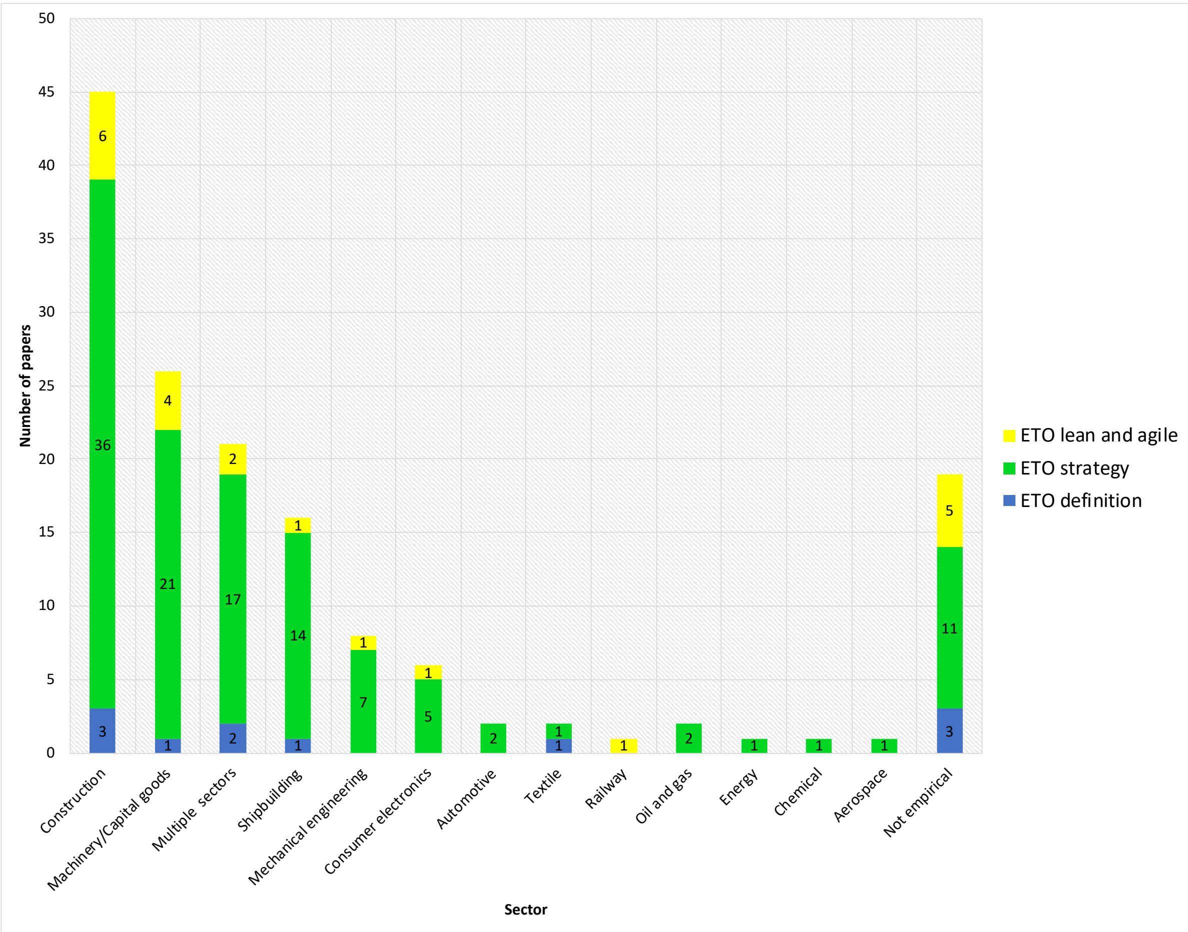

Figure 2. Sector analysis of the papers across the streams

As underlined in 2009 by Gosling and Naim, also in the last decade (2010-2020) a predominance of studies focused on the construction sector has emerged, followed by machinery/capital goods and shipbuilding sectors. In addition, the number of sectors addressed has increased over the years and new ETO sectors have been included such as mechanical engineering, consumer electronics, automotive, textile, railway, oil and gas, chemical, and aerospace. Finally, over the past decade, there has been a focus on multiple sectors studies, which have combined construction with shipbuilding, machinery, aerospace, and other industries. By analysing the streams, it can be seen that 'ETO definition' stream, which was mostly conceptual in 2009, has now been enriched by specific sector analyses. The 'ETO strategy' stream, on the other hand, is still mainly focused on construction and machinery/capital goods, as in 2009, but the analysis of multiple sectors and shipbuilding have also emerged as important trends. Finally, 'ETO lean and agile' stream, has presented, as in 2009, a varied profile by exploring a wide range of sectors.

Finally, table 3 shows the categorisation of the literature based on how the different streams are distributed in the journals used in the study, ranked by the total number of papers appearing in this review. It is possible to see that the International Journal of Production Economics, Production Planning and Control, and International Journal of Production Research were the most popular journals.

Literature streams category				
Journal title	**Stream 1: ETO definition**	**Stream 2: ETO strategy**	**Stream 3: Lean and Agile**	**All**
Production Planning and Control		16	6	22
International Journal of Production Research	1	17	3	21
International Journal of Production Economics	2	11	1	14
Journal of Manufacturing Technology Management		7	1	8
International Journal of Industrial Engineering and Management	1	5		6

International Journal of Operations and Production Management	2	3		5
Construction Management and Economics	2	2		4
Journal of Construction Engineering and Management		3		3
IFAC-PapersOnLine		3		3
Advances in Manufacturing		2		2
Buildings		1	1	2
International Journal of Project Management		2		2
Production and Manufacturing Research		2		2
Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment	1	1		2
Construction Innovation		2		2
Journal of Japan Industrial Management Association		2		2
Automation in Construction		2		2
International Journal of Managing Projects in Business		1	1	2
International Journal of Product Lifecycle Management		2		2
International Journal of Lean Six Sigma			2	2
Project Management Journal		2		2
Computers in Industry		2		2
International Journal of Quality and Reliability Management			1	1
Problems and Perspectives in Management		1		1
Applied Sciences (Switzerland)			1	1
Journal of Intelligent and Fuzzy Systems		1		1
Knowledge Management Research and Practice		1		1
International Journal of Logistics Systems and Management		1		1
International Journal of Integrated Supply Management		1		1
International Journal of Logistics Research and Applications		1		1
Total Quality Management and Business Excellence	1			1
International Journal of Logistics Management		1		1
Management and Production Engineering Review		1		1
Journal of Information Technology in Construction		1		1
IEEE Engineering Management Review		1		1
Journal of Design Research		1		1
Logistics Research		1		1
Supply Chain Management: An International Journal	1			1
International Journal of Naval Architecture and		1		1

Ocean Engineering				
Wind Engineering		1		1
Applied Mathematical Modelling		1		1
Sustainability (Switzerland)		1		1
Canadian Journal of Civil Engineering			1	1
Engineering, Construction and Architectural Management		1		1
Organization, technology & management in construction: an international journal		1		1
Energies		1		1
Advances in Production Engineering And Management		1		1
Journal of Cleaner Production		1		1
International Journal of Productivity and Performance Management			1	1
International Journal of Simulation and Process Modelling		1		1
Journal of Advanced Manufacturing Technology			1	1
Computers in Industry		1		1
Architectural Engineering and Design Management		1		1
Computers and Industrial Engineering		1		1
Theoretical Issues in Ergonomics Science		1		1
CIRP Annals - Manufacturing Technology		1		1
International Journal of Product Development		1		1
International Journal of Services and Operations Management			1	1
Producao		1		1
International Journal of Engineering, Transactions A: Basics		1		1
International Journal of Business Information Systems		1		1
All	**11**	**119**	**21**	**151**

[Table 3 near here]

5 Thematic Analysis of Literature Streams: ETO definition

When focusing on defining the unique features of ETO situations, Gosling and Naim (2009) concluded that production flow in an ETO situation is all driven by actual customer orders with the decoupling point located at the design stage, and opened the possibility that several types of supply chain organisation exist in ETO situations. They called for more research relating potential ETO sectors, a greater understanding of the application of decoupling strategies in the design phase, and ETO types. The review also underlined a need for a better understanding of the engineering dimension and its interface with the production dimension, as per the two-dimensional customer order decoupling point (CODP) conceptualised by Wikner and Rudberg (2005).

Table 4 categorises the papers according to new insights into ETO definitions.

Definition	**Stream 1: supply chain structures**	**Stream 2: ETO strategy**	**Stream 3: lean and agile**	**All**
ETO can involve big and bulky products with site-based logistics processes	1 (Zennaro et al., 2019)	2 (Ahmadian et al., 2016; Dubois et al., 2019)	2 (Dallasega et al., 2018; Tezel et al., 2018)	5
ETO are typically ‘complex’ products and are realised via project delivery models	1 (Gosling et al., 2017)	13 (Adrodegari et al., 2015; Denicol et al., 2020; Gosling et al., 2013, 2015a; Guillaume et al., 2013; Jansson et al., 2015; Li et al., 2017; Lian and Ke, 2018; Mello et al., 2015a, 2017; Pacagnella et al., 2019; Pal et al., 2017; Reid et al., 2019)	2 (Birkie et al., 2017; Birkie and Trucco, 2016)	16
A number of ETO order fulfilment strategies can be adopted, involving co-ordinated configuration of engineering and production structures.	3 (Cannas et al., 2019; Dekkers et al., 2013; Semini et al., 2014)	7 (Cannas et al., 2020; Gosling et al., 2015b; Larsson et al., 2016; Mello et al., 2017, 2015b; Tiedemann et al., 2019; Viana et al., 2017)		10

ETO forms may compete using different types and levels of customisation.	6 (Cannas et al., 2019; Mishra et al., 2019; Mosig et al., 2017; Schoenwitz et al., 2012; Segerstedt and Olofsson, 2010; Willner et al., 2016b)	7 (Cannas et al., 2020; Fatodu and Feizabadi, 2015; Hendry, 2010; Johnsen and Hvam, 2019; Lessing and Brege, 2015; Sandrin et al., 2018; Sousa and da Silveira, 2019)		13
Engineering flows are underpinned by a diverse range of pre-engineering approaches	4 (Cannas et al., 2019; Gosling et al., 2017; Johnsson, 2013; Segerstedt and Olofsson, 2010)	6 (Cannas et al., 2020; Grabenstetter and Usher, 2013; Jansson et al., 2018, 2014; Said et al., 2017; Willner et al., 2016a)		10

[Table 4 near here]

Some attention was given in the last years to the physical logistics differences. Products are often ‘big and bulky’ with site based logistics (Zennaro et al., 2019). The latter means that there are site and installation processes to be managed and integrated with the supply chain (and hence in the strategy themes it is possible to see prefabrication and offsite as a proposed strategies). Products are also typically innovative, since they are produced for a single customer, complex and uncertain, and, therefore, are typically organised as projects (Denicol et al., 2020). Hence, there is a link with the project management body of knowledge.

Some studies have also focused on enriching ‘ETO definitions and types’. Segerstedt and Olofsson (2010) editorial focused on supply chain management in the construction industry, and argues that the ETO characteristics of construction introduces a range of complications and requirements. Willner et al. (2016b) have also developed and described four distinct ETO archetypes validated in multiple industries (machinery, aerospace, elevators, etc.) and specified the most suitable organisational structure for each archetype. These archetypes are based on a positioning matrix that intersects annual units sold and engineering complexity as dimensions.

There is also an interesting link with the mass customisation literature. Hence, there is a need to consider ETO as part of an overall customisation strategy. The literature shows a range of approaches are available. For example, the study of mass customisation in the textile industry has been addressed by Mosig et al. (2017), identifying three different types of mass customisation business models.

Our understanding of engineering flows and decoupling points in ETO situations has progressed, and there now exists models and evidence for decision making (Gosling et al., 2017; Johnsson, 2013). However, evidence across multiple sectors suggests that engineering flows need to be considered with reference to the interactions with production flows (Cannas et al., 2019; Dekkers et al., 2013; Semini et al., 2014). Strategy stream papers echo this challenge by highlighting the need to manage process and product interactions (Viana et al., 2017). A comprehensive synthesis and a better understanding of all ETO definitions developed by the literature over years has been recently provided by Cannas et al. (2019). They developed a two-dimensional CODP framework from an extensive literature review, and empirically validate it within the machinery industry, improving the understanding of ETO strategic decoupling choices and adding insights to the ETO debate. Additionally, they analysed the performance outcomes of decoupling configurations and the managerial approaches employed in both engineering and production processes.

Multiple studies empirically explored ETO definitions in different sectors. Evidence from machine tools and shipbuilding have moved forward the two-dimensional CODP framework considerably. Mishra et al. (2019) demonstrated by means of a survey with 257 respondents that the position of the decoupling points results in different business strategies employed by companies that want to achieve manufacturing flexibility. In the house-building sector, studies demonstrated that not all components need to be highly customised (Schoenwitz et al., 2012) and different engineering customisation strategies can be identified depending on the degree to which the design platforms are defined, based on the market scope (Johnsson, 2013). In the shipbuilding industry, Semini et al. (2014) studied the engineering customisation strategies employed and underlined the existence of multiple strategies, link to market and product characteristics.

From our synthesis and critique of the 'ETO definition' theme, we conclude that:

- Understanding of engineering flows, potential engineering decoupling points, and two-dimensional CODP interactions between production and engineering processes has progressed in terms of definitions, understanding of competitive trade-offs and advantages for different positions or structures.
- The are some exploratory studies linking ETO to customisation or mass customisation approaches, but further working is needed to embed and integrate the ETO and Mass Customisation bodies of knowledge.
- Evidence for definitions is primarily drawn from literature reviews and case studies. In 2009 these were primarily conceptual, so there is some progression. It is also encouraging to see work spanning a range of industrial sectors.
- There are clear links with the Project management literature, which also seeks to characterise and define approaches for project situations. There is a need to explore this link further to understand how the project management body of knowledge and the ETO literature can be integrated for theoretical enrichment.

6 Thematic Analysis of Literature Streams: ETO strategy

The strategy stream of literature focused on performance improvement strategies relevant for ETO sectors. Gosling and Naim (2009) categorised strategies as 'shift between supply chain structures', 'supply chain integration', 'information management', 'business systems engineering', 'flexibility', 'time compression' and 'new product development process improvement'. They called for more research identifying synergies and trade-offs between different strategies.

How do the strategy themes discussed by ETO literature in the last decade (2010-2020) compare to those identified in 2009 (Gosling and Naim 2009) and what progress has been made? Table 5 displays the thematic analysis and number of papers for the 'ETO strategy' literature stream addressed in the last decade (2010-2020), as well as connections between key themes where a specific paper has made links between different themes.

Definition	**Stream 1: supply chain structures**	**Stream 2: ETO strategy**	**Stream 3: lean and agile**	All
Complexity reduction and standardization	1 (Johnsson, 2013)	14 (Amrani-Zouggar and Zolghadri, 2014; Barbosa and Azevedo, 2019, 2018; Haug, 2013; Jansson et al., 2018, 2015, 2014; Larsson et al., 2016; Ng et al., 2015; Oliveira et al., 2018; Pero et al., 2015; Said et al., 2017; Schoenwitz et al., 2017; Viana et al., 2017)	2 (Birkie and Trucco, 2016; Willner et al., 2016b)	17
Configuration of supply chain structure	5 (Cannas et al., 2019; Gosling et al., 2017; Schoenwitz et al., 2012; Semini et al., 2014; Willner et al., 2016b)	5 (Amrani-Zouggar and Zolghadri, 2014; Cannas et al., 2020a; Hendry, 2010; Schoenwitz et al., 2017; Tiedemann et al., 2020)		10
Supply chain integration		18 (Bozorgmehr and Tavakoli, 2015; Carneiro et al., 2014; Dixit et al., 2019; Dubois et al., 2019; Ekeskär and Rudberg, 2020; Gosling et al., 2015a; Korpysa et al., 2020; Leseure, 2015; Mello et al., 2015a, 2015b, 2017; Mello and Strandhagen, 2011; Pal et al., 2017; Sabri et al., 2020; Seth and Rastogi, 2019; Tsinopoulos and Bell, 2010; Vasara and Kivistö-Rahnasto, 2015; Zeng et al., 2018)	2 (Meng, 2019; Tezel et al., 2018)	20
Planning and control techniques		24 (Adrodegari et al., 2015; Ahmadian et al., 2016; Alfieri et al., 2011; Bortolini et al., 2019; Carvalho et al., 2017, 2016, 2015; Dal Borgo and Meneghetti, 2019; Ghiyasinasab et al., 2020; Grabenstetter and Usher, 2014, 2013, 2015; Jiang and Xi, 2019; Kim et al., 2020; Medini, 2015; Mourtzis et al., 2016; Nam et al., 2018; Pacagnella et al., 2019; Poeschl et al., 2019; Riezebos, 2010; Sjøbakk et al., 2015; Telles et al., 2019; Wesz et al., 2018; Yang, 2013)	7 (Bataglin et al., 2020; Cannas et al., 2018; Dallasega et al., 2018; Gejo García et al., 2020; Mahmood et al., 2018; Strandhagen et al., 2018; Villar-Fidalgo et al., 2019)	31
Uncertainty/risk management		15 (Ferreira et al., 2018; Gosling et al., 2013b, 2013a; Guillaume et al., 2013; Hernadewita and Saleh, 2020; Ishii et al., 2011; Kayis and Karningsih, 2012; Li et al., 2017; Lian and Ke, 2018; Radke and Tseng,		15

		2012; Reid et al., 2019; Shen et al., 2011; Shurrab et al., 2020a, 2020b; Sylla et al., 2020)		
Industry 4.0		10 (Dallasega, 2018; Fox and Do, 2013; Kozjek et al., 2020; Oettmeier and Hofmann, 2016; Oluyisola et al., 2018; Pero and Rossi, 2014; Silvola et al., 2019; Sjøbakk et al., 2014; Strandhagen et al., 2020; Weng et al., 2020)		10
Better system design		8 (Böhme et al., 2014; Dekkers, 2011; Denicol et al., 2020; Donha and Guimarães, 2020; Gosling et al., 2015b; Johnsen and Hvam, 2019; Moretto et al., 2020; Sandrin et al., 2018)	1 (Seth et al., 2017)	9
Appropriate Business Models		4 (Andersson and Lessing, 2020; Fatodu and Feizabadi, 2015; Lessing and Brege, 2015; Sousa and da Silveira, 2019)		4
New product development portfolio and capabilities		4 (Galati et al., 2019; Jääskeläinen et al., 2017; Jansson et al., 2013; Tiedemann et al., 2019)		4
Design automation		14 (Cannas et al., 2020b; Chatziparasidis and Sapidis, 2017; Fox, 2014; Grafmüller et al., 2018; Haug et al., 2019b, 2019a; Kristjansdottir et al., 2017; Lee and Lee, 2014; Mäkipää et al., 2012; Montali et al., 2018; Shafiee et al., 2017, 2014; Weng et al., 2014; Willner et al., 2016a)		14
Engineering management		4 (Akasaka et al., 2016; Barbosa and Azevedo, 2019; Iakymenko et al., 2020b, 2020a)	1 (Lorenzi and Ferreira, 2018)	5

[Table 5 near here]

In the following sub-sections, we discuss how the last decade themes are new and different from the Gosling and Naim (2009) themes, by classifying their contribution to the old themes and placing emphasis on any evidence presented for performance improvement within the papers.

6.1 Shift between supply chain structures

The ‘shift between supply chain structures’ theme identified in 2009 was related to the studies that discussed the strategic ‘forward shifting’ through supply chain structures from ETO to more standard configurations, through modularity, for reducing complexity. The results of the review shown that little literature contributions were addressing the topic and further studies were needed to understand the shifting strategies and study the impact on performance. Consequently, this theme has been significantly expanded in the last decade (2010-2020) by studies addressing two main themes: the theme ‘complexity reduction and standardization’ and the theme ‘configuration of supply chain structure’.

6.1.1 Complexity reduction and standardization

Through the analysis of the papers a range of papers addressed the issue of ‘complexity reduction and standardisation’ in ETO situations. One important topic analysed by literature has been ‘product platforms’. In particular, Haug et al. (2013) proposed a procedure for reducing product solution spaces in ETO situations, Haug (2013) analysed the role of product knowledge integration between manufacturers and supplier to increase product standardisation, and Jansson et al. (2014) described support methods to develop product platforms while handling project uniqueness. The product platforms have been demonstrated to be subject of continuous improvement within ETO situations, by means of feedback channels that enrich the knowledge incrementally in ongoing projects (Jansson et al., 2015). New technologies to collect and analyse data can also support such processes (Ng et al., 2015), for example through database-driven simulations (Larsson et al., 2016), and optimised by means of mathematical models (Said et al., 2017). Jansson et al. (2018) underlined also that the importance to consider the trade-off between creativity and standardisation when addressing product platforms. A last important topic addressed by literature was ‘modularity’ applied to ETO products. The literature demonstrated that modularity has a positive impact on performance, reducing complexity and, consequently, lead times while assuring high flexibility, thanks to the decoupling of design decisions and the standardization of different types of processes (Amrani-Zouggar and Zolghadri, 2014; Oliveira et al., 2018; Schoenwitz et al., 2017; Viana et al., 2017). However, this is possible only if supported by investments in resources to increase production capabilities, supply chain coordination and designers knowledge (Pero et al., 2015).

Across this theme, the evidence is primarily qualitative, and case based, reflecting on the advantages and disadvantages of platform-based approaches, as well as modularization (Pero et al 2015). There is tentative evidence for potential of standardization to reduce lead times (Viana et al 2017), which concurs with the definitions papers suggesting that there are competitive trade-offs across the customization and standardization continuum. Finally, simulation models have been developed by Barbosa and Azevedo (2019, 2018) to quantitatively assess the impact of different engineering determinants such as the design reuse and engineering workload on project time, manufacturing and assembly time, and total cost and jointly analyse the development/customisation, production, resources allocation and management tasks.

6.1.2 Configuration of supply chain structure

Following the recent progress on the definition of ETO, recent studies focused on enriching the body of knowledge related to the forward and backward shifting between different supply chain structures (for instance in terms of either production or engineering decoupling points), and the reasons for doing so. Hendry (2010) empirically demonstrated that in different ETO sectors external and internal factors can influence competitive priorities of companies, and, consequently, customisation strategies. Amrani-Zouggar and Zolghadri (2014) studied the electronic industry and analysed the parameters to decide whether to shift or not to different product management strategies, building on Olhager (2003), looking mainly at market, product, and production factors. Schoenwitz et al. (2017) focused on house-building sector and underlined that, in the case of ETO context, the complexity of products requires to take into account the component and attribute level of the product architecture when dealing with customisation decisions. Building on this point, they demonstrated that the operational strategies involved by ETO companies should align the customisation level with the customer preferences for choice for various elements of the architecture, considering, in case of misalignment, the product re-design, processes reconfiguration or market repositioning. Cannas et al. (2020a) studied the machinery industry and empirically analysed the contingent factors for choosing order-fulfilment strategies in ETO context, including among them the market, the product, the production process and the engineering process. Also, by comparing the empirical results with the literature, Cannas et al. (2020a) confirmed the existence of a trade-off between performance outcomes shifting from highly standardised to highly customised strategies and the current paradox of ETO companies aiming at multiple conflicting competitive priorities. However, no operational performance evidence has been shown in these studies. Finally, Tiedemann (2020) contributed by , providing a practical method for operations and supply chain managers to use in establishing and maintaining supply chain fit in demand-driven environments.

6.2 Supply chain integration

The 'supply chain integration' theme made Gosling and Naim (2009) concluded that not all the strategies of integration seemed suitable for ETO situations, indeed literature contributions were mixed, and additional empirical studies were needed. This theme remained a popular area of research in the last decade (2010-2020). Recent studies further analysed the specific supply chain integration strategies in ETO situations and included co-ordination of the actors as a critical issue.

Tsinopoulos and Bell (2010) identified three key barriers to the implementation of supply chain integration systems by small ETO companies, such as the intensity of skills needed. Accordingly, they developed a model for overcoming these barriers to achieve operational improvements through supply chain integration. Recent contributions worked on the 'interfaces/integration' between the supply chain actors analysing innovative methodological approaches to support collaboration amongst ETO small-medium enterprises for customised product design and manufacturing (Carneiro et al., 2014), integration and management of the project supply chains (Korpysa et al., 2020), different transport and logistics configurations to enhance efficiency (Dubois et al., 2019), the impact on sustainable performance (Zeng et al., 2018), and the effects of engineering and production coordination and the factors affecting this coordination (Mello et al., 2017, 2015a, 2015b; Mello and Strandhagen, 2011). Moreover, the 'relationships' with customer and suppliers have been analysed. Bozorgmehr & Tavakoli (2015) developed and empirically validated a new multi-disciplinary two-stage supplier evaluation and verification methodology, which resulted in an accurate and reliable supplier selection process. Leseure (2015) analysed trust in complex and high risk manufacturing engineering projects through a longitudinal study that demonstrated that collaborative relationships based on trust are not a sustainable solution for all supply chains, perhaps in line with Gosling et al. (2015a) who propose a continuum of relational forms. Additionally, the studies analysed the performance of different relationships and supplier development initiatives (Gosling et al., 2015a), the critical factors to manage construction projects (Pal et al., 2017), the role of the third-party logistics as systems integrator in construction supply chains (Ekeskär and Rudberg, 2020), the importance to include the supply chain configuration as a capability in selection of Engineering-Procurement-Construction projects environment suppliers (Sabri et al., 2020), and coordination and vendor rationalisation (Seth and Rastogi, 2019). Also, the topic of customer involvement, with thorough technical knowledge, as resource and co-producer, has been analysed by Dixit et al. (2019) by analysing analyses the impact of customer involvement in sourcing decisions and project execution on project performance. Finally, on this topic, attention has been given to the 'product delivery strategies' to assure product safety compliance and conformity within the supply chain (Vasara and Kivistö-Rahnasto, 2015).

Across the theme, a convincing range of evidence for performance improvements is presented. Dubois et al. (2019) show that different supply configurations appear to lead to efficiency potentials, while Mello et al (2015a 2015b) present tentative evidence that better co-ordination across the supply chain can improve efficiency, effectiveness, and efficacy. In addition, a before and after lead time analysis of supply chain initiatives can reduce lead times and impact on time completion (Seth and Rastogi, 2019). Analysis of a large performance data set also shows that the higher the level of partnership in the relational category, the more consistency there will be in performance across projects (Gosling et al., 2015a).

6.3 Planning information management, flexibility and time compression

'Information Management' theme, proposed by Gosling and Naim (2009), was related to strategies to trace and control project and manage the information for production control. 'Flexibility' theme was related to strategies for product, assembly, workforce, volume, and supplier flexibility to reduce and cope with uncertainty. Finally, 'time compression' theme was related to strategies for reducing project time and achieve competitive bidding and a fast design stage. The 2009 review concluded that there was agreement in the literature regarding the usefulness of information management, flexibility, and time compression strategies but there were still open questions regarding what information management systems and flexibility types are most suitable for the ETO sector.

By analysing the studies of the last decade (2010-2020) we linked the information, flexibility, and time compression themes with the most popular area of research over the last decade, which is 'planning and control techniques', where literature contributed by reflecting on the complexity and challenges of project planning in ETO situations. Also, in the last decade (2010-2020), literature was influenced by these themes, focusing on, and further improving, the issue of 'uncertainty/risk management' theme. Finally, we see the information management theme influence the 'industry 4.0' theme, where developments in data management, process automation and RFID make better use of digital information.

6.3.1 Planning and control techniques

'Planning and control techniques' theme has been the most popular topic in the papers selected. Riezebos (2010) designed a material control system for throughput time control in ETO situations and implemented it in an ETO company. The application of this system showed a reduction of lead times by more than 70%, an increase in productivity per employee, progress visibility, employees' satisfaction, and control of workload. Alfieri et al. (2011) developed and empirically tested a project scheduling approach using variable intensity formulations to allow the effort committed to the execution of activities to vary over time. The empirical validation demonstrated the approach to be advantageous for the management of changes, when they occurred. Yang (2013) empirically demonstrated that there is a relationship between manufacturing practices such as planning and control and capacity management, manufacturing capabilities and the achievement of project manufacturing goals in ETO companies. Adrodegari et al. (2015) focused on 'information management' and identified software functionalities needed for the production planning and control problems in the machinery industry. Moreover, Bortolini et al. (2019) analysed the Building Information Modelling (BIM) functionalities in logistics planning and control in the construction industry. The continuous relationship with the customers and the need to assure order fulfilment in a context of uncertain and unpredictable demand is one of the most addressed issues in ETO planning and control.

Some studies analysed tactical 'capacity planning' (Carvalho et al., 2017, 2016, 2015), 'performance management systems' (Pacagnella et al., 2019; Sjøbakk et al., 2015), and advanced 'production planning' methods to optimise materials and human resources (Nam et al., 2018), and dynamic scheduling approach for supporting material management (Grabenstetter and Usher, 2013; Medini, 2015; Mourtzis et al., 2016). Also, interesting quantitative models for production planning have been implemented. Dal Borgo and Meneghetti (2019) developed an optimisation model for mid-term production and shipment planning; Jiang and Xi (2019) developed an approach for the minimization of rescheduling cost as the objective for solving dynamic scheduling problems in ETO; whereas, Telles et al. (2019)

developed a drum-buffer-rope in the aerospace industry. Recently, Ghiyasinasab et al. (2020) proposed a production planning method for managing multiple construction projects and Kim et al. (2020) developed an environment for determining highest reward value in spatial arrangement problems in the ship block stockyards. ‘Project management’ has been another topic of interest in ETO planning and control research area, considering new variables in project planning such as the transportation time for improving the on time performance (Ahmadian et al., 2016), and defining the most significant critical success factors to use when assessing the success of project execution and management in ETO (Pacagnella et al., 2019). A last topic of interest has been ‘engineering/design planning’. Grabenstetter and Usher (2015, 2014) developed a model for accurately predicting ETO engineering flow times in the absence of normally assumed information and scheduling policy application to the engineering activities, Poeschl et al. (2019) proposed a methodology for engineering process planning in mechanical engineering, Wesz et al. (2018) developed a model for design planning, including ad-hoc mechanisms for ETO project environments.

In this theme, we see anecdotal evidence that planning can be improved through better predictions, decision making, and adoption of more visual techniques. Evidence is presented to show that process times can be reduced via planning and control techniques. For example, transport times can be reduced by offsite approaches (Ahmadian et al., 2016), and commissioning process can be reduced by as much as 40% (Poeschl et al., 2019). Work in progress can also be reduced (Bortolini et al., 2019).

6.3.2 Uncertainty / risk management

Studies that covered the ‘uncertainty/risk’ theme aimed at defining methods and developing instruments to identify uncertainty, measure risk and react to them (Ferreira et al., 2018; Gosling et al., 2013b, 2013a; Guillaume et al., 2013; Hernadewita and Saleh, 2020; Kayis and Karningsih, 2012; Li et al., 2017; Lian and Ke, 2018; Radke and Tseng, 2012; Reid et al., 2019;

Shen et al., 2011; Shurrab et al., 2020a, 2020b; Sylla et al., 2020). While the majority of papers in this theme were analytical and theoretical papers, the empirical evidence presented is primarily concerned with illustrating and characterising causes and categories of risk and uncertainty (e.g. Reid et al. 2019) and identifying possible cross-functional mechanisms (Shurrab et al., 2020a) as well as tactical level decisions that have potential reducing or absorbing uncertainty (Shurrab et al., 2020b). Additionally, Sylla et al. (2020) proposed a multi-criteria decision making (MCDM) support approach to help bidders to select the most attractive and feasible solution during an uncertain ETO bidding process and empirically demonstrated its applicability and effectiveness. Ferreira et al. (2018) performed a survey study in the Brazilian shipbuilding industry and demonstrated that the risk exposure for production delays and exceeding project budgets depends on both internal and external factors but most of the companies analysed recognised only the internal ones, failing, as a result, in risk management.

6.3.3 Industry 4.0

A new emerging trend of the last decade (2010-2020) is represented by 'Industry 4.0' theme, including software and hardware to help manage ETO situations. A recent technological trend has been identified by Fox and Do (2013) in the addition of micro-electronic devices to ETO goods, which can enable innovative product-services, such as the remote monitoring and reporting of performance in use, by means of Big Data. This study performed an action research in the shipbuilding industry, which allows the authors to identify the challenges in achieving informational and transformational effects. Sjøbakk et al. (2014) developed a methodology for systematic 'automation' decisions in the ETO production situation. Oettmeier and Hofmann (2016) analysed the adoption of 'additive manufacturing' within ETO environment; whereas, Pero and Rossi (2014) and Oluyisola et al. (2018) proposed an approach for Radio-Frequency identification (RFID) implementation in the ETO industry. Dallasega (2018) analysed the role of various Industry 4.0 concepts for reducing uncertainty and proposed seven action points as guidelines to improve construction supply chain management, based on lessons learned from ETO construction supplier companies. Silvola et al. (2019) analysed 'Master Data Management' and the linkage of product data requirements with business drivers. The evidence in this theme is primarily exploratory, concerned with understanding and describing technologies and their potential application. However, there is some evidence that process automation can lead to cost reductions and increased available processing time. Kozjek et al. (2020) highlighted that a useful framework for big data analytics can be beneficial for ETO companies. They analysed the application of a machine learning model in a case study, used to predict when planned sequence of work orders operations will not match the actual ones, and the precision in the test resulted as 75%. Weng et al. (2020) proposed a new manufacturing operating system that can aid ETO factories in becoming "smart" for increasing orders and reducing parts inventory. Finally, Strandhagen et al. (2020) analysed the impact of Industry 4.0 on sustainability performance in the ETO industry, proposing a set of nine digital solutions to support sustainable operations in shipbuilding.

6.4 Business systems engineering

'Business systems engineering' theme was proposed by Gosling and Naim (2009) as related to the studies focused on the ways how to design, integrate, and manage complex systems, and business process reengineering techniques for ETO contexts, concluding that confusion exists in literature regarding this issue. In the last decade (2010-2020) this theme has received some attention in the form of two main themes: 'better systems design', including co-ordination of people, process, technology and organisations, to support the new ETO trends; 'appropriate business models', developing 'product-oriented' business models and analysing the new 'servitisation' trends in the ETO sector.

6.4.1 Better System design

One problem addressed by ETO literature has been the issue of outsourcing decisions in ETO and make-to-order situations. In particular, Dekkers (2011) empirically analysed this issue in multiple sectors, identifying a lack of methods and tools usage and extracting directions for research to get a better picture of methods and tools that really support effective strategic decision making on outsourcing. Böhme et al. (2014) offered comprehensive guidelines for the evaluation of supply chain processes, and their rapid and radical redesign, for the purpose of improving innovation capability in ETO situations. Gosling et al. (2015b) focused on 'principles' for supply chain management in ETO situations, providing tentative evidence for the impact of aligning principles, goals and practices across the supply chain. Moretto et al. (2020) empirically studied how procurement can be organized in project-based firms under different contextual conditions, identifying three different typologies of procurement department organisations, procurement-focussed, hybrid or project-focussed, which are employed depending on specific contingencies. Sandrin et al. (2018) focused on people and 'human resource management' to implement in the transition from ETO to mass customisation, showing that HRM practices can support mass customisation capability (measured via an index). Johnsen & Hvam (2019) proposed a framework to support ETO companies in estimating costs of non-standard customisation, finding that none standard customisation (i.e. additional complexity) can reduce profitability by 0-3%. Donha & Guimarães (2020) focused on the organisational environment showing that 20 organisational factors can influence success or failure of the innovation process in ETO product development projects. Finally, a recent literature review performed by Denicol et al. (2020) underlined the main causes and cures of poor megaproject performance, highlighting the importance to address further research on how to design the dynamic interorganizational systems that characterise megaprojects.

6.4.2 Appropriate business models

New 'business models and market requirements' have been identified by last decade (2010-2020) papers, with an interest on developing 'product-oriented' business models for house-building sector (Lessing and Brege, 2015), and analysing the new 'servitisation' trend and its effect on customer role (Fatodu and Feizabadi, 2015). The latter find that customer orientation can have a significant influence on the three critical KPIs (e.g., losses and none-productive time). Sousa and da Silveira (Sousa and da Silveira, 2019) examined the relationship between product customization and servitisation strategies, giving further evidence for the link between customisation intensity and service provision. Recently, Andersson and Lessing (2020) underlined the importance for construction industries to strengthen the understanding of the interplay between the adoption of standards and business model renewal in the context of digital transformation.

6.5 New product development process improvement

Finally, Gosling and Naim (2009) defined the 'new product development improvement' theme by referring to studies that analysed how to reduce design iterations and reworks and build quality into design and manufacturing in ETO context, and little contributions were identified related to this topic. In the last decades, important new insights on this theme have been introduced, included advances in design and engineering management. In particular, this theme influenced three new themes: (i) 'design automation', which focused on the role of product configurators and defined strategies to effectively implement and use them in ETO contexts; (ii) 'NPD portfolio and capabilities', which considers changes in the NPD process, for instance regarding the external interactions with customers and suppliers, and internal interactions with the production process; (iii) 'engineering management', which analysed how to manage effectively engineering changes in product development.

6.5.1 Design automation

Over the years, several ETO studies discussed the important role of product lifecycle management (PLM) and product data integration, including design and manufacturing characteristics (Lee and Lee, 2014), as well as the importance to accurately grasp customer requirements at an early product development stage (Weng et al., 2014). Accordingly, the applicability of design automation and configurators in ETO industries have been analysed (Chatziparasidis and Sapidis, 2017; Fox, 2014; Mäkipää et al., 2012; Shafiee et al., 2017, 2014; Willner et al., 2016a).

Despite these contributions, Montali et al. (2018) underlined that Knowledge-Based Engineering (KBE) applications for providing a digital product model to ETO designers continue to focus on single disciplines, rather than integrating design principles and manufacturing constraints. However, the recent interest of ETO literature on mass customization strategies pushed further these investigations, providing new solutions. Grafmüller et al. (2018) addressed the issue of complex mass customisation product development, deriving a business model to employ within small-medium enterprises that aim to achieve successful mass customisation strategies by using 'solution spaces'. Also, recent studies (Cannas et al., 2020b; Haug et al., 2019a, 2019b; Kristjansdottir et al., 2017) explored possible applications of product configurators in ETO companies, the challenges that ETO companies can potentially face before, during and after implementation of product configurators and the possible actions to overcome these challenges.

6.5.2 New product development portfolio and capabilities

Jansson et al. (2013) treated the process of complex translation of customer requirements into production specifications through a case study in the house-building sector. They proposed a requirement management model that assures transparency on the customers' constraints and the downstream constraints coming from engineering, production and supply. Jääskeläinen et al. (2017) proposed a method to make customers and suppliers more involved in the NPD process; whereas, Tiedemann et al. (2019) proposed an NPD process portfolio model to support the organisation of mixed standard and custom products within ETO realities, triggering new interesting directions for ETO NPD literature. Concerning the effective use of knowledge and the knowledge protection in the knowledge-intensive ETO context, Galati et al. (2019) explored the relationship between defensive mechanisms and the need to balance knowledge sharing and protection.

6.5.3 Engineering management

Finally, the topic of 'engineering management' has been analysed by ETO literature. Akasaka et al. (2016) proposed a product functional structure model that can support ETO companies in clearly defined customer requirements and avoid engineering changes (EC) after the order. Iakymenko et al. (2020b, 2020a) analysed the factors affecting the EC implementation performance, underling time of EC occurrence, competence and experience of engineering and production staff, and degree of vertical integration in a supply chain as the ones with the highest impact, and proposed a theoretical framework for EC management in ETO industries.

Very little performance outcome data is offered across this category. The simulation study by Barbosa and Azevedo (2019) is the only one that addressed the impact of product development choices on performance.

6.6 Summary of ETO strategy themes

Figure 3 summarises the last decade (2010-2020) themes contributing to ETO strategies and classified them across the themes proposed by Gosling and Naim (2009).

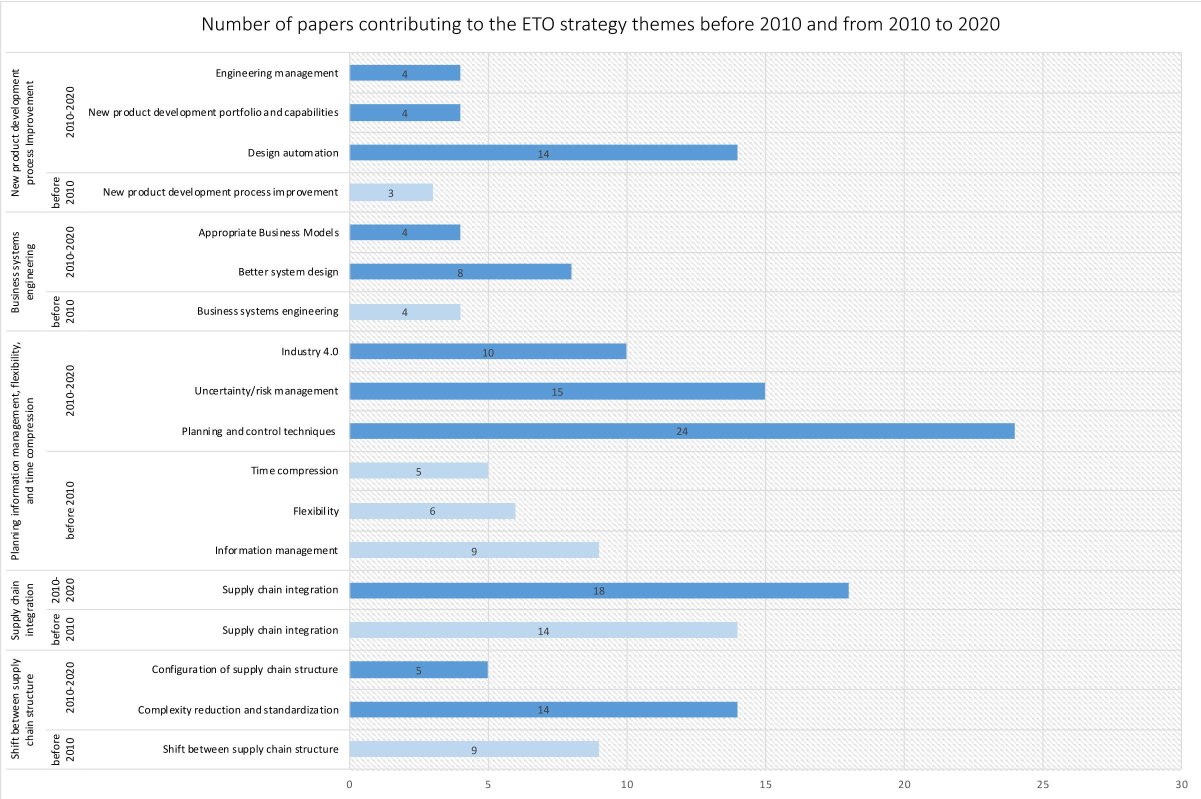

Figure 3. ETO strategy themes evolution in the last decade (2010-2020)

The number of studies contributing to each theme incremented in the last decade and much more details have been provided to overcome the limitations identified in 2009 by Gosling and Naim, related, for example, to the application of postponement strategies and decoupling thinking to the engineering dimension or the identification of supply chain integration techniques suitable for ETO.

From our synthesis and critique of the 'ETO strategy' theme, we conclude that:

- While established themes, such as integration and planning and control, continued to receive attention by researchers, a number of new and emerging themes/sub themes have been identified, many driven by technological developments. These include 'Industry 4.0', 'Design Automation', 'Appropriate Business Models' and 'Uncertainty/risk management'.
- The most convincing evidence of progress and performance outcomes can be found

across the 'supply chain integration' theme (with widescale benefits), as well as the 'planning and control techniques' theme, where it is possible to see evidence of some specific operational improvements.

- 'Industry 4.0', as well as 'Uncertainty/risk management', were more exploratory in the evidence presented, focusing more on characterising, categorising, illustrating and defining particular phenomenon.

7 Thematic Analysis of Literature Streams: Lean and Agile

Gosling and Naim (2009) expressed the need for future research concerning the lean and agile dimensions, suggesting that definitions, boundaries and applications of lean and agile in ETO were unclear.

Theme	**Stream 1: supply chain structures**	**Stream 2: ETO strategy**	**Stream 3: lean and agile**	All
Lean bundles or specific practices and their applicability to ETO		5 (Böhme et al., 2014; Bortolini et al., 2019; Gosling et al., 2015; Jansson et al., 2015; Telles et al., 2019)	18 (Bataglin et al., 2020; Birkie et al., 2017; Birkie and Trucco, 2016; Braglia et al., 2019b, 2019a; Cannas et al., 2018; Dallasega et al., 2018; Gejo García et al., 2020; Lorenzi and Ferreira, 2018; Mahmood et al., 2018; Matt, 2014; Meng, 2019; Portioli-Staudacher and Tantardini, 2012; Primo et al., 2020; Seth et al., 2017; Strandhagen et al., 2018; Tomašević et al., 2020; Villar-Fidalgo et al., 2019)	23

Match operational practices to decoupling configuration or type of ETO	6 (Cannas et al., 2019; Gosling et al., 2017; Johnsson, 2013; Schoenwitz et al., 2012; Semini et al., 2014; Willner et al., 2016)	4 (Cannas et al., 2020; Gosling et al., 2015; Hendry, 2010; Schoenwitz et al., 2017)		10
Lean Construction		1 (Dallasega, 2018)	4 (Bataglin et al., 2020; Braglia et al., 2020; Dallasega et al., 2018; Meng, 2019; Tezel et al., 2018)	5
Agility/ Flexibility in ETO		2 (Gosling et al., 2013; Zennaro et al., 2019)	1 (Godinho Filho et al., 2017)	3

[Table 6 near here]

Table 6 presents a synthesis of the lean and agile literature stream. The first theme highlights a ‘bundling’ approach to lean, whereby practices are separated out and bundled together for the purpose of implementation. Birkie and Trucco (2016), for example, identifying appropriate bundles, structures and definitions, extending the understanding of complexity and dynamism in ETO context and demonstrating the applicability of lean to reduce their effects. Building on this, Birkie et al. (2017) proposed lean practices modified for ETO through a customised approach, such as, for example, customised Kanban cards for different orders to suit information specific of the dynamic contexts analysed. This study showed, based on the empirical study of two ETO cases, that lean application is valuable also in uncertain sectors such as ETO, since it can improve performance in terms of on-time delivery, average lead times, manufacturing and purchasing costs, and costs of poor quality. Tezel et al. (2018) adopt a similar approach, identifying 20 tools and techniques. However, they find that this is largely motivated by external factors, such as demands by clients, and hence adoption is generally shallow, partial or selective across the sector. Meng (2019) explored the implementation of each of the lean principles in the construction sector, presents a more optimistic view. Their survey results indicate a correlation between lean characteristics and time, cost and quality, but compared to time and quality performance, lean construction has a greater impact on cost performance.

Within the 'lean' strategy papers, it is also possible to identify studies focusing on particular lean practices. For example, Portioli-Staudacher and Tantardini (2012) developed a lean-based order review and release (ORR) system specifically designed for make-to-order and ETO companies, named BaLancing Release, and tested it through a simulation model, achieving a higher output than one of the best existing ORR models, i.e., Upper bound-only release. Value Stream Mapping (VSM) applications and adaptations to ETO contexts have been shown by Matt (2014), Seth et al. (2017) and Strandhagen et al. (2018). Also, a set of lean techniques for planning and control of engineering and production activities has been introduced by empirical studies performed within ETO companies, such as visual management (Cannas et al., 2018), pull production control (Bataglin et al., 2020; Gejo García et al., 2020; Mahmood et al., 2018; Villar-Fidalgo et al., 2019), collaborative planning (Cannas et al., 2018; Dallasega et al., 2018), and lean project management applications (Cannas et al., 2018; Dallasega et al., 2018; Jünge et al., 2019). Lorenzi and Ferreira (2018) empirically demonstrated the feasibility of failure mapping using FMEA and A3 in ETO product development. They provided evidence by applying these techniques to a company of the industrial automation sector that manufactures ETO products. In particular, they shown that a reduction of reworks between 5% and 10% can be obtained. Also, a new lean metric named overall task effectiveness (OTE) has been proposed by literature (Braglia et al., 2019b) for ETO environment as well as a modified version of the Manufacturing cost deployment (MCD) method to analyse ETO production systems, named Project cost deployment (PCD), and applied it to a train assembly system: the expected savings are about 8% of the total costs to assembly the 15 trains (Braglia et al., 2019a). Through VSM and associated improvement initiatives, one study reports an overall cycle time reduction of 17.3% (Seth et al., 2017). In addition, visual collaborative planning was able to improve a company's delivery performance (i.e. on time delivery) of 60% more (in terms of number of pieces delivered on time to the total number of pieces delivered ratio) (Cannas et al., 2018). Primo et al. (2020) highlighted that lean applications in ETO can decrease costs significantly. Additionally, their study showed that Just-in-Time (JIT) techniques can improve time performance: the total production time were reduced by 68%. Also, lean quality development resulted through six sigma approach brought around US$5 million savings. A subset of studies also addressed 'lean construction', exploring how lean principles and practices may be implemented or adapted in the construction sector (Bataglin et al., 2020; Braglia et al., 2020; Dallasega et al., 2018; Meng, 2019; Tezel et al., 2018). In particular, Bataglin et al. (2020) demonstrated that pull production and reduce of variability in synergy with BIM functionalities increased the reliability of the overall planning process by 95% and productivity (39 components per day). Also, Braglia et al. (2020) proposed a novel metric named Overall Construction Productivity (OCP) supporting the quantification of the overall impact of losses and the implementation of improvement actions and empirically demonstrated that if these improvement activities are completely successful, the OCP can gain of about 18%.

Recently, a systematic literature review was performed by Tomašević et al. (2020) on the application of lean in High-Mix/Low-Volume industry, where ETO companies are included. Their results confirmed that some practices and tools, such as 5S, Single Minute Exchange of Die (SMED), and Total Productive Maintenance (TPM), are fully applicable to ETO contexts, while others, such as VSM and pull production, need adaptation. They conclude that the lean tools and practices used are often implemented to reduce variability, which is not always possible in ETO, since variability can be also strategic. Thus, Tomašević et al. (2020) underlined that the study of practices to manage the variability that cannot be reduced is still a gap in literature that should be addressed by future research.

Crossing over with the other literature streams, there is also a live debate about which strategy is best in different situations (Cannas et al., 2019; Cannas et al., 2020a; Gosling et al., 2017, 2015b; Johnsson, 2013; Schoenwitz et al., 2017, 2012; Semini et al., 2014; Willner et al., 2016b), underling the need to understand also what lean or agile practice is suitable according to the potential different order fulfilment strategies employed by the ETO companies. Also, only three papers explored the flexibility and agility of ETO situations (Godinho Filho et al., 2017; Gosling et al., 2013b; Zennaro et al., 2019), only one focusing on the agile practices. Godinho Filho et al. (2017), in fact, empirically investigated the application of Quick Response Manufacturing (QRM) practices in make-to-order and ETO situations and underlined that the use of lean favours the adoption of QRM.

From our synthesis and critique of the lean and agile in ETO theme, we conclude that:

- The definitions of potential lean bundles have progressed and there is an increasing number of studies working on the evidence of their application and success, whereas examples of failures are missing in the literature
- Very little additional contributions and insight into agility and flexibility in ETO, most of the studies focused on how to reduce variability, without giving attention on how to manage the remaining variability, which is peculiar in the ETO context. Indeed, none of the recent studies analysed the lean and agile interfaces and leagile topic
- Even if recent studies on ETO definitions show how much ETO strategies can be different based on decoupling configurations, little attention was given to this in the ETO lean studies, where lean practices were applied without the appropriate sensitivity to the context
- Lean construction has given some interesting sector insights, and there seems to be potential for concepts to impact on cost performance, but care needs to be taken in

adoption and application.

8 Discussion – synthesis and looking ahead to the next decade

Based on our analysis of the papers selected, and reflection on current trends in research and practice, it is possible to identify future research areas to guide the next decade of research for ETO situations.

8.1 Future research relating to structure and defining supply chain management in ETO situations

Through the content analysis, we have shown numerous advances in our understanding of definitions (see section 5). However, there are a few important areas worthy of future development. Firstly, there are some tentative linkages between different disciplinary areas and ETO. For example, Denicol et al. 2020 with respect to megaprojects and ETO and Mosig et al. (2017) in relation to Mass customisation and ETO, but we would encourage further cross fertilisation of disciplinary perspectives. Consequently, we pose the following future research questions:

- How can project management, mass customisation, innovation management and ETO literature be cross fertilised to enrich definitions and ETO characterizations?

8.2 Future research in relation to strategies for improving supply chain management performance in ETO situations

A wide range of research was presented through section 6 in relation to ETO strategy. However, evidence emerging from the different themes with regard to effectiveness and performance outcomes was variable. There are a number of gaps in our understanding, and we focus on those that we envisage will be the most pressing in line with the business environment over the next decade. Firstly, given the proliferation of new technologies, and their likely advance over the next decade, this will likely be a significant area of attention. From the literature analysis, it is possible to see some studies exploring Industry 4.0 technologies, but further evaluation of their particular application in ETO contexts would be very welcome. Hence, we frame the following future research question:

- How can new technologies and innovation systems improve supply chain management in ETO situations, and how should they be implemented?

Second, the configuration and alignment of supply chain structure still appears fundamental as a building block to effective supply chain management in ETO situations. A range of studies addressed this, arguing for the need to align markets, production, engineering, and processes. However, the guidance for what is appropriate still seems far from clear, especially if organisations need to change configuration in response to market conditions. Hence, we pose the future question:

- How should transitions between decoupling configurations be managed, implemented and justified?

Finally, given the broader servitisation movement, further research would be welcome that explores the link between ETO body of knowledge and servitisation. A few studies have begun to focus on this area, but we encourage further research in this area by articulating the following future research question:

- Which new business models and supply chain configurations are needed to support servitisation trends?

8.3 Future research in relation to lean/agile in ETO situations.

A good number of papers have focused on lean supply chain management in ETO situations, but little studies focused on agile supply chain management in ETO situations. While some advances have been made in applications of lean thinking, the agile and lean/agile debate within ETO seems not to have progressed much over the last decade, and the issue of whether to adopt, adapt or reject particular practices is still an ongoing debate. Some interesting performance evidence was presented across this theme, but there was a notable lack of insight into failures (i.e. what didn't work). Our suggested questions to guide further study with respect to definitions include:

- Should specific lean bundles be adopted, adapted or rejected in ETO settings?
- How can agility concepts be exploited in ETO?

8.4 Future research integrating the literature streams

Finally, there is a need to discuss the interactions between the literature streams and themes and reflect more broadly on research challenges ahead. Through the integration of the literature streams, we are starting to build a better understanding of ETO situations. It is encouraging to see some multi-disciplinary papers emerging. For example, ETO papers drawing on project management and new product development concepts. This could and should go further across the next decade. However, there are a number of research challenges we have identified associated with future research relating to the interactions between the streams, and we position our future research agenda against those challenges.

The positive science challenge. The need to understand failure is challenged by an observed 'publication bias' or 'positive science' bias, whereby it is more commonplace to study and publish what does work (rather than what doesn't). This has been observed in the physical sciences but is also pervasive in management research (Harrison et al., 2017). Overall, further guidance is still needed regarding what to adopt, adapt, and reject from mainstream operations and supply chain literature, but the majority of papers focus on what should be adopted. Consequently, when researchers address our future research questions, we would encourage research that demonstrates negative results, strategies or approaches that have not worked out as expected or refuting commonly held assumptions.

The comparative research challenge. As observed by Birkie at el. (2017), measurement of performance gains is not always easy in ETO manufacturing, because a single ‘like-for-like’ reference may not be valid for comparing the diversified projects and orders. Nevertheless, the research base would benefit from, where possible, performance data or proxies for performance outcomes. This is particularly relevant to the future research directions concerning strategies for ETO and the applicability of lean/agile in ETO situations.

The prescriptive research challenge. Some researchers have noted (e.g., Dixon, 1989) that, as bodies of knowledge mature, it is helpful for high quality prescriptive models to emerge (how things should or can be done in particular circumstances, and why it works in those circumstances), rather than just relying on descriptive models (what happens in a particular system or situation). This challenge is particularly relevant to integrating literature streams. highlighting the need to link the description of situation (e.g., as per the definitions literature stream) to possible strategies that can be used to guide those situations (as per literature streams 2 and 3). Clearly, there is a need to reflect on the type of prescriptions required in ETO environments, and linking to the previous point, what type of evidence is required to demonstrate, test, and validate any proposed prescription.

The multidisciplinary research challenge. A common observation in scientific research is the need to work across disciplinary silos and interfaces, but in doing so there are many barriers. Through the literature analysis, we have noted evidence of ETO research beginning to link with different disciplines and communities, for example in the project management, mass customisation, different specialist sectors, and design. We would welcome this to go further and encourage collaborations between researchers with different expertise and backgrounds in pursuit of new knowledge relating to ETO situations.

Figure 4 shows a synthesis of the findings of this research, related to the progresses on the ETO streams, the new questions opened based on the future research areas identified and the key challenges related to the integration between the three literature streams.

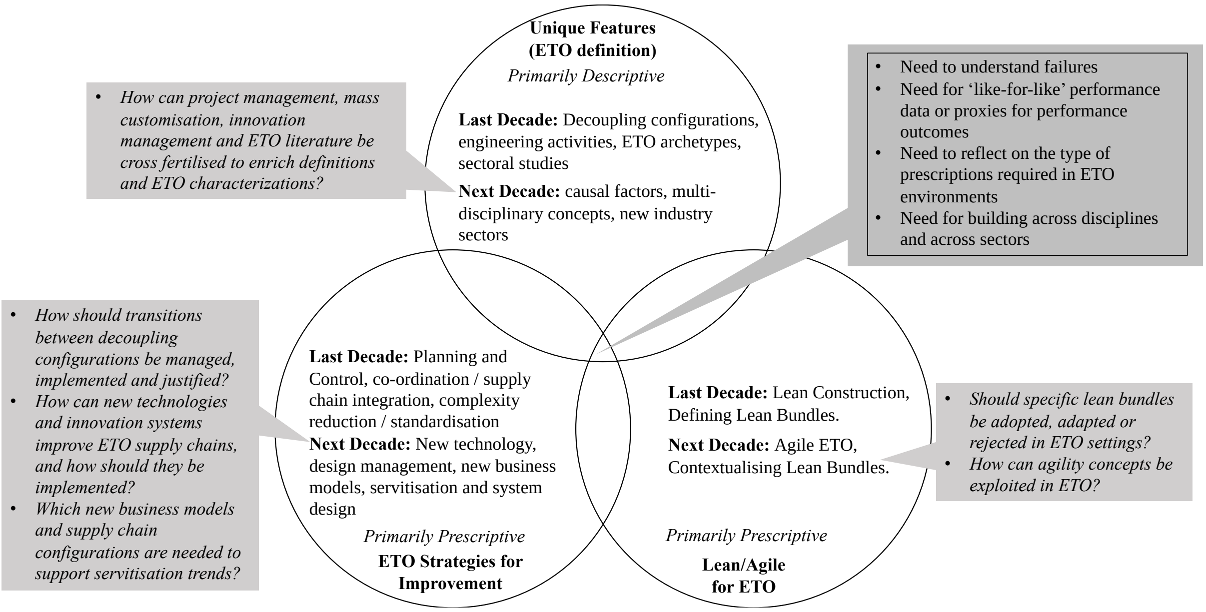

Figure 4. Synthesis and integration of literature streams

9 Conclusions

This article makes contribution to the literature by identifying, synthesising and analysing research across the last decade (2010-2020) to assess the progress made in our understanding of supply chain management in ETO situations, and by identifying categories of research challenges and future research questions flowing from the content analysis. It is the first to systematically assess progress specifically across the ETO body of knowledge using a literature analysis approach since Gosling and Naim (2009). The aim of this research is to present a review, including a descriptive and thematic analysis, of the papers contributing to ETO literature between 2010-2020, identifying the main patterns, themes, and major advances in ETO research revealed over the last decade, and to develop an agenda to guide the next decade.

This aim was developed into two research questions to guide the enquiry. First, we asked *'what themes, patterns and evidence relating to supply chain management in ETO situations emerge over the last decade (2010-2020)?'*. The systematic review of 151 articles show that changes are affecting the ETO research field in terms of research methodologies: the number of alternative methodologies applied is increasing, and the distribution is becoming more homogenous compared to the previous years. Also, the number of empirical studies and sectors addressed has increased over the years and new sectors have been included. By analysing the literature streams, additional insights on decoupling configurations and ETO archetypes have been related to the progresses on the ETO definition stream. The analysis also identified clear links with the project management literature. Progresses on ETO strategy stream provide much more details to overcome the limitations identified in 2009 by Gosling and Naim. Established themes, such as ‘complexity reduction and standardisation’, ‘configuration of supply chain structure’, ‘supply chain integration’ and ‘planning and control’, continued to receive attention by researchers, and a number of new and emerging themes/sub themes have been identified, many driven by technological developments. These include ‘industry 4.0’, ‘design automation’, ‘appropriate business models’ and ‘uncertainty/risk management’ Finally, progresses have been made in the ETO lean and agile stream, mainly regarding the definitions of potential lean bundles and the evidence of their application and success.

Second, we asked, *‘what are the future research challenges and questions regarding supply chain management in ETO situations for the next decade (2020-2030)?’*. Based on the results obtained from the literature review and reflecting across the literature streams, we would encourage: further cross fertilisation of disciplinary perspectives to enrich definitions and ETO characterizations; further evaluation of industry 4.0 technologies application in ETO contexts; further guidance on how to manage, implement and justify transitions between decoupling configurations; further research to explore the link between ETO body of knowledge and servitisation; further insights on the adoption and adaptation of lean bundles; and further studies on ETO agile and lean/agile debate. Also, we identified four main research challenges, including the positive science challenge, the comparative research challenge, the prescriptive research challenge and the multidisciplinary research challenge. These results can guide future research on addressing research issues and current research challenges that still need for additional investigations and analysis to support and enrich the supply chain management body of knowledge. Managers and practitioners may find this timely synthesis and analysis of the literature themes useful to reflect on best practice and to use as a guide to identify what may or may not be suitable initiatives for supply chain management in ETO situations.

In this study, we decided to exclude additional keywords used by Gosling and Naim (2009), such as 'build-to-order', 'make-to-order', 'one-of-a-kind', etc., since today, after 10 years, the knowledge base is much more coherent, and the ETO concept has become more mature and widespread and ETO keywords cover a wide range of relevant studies and make the scope manageable. However, we are aware that this could represent a limitation and some studies could be excluded because of this choice. Therefore, this study is limited to the systematic citations of Gosling and Naim (2009) and a focused keyword search and filtering criteria to identify papers directly relevant to supply chain management in ETO situations. Future researchers could consider broader keyword search and an alternative screening process.

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