The System Dynamics of Engineer-to-Order Construction Projects: past, present, and future

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Abstract

System Dynamics (SD) applications in high volume production operations is ubiquitous, helping to define decision rules to reduce costs associated with the variance in planning orders and inventory. The exploitation of SD in engineer-to-order (ETO) project-oriented supply chains, e.g., in construction, shipbuilding, and capital goods, is less well established. Hence, this research reviews papers which take a systematic ETO perspective modelling construction project, exploiting SD approaches. To comprehensively identify and filter previously published papers, we use a keyword searching method using Web of Science and Scopus databases. After applying relevant exclusion criteria, 145 papers are finally selected. While there have been previous reviews of ETO literature more generally, this paper contributes to the body of knowledge by specifically reviewing SD applications in ETO industries and providing insights by creating a categorization system by which to determine where existing gaps reside. Papers are categorized into the classic four phases of a project: aggregated planning, pre-project planning, project execution, and post-delivery phase. Analyses of the methods, attributes and applications of SD are undertaken for each phase. Findings indicate that SD research covers the range of ETO industries of which construction is the most dominant, demonstrating SD's high applicability. The wealth of case-orientated research in the construction field provides a solid foundation for further SD studies in the ETO field. Further research should focus on 1) developing a general ETO archetype used for performance benchmarking and strategy development in construction projects, 2) introducing analytical tools, such as control theoretic approaches as found in manufacturing production planning and control design, to improve understanding of the ETO systems' dynamic behaviors, and 3) developing cross-phase, cross-project, design production integrated, aggregated planning models via hybrid techniques modelling, which can contribute to a better understanding of an ETO system's performance.

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4) improve model fidelity. Besides, 5) we also provide a research agenda for each phase of the ETO production.

keywords: Literature review, Modeling, Project management

1 Introduction

ETO production, such as in construction, shipbuilding, and capital goods, often face cost overruns and schedule delays. For example, in the United States, the cost increases of medical center construction projects from the Department of Veterans Affairs range from 59% to 144%, with in total $1.5 billion overrun. The delay for those projects ranges from 14 to 74 months (GAO 2013) . The same issues were also observed in nuclear power project construction, where the mean duration time is 239% of that planned, and the mean cost was 338% of the original estimate (Taylor and Ford 2008). These problems can be attributed to the complexity of the ETO supply chain structure, interactions between engaged entities, and the associated uncertainties such as specification, supplier lead time, relationship management production structure, and engineering lead times (Alfnes et al. 2021).

Based on the existing research, ETO supply chains are defined as dynamic complex systems wherein products, or services, are driven by individual customer orders (Gosling and Naim 2009). Hence, the customer order penetration point locates at the engineering design stage, which's yields an individualized product delivered via a project-based production system (Wikner et al. 2007, Gosling et al. 2017). An ETO process consists of design, procurement, fabrication, assembly and distribution (Naim et al. 2021), wherein the design activity is an integral phase in the total process, so as to deliver an end product made to a specific requirement and managed as a project (Yang 2013; Kaufmann and Kock 2022). This is in contrast to other forms of production, as in the automotive, fast-fashion or speculative built homes sectors, where production design is a separate process predominantly aimed at mass markets or their segments, and the focus is on managing repetitive material flows.

There exists a rich vein of qualitative research into ETO production. Such research deepens our understanding of the ETO by conducting in-depth empirical research into infrastructure projects (Naim et al. 2021), machine tool manufacturing (Adrodegari et al. 2015), and shipbuilding (Alfnes et al. 2021). Also, some attention has been given to the definition of ETO including developing and exploring the sub-classes of ETO (Gosling et al. 2017). However, the adoption of quantitative methods in ETO sectors is relatively small in comparison to qualitative approaches (Giada and Gosling 2021), with less research in ETO system dynamics analysis. However, due to the strong connection between ETO with project management (Cannas and Gosling 2021), Models adopted in the project management context unfold some ETO systems' dynamic properties. However, due to the un-unified terminology and the boundary between supply chain and project management, these models have not been fully reviewed and assessed from the ETO supply chain perspective.

System Dynamics (SD), and the related Control Theory (CT), are two typical system approaches frequently used in analyzing and synthesizing production systems. Both adopt time delays, feedback paths, and decision rule attributes in the modeling process to represent the system structure. While SD is more simulation-focused and CT more mathematical and analytical, the two techniques can be used synergistically and/or interchangeably, both techniques are widely used in production system development and analysis (Wikner 2003; Lin et al. 2017), to provide a platform for establishing system archetypes. For instance, the Inventory and Order Based Production Control System (IOBPCS) (Towill 1982) archetype provides an insight into inventory management. The Make-To-Order archetype (Wikner et al. 2007) presented a model-based approach to better manage the supply chain in a mass-customized environment. Figure 1 demonstrates the structure of an MTO system in causal loop diagram form based on Wikner et al. (2007). More recently, the assemble-to-order archetype (Lin et al. 2020) analyzed the dynamic behavior of the semiconductor supply chain under different inventory levels. The application of SD and CT in supply chains has been reviewed by Sarimveis et al. (2008) and Lin et al. (2017). In the meantime, Wu et al. (2020) reviewed system dynamics research in the construction field, while there is no review aimed at the SD and CT's application in the ETO sector. Thus, this research gap motivates us to conduct this review.

Figure 1 Causal loop diagram of a make-to-order system (based on Wikner et al. 2007)

(Wu et al. 2020)This paper aims to bridge the gap between Project Management modeling with Supply Chain modeling by reviewing the application of SD and CT in the ETO systems and its sub-fields, providing readers with an insight into the development of SD and CT in this interdisciplinary field, and discussing the opportunity and difficulties in ETO system modeling. For ETO researchers, this paper can benefit them in the research methods aspect. For SD or CT model experts, this paper provides them with an extended application field. The aim of this article can be broken down into three objectives, as shown in **Table 1**. Based on the objectives, three research questions are posed.

Table 1 Research Objectives and questions

2 Background

2.1 An overview of the ETO supply chain

ETO supply chain research emerged in the 1980s but is now becoming a coherent body of knowledge for those interested in managing highly customized engineering solutions (Cannas and Gosling 2021). Bertrand and Muntslag (1993) categorized the supply chain into four groups: Make-to-Stock, Assemble-to-Order, Make-to-Order, and ETO supply chains. Although ETO emerged in the context of the operations and supply chain discipline, it has a strong connection with project management, which can be seen from the typical ETO industries, including construction (Wesz et al. 2018; Barbosa and Azevedo 2019), shipbuilding (Mello et al. 2015; Papachristos et al. 2020b), and capital goods (Wrzaczek and Kort 2012; Birkie et al. 2017). Products in these industries are often delivered via projects, rather than as continuous high volume production processes.

2.2 An overview of System Dynamics

SD was developed in the mid-1950s by Forrester (Forrester 1958) and has been widely used as a simulation method in supply chain management and project management (Lyneis 2012; Wikner et al. 2017). By simulating the causal relationships among quantified variables, SD combines the advantages of conceptual systems thinking with mathematical formulation, providing a platform for designing solutions to problems.

SD is widely used in supply chain management, such as inventory control, lead time analysis, and ordering policies development (Lin et al. 2020). Multiple effective and efficient models were developed based on SD, such as the Inventory and Order Based Production Control System (IOBPCS) family (Wikner et al. 2017), which has been adopted in multiple supply chains but not yet for ETO situations. Adopting SD in supply chain design helps managers to understand the potential variability induced by internal systems structure and internal and external disturbances. Hence, SD provides management with a policy testing platform to determine stock holding, lead-time, and capacity level requirements.

SD also plays a decision support role in project management, especially in construction. Compared with the supply chain quantity-oriented applications, most SD in project management are process-oriented (Lee 2006; Shafieezadeh et al. 2020). SD has been adopted in most project phases, covering aggregate planning (Huang and Wang 2005), pre-construction planning (Lingard and Turner 2017a), project execution (Alvanchi et al. 2011), and post-delivery (Hao et al. 2007). SD is used in national macro real estate regulation (Huang and Wang 2005), policymaking (Park et al. 2011), and execution from the management level (Lee et al. 2006a), which enabled SD to become a potential bridge to connect project management and supply chain management.

Because of SD's excellent scalability, more and more SD-based hybrid simulation modeling approaches have emerged, such as SD-Agent Based Modelling (SD-ABM) (Barbosa and Azevedo 2019; Hafeez et al. 2020) and SD-Discrete Event Simulation (SD-DES) (Shin et al. 2014; Goh and Askar Ali 2016). Such amalgamations extend the application range of the models and improve their fidelity, which shows greater potential to be adopted in a complex system simulation and modeling.

3 Method and research design

To guarantee the objectivity of this work, we follow the literature review guidelines and a four-step process proposed by Seuring and Gold (2012), namely, (1) Material collection and filtering, (2) Descriptive analysis, (3) Category selection, and (4) Material Evaluation. This section will introduce a research procedure based on these four-step processes following the structure presented in **Figure 1**.

3.1 Material collection and analysis process.

The scope of this review is on the research that adopt SD and CT in modelling ETO projects, to provide insights into the status and development of these methods, thereby addressing research question 1 and research question 2. The reason to place our focus on SD and CT is that, while there have been more general ETO supply chain literature reviews (Gosling and Naim 2009; Cannas and Gosling 2021), there has been no review conducted focused on those specific methods. After preliminary research, we found those systems-based approaches are widely used in both fields, hence potentially providing a bridge for knowledge sharing between Project Management (PM) and Supply Chain Management (SCM). While we focus on the quantitative SD and CT techniques the models developed from empirical studies are often founded on qualitative systems approaches such as systems thinking and soft system methodology (Naim and Gosling 2022) but such methods are beyond the scope of this study.

Given the consideration that terminology in PM and SCM might be different, we adopt a Key Word Search method on two mainstream academic databases "Web of Science" (WoS) and "Scopus," thereby comprehensively sampling papers across a range of journals and related disciplines. The keyword-setting process went through two iterations to collect papers precisely and comprehensively, as shown in **Table 2**, which also explains the rationale for redefining the terms of the keywords. The final keyword terms were determined and are presented in **Table 3**. Because of the limitations of character representations in the Scopus and WoS databases, four search terms combinations were utilized in **Table 4**. To narrow down the scope and focus on the SD and CT applications in

ETO fields, we adopted five exclusive criteria which are listed in **Figure 2**. The first and second criteria guarantee the material's quality and readability, and the third criterion limited our scope before November 2023. The fourth and fifth criteria exclude papers that are not relevant to our study. 575 papers were identified by exploiting the search terms combinations, and five filtering criteria were used to ensure adequate scope, as listed in **Figure 2**, yielding 145 articles that were then the subject of the analysis.

Figure 2 Literature review material collection and filtering process (based on Lin et al. 2017)

Table 2 Keyword setting process.

Table 3 Final version of searched keyword combinations.

Table 4 Keywords Combination used for searching databases

3.2 Descriptive analysis

Following the material collection, descriptive analysis was conducted to quantitatively analyze the publication trends and distribution of publications in journals, which provides readers with an up-to-date introduction to the status of knowledge development. In addition, after categorization, the detailed descriptive analysis will be presented in section 4.2 to illustrate the allocation of sampled papers across each category.

3.3 Categorization Selection

Phases categorization

The phases categorization was developed based on Gosling et al. (2016)'s work, which contains four groups, namely: Aggregating planning, Pre-project planning, Project Execution, and Post-Delivery. Aggregating planning includes papers that study ETO from a macro level, and that group of research provide readers with analysis, understanding, or guidelines in company, organization, or market level management. The pre-project phase refers to the project preparation and mobilization stage, covering papers focusing on enhancing the project performance at the preparation stage. The project execution phase comprises papers study on project level management; compared with the aggregating planning phase, project execution phase research mainly focuses on individual project (product) execution (production). Post-delivery contains research focus on activities after the project is delivered, including but not limited to waste management, demolition management, and maintenance. As a complementary to the phase categorization, papers will be categorized into two groups based on their purposes, namely to demonstrate the structure of the system, and to demonstrate the mechanism of interventions. Finally, the categorization result will be shown in a matrix, with phases as the horizontal axis, with model's purpose as the vertical axis.

Topics Categorization

Table 5 Coding table

Considering the dispersed status of current research in ETO research, we adopt an inductive method to classify papers according to the main goal or topics. These topics were identified based on emerging themes from each paper read. Adopting the inductive approach in this paper contributes to the comprehensiveness of this review. This advantage has been recognized in the following review papers. Seuring and Gold (2012) adopted inductive methods to collect the research direction of the supply chain literature review. Wu et al. (2020) undertook a topic identification method in the construction management field, nine popular topics were summarized.

3.4 Material Evaluation

The collected papers will be evaluated according to the coding table in **Table 5** and analyzed by categorization. Each article was reviewed by in-depth reading and subsequently coded by **Table 5**, which provides the description and reason for using each code to extract information from papers. To note here, the first column indicates where each code will be used and match each code to a particular categorization or analysis.

4 Findings

4.1 Citation network

Figure 3 demonstrates the citation network of sampled papers, wherein 61 papers do not cite or are cited by other articles, 84 articles cite or are cited by at least one paper. This finding illustrates that adoption of SD in ETO field is scattered because almost a quarter of the research in the sample group is independent. However, some research direction emerged, color in **Figure 3** representing the cluster that the paper belongs to, and the name for each cluster were labeled. These clusters are automatically generated by the Vosviewer's algorithm, which follows a five-step procedure, 1) extracting, 2) categorizing 3) counting. 4) association strength calculation 5) Euclidean norm value calculation (Van Eck et al. 2008).

Figure 3 Citation network produced by Vosviewer

4.2 Descriptive analysis

Figure 4 Publications trend

Figure 4 shows the trend of the publications from 1985 to 2022. This paper aggregates research in a 5-year bucket, which helps readers have a clear view of the primary trend instead of fluctuations. A rising interest in applying SD simulation in ETO can be seen. However, only three papers adopt CT in research. Compared to the SD, CT can analyze the system and explain how certain phenomena happen (Lin et al. 2017). This finding suggests that most models' built-in research is simulation-orientated, and analytical research is inadequate in the current stage.

Table 6 Sample distribution across journal

The distribution of papers across journals highlights the appropriateness of using the keywords searching method. Fifty-four different journals are identified, contributing three or more papers to the sample listed in **Table 6**. Listed journals contribute 59% of the total collection of paper is 145.

Four primary industries were identified in the ETO sectors, construction 94%, shipbuilding 3%, capital goods 2%, generic ETO 2%. The construction sector is the leading sector, demonstrating the maturity of the adoption of SD in that sector. Moreover, three papers adopt CT, distributed in construction (2 papers) and shipbuilding (1 paper).

Table 7 Publication distribution over phase

The papers' distribution across phases is shown in **Table 7**. The pre-project stage attracts most of the attention from researchers, which occupies 26%, followed by the post-delivery phase, which contributes 25%. 23% of papers focus on the project execution phase, and 120% focus on the aggregated planning period.

Besides research focusing on a single-phase, 6% of papers undertake cross-phase simulation, which indicates the start of research looking at inter-phase and a more holistic view to analyzing the ETO supply chain. This novel direction provides a potential foundation for ETO archetype building.

Table 8 Publications distribution over methods and project stages (DES: Discrete Event Simulation; ABM: Agent Based Modelling)

According to **Table 8**, SD is the dominant simulation method in the papers identified, while only four papers exploit CT. We also observe that 16 papers, almost 9%, adopt hybrid simulation techniques in ETO research. Therein, eight papers study Project Execution (PE) or PE centered cross-phase modelling, while the other four are in Pre-Project planning (PP), with the other four in post-delivery phase. The first hybrid modelling paper of our sampling group was published in 2006 and yet the application of hybrid modelling in the ETO field is still in its infancy stage.

4.3 Phase Categorization

4.3.1 Aggregate results

In this section, papers will be categorized, summarized, and analyzed. In section 4.3.1, **Figure 5** demonstrates an aggregated map to give readers an overview of the categorization result from a macro level. From 4.3.2 to 4.3.5, we dive into the categorization and analyze the topics distribution of each group. In each section, we also provide a discussion regarding the research topic (the result of topic categorization) to give an in-depth review of each topic.

Figure 5 Research topic distribution against phases

96% of the papers take a PM perspective instead of an ETO-supply chain view. That may be attributed to the following reasons: 1) ETO is an emerging topic in supply chain that has not received adequate attention, while project management, especially in construction, is a well-established field of endeavor. 2) As ETO production tends to be 'one/first of a kind,' scholars take a project perspective to study this field. 3) ETO systems require models representing both the supply chain and project perspectives; however, such techniques are in the infancy stage of development, and there is a lack of related modeling guidance. Although much of the PM research included in this review does not explicitly mention ETO, they do offer PM models that provide a reference base to allow simulation of the production aspect in the ETO system, thereby enriching the toolbox for ETO research and promote knowledge sharing between PM and SCM. The following analysis provides a systematic assessment of Phase-Topics categorization in a tabular form **Figure 5**.

4.3.2 Review for aggregate planning group

This group covers papers focusing on innovation, finance, and marketing topics (See **Table 9**). Research in this group holds an aggregated view and aims to improve the organization's performance by providing a better understanding of the system nature and the policies' influences. While few papers in this group investigate aggregate-level capacity management, even fewer papers study the impacts of an organizations' capacity on the tendering decision. Although capacity shortage may sometimes be overcome by outsourcing, if not addressed, such capacity limitations will directly result in lead time delays and customer service levels will decrease.

Innovation: The construction industry often confronts new and complex problems that require unique, innovative solutions (Park et al. 2004), while it is often criticized for lacking innovation (Suprun et al. 2019). SD was adopted to investigate innovation management and explore solutions to accelerate the development and diffusion of innovations.

Finance: As mentioned in the introduction section, ETO companies are often confronted with schedule and cost overrun. Four papers focus on cost management, including cost overrun causes analysis and construction financial performance investigation. The other group focuses on cash flow policies development, which utilizes SD to simulate the cash flow system.

Marketing: 12 papers target the ETO market modeling and analysis, covering shipbuilding, houses, and capital goods markets. Research in this group often holds a macro view to investigate the mechanism and structure of the market system and assesses intervention policies' impact on the market.

Others: Besides those topics mentioned above, another two topics are detected. One aims at supplier management and the other aims at the government's role in diffusing prefabrication constructions.

Table 9 Aggregate Planning category

4.3.3 Review for Pre-project phase

Topics in this group cover safety and health management, risk management, and training and learning management (See **Table 10**). Adoption of SD enables researchers to have a systemic view to study the problems in pre-project stage. However, two issues were identified. Most models in this group are case-orientated, there is a need for further generalization and categorization. Second, the Causal Loop Diagram (CLD) technique demonstrates the causal relationship between variables, while some modeling examples in this topic did not clarify relations between variables as correlation or causal relationships, which may lead to misunderstanding for readers.

Safety and health: Unsafe and unhealthy behaviors damage workers' productivity in the short term and have a long-term influence on their health. This may also lead to other adverse consequences to the project implementation by knock-on effect, such as, organizational productivity decrease, non-conformance rate increase and cost overrun (Mohamed and Chinda 2011). The introduction of SD modeling contributes to this topic by providing a systematic view of the safety and health management system, which overcomes the barrier created by the project's complex implementation environment.

Training and learning: Training and learning are core activities in improving the team's performance, especially in the project preparation stage. A well-trained implementation team may benefit from the construction quality, overall project performance, and reduction of rework. In the meantime, a well-designed experience to knowledge transferring process contribute to the organization's long-term improvement. SD was utilized to investigate the causes for inefficient training and simulate the experience transfer process.

Risk Management: Risks in the project are diverse and scattered, depending on the project's diverse properties. Besides, risks' impact may be aggravated due to the complex structure and interactions in projects. SD was adopted to simulate how the risks affect the project and analyze the interactions among risks factors. SD also demonstrates its strength in determining knock-on or unintended consequence effects by providing visibility of how the original problem yields adverse impacts to the whole system, and which variables finally respond to such outcomes.

Others: Besides the topics above, this group also includes information management, construction performance assessment, labor shortage problem and adoption, and Six-sigma.

Table 10 Pre-project category

4.3.4 Review for project execution phase

As the core activity in both the project management and the supply chain management fields, this stage attracts the most attention (See **Table 11**). A potential archetype has been identified from this stage. However, according to the ETO definition, the model should compose of both design and production systems; while there are only few references (Lee et al. 2005; Park et al. 2009) combine design with the production system, further research could attempt to model the system by amalgamating design with production, thereby exploring the dynamic of ETO system.

Design: Design and production are often regarded as separate activities. However, the ETO system should include design activities, as the engineering process is integral to such a system (Parvan et al. 2015). Thus, we regard design as an essential client-specific value adding activity and classify design-relevant papers in this group. SD was utilized in 1) design process simulation, 2) design error research, and 3) design sharing analysis, which demonstrates the applicability of SD in design process modeling.

Production: Production is the core activity of the project execution, which is also a determinator for schedule and cost performance. This research direction attracts quite a lot of attention from academia. SD was applied to 1) analyze causes of poor productivity, 2) model the production process, 3) study the rework, 4) improve the schedule performance, and 5) simulate the prefabrication process. These models provide a quantified and systematic view of production control which deepens our understanding of project management. Besides, this group contains three papers that adopted CT. The introduction of optimal CT provides a set of mathematical, analytical tools in earthmoving processes, capital goods production and ship panel manufacture schedule optimization.

Quality: One of the construction industry's primary trade-offs is between quality and cost. (Shafiei et al. 2020) first adopted SD into the quality-cost trade-off analysis and proposed a model to analyze the effect of policies that are designed to decrease the cost of quality.

Dynamic Planning Methodology: Dynamic Planning Methodology (DPM) is identified as a potential candidate for ETO system archetype, which is adopted in 5 papers. This model, which is developed based on SD, simulates the construction project process. This method has been utilized in production process research, rework simulation, and design errors analysis. Demonstrate its applicability in the project management field.

Table 11 Project Execution category (DEMATE: Decision-Making Trial and Evaluation Laboratory)

Table 12 Post Delivery category

Figure 6 Dynamic Planning Methodology (reproduced from Lee et al. 2005)

The main structure of DPM is illustrated in **Figure 6**. This model has been utilized in 1) cost of quality analysis (Lee et al. 2005), 2) change management (Lee and Peña-Mora 2007), 3) fast-track technique analysis(Peña-Mora and Li 2001), 4) design error investigation (Lee et al. 2006a), and 5) non-conformance analysis (Love et al. 2010). This research further upgrades this model by adding new variables and feedback loops.

4.3.5 Review for post-delivery phase

With the increasing attention paid to life-cycle project management, an increasing amount of research has been conducted in this phase (See **Table 12**). Wherein three main topics are identified: 1) environmental performance analysis, 2) maintenance repair and operation, and 3) Dispute solving. The post-delivery phase received more attention, not only because of the increasing demand for environmentally friendly production, but also because of the great potential for cost saving, e.g., via remanufacturing and recycling.

Environmental performance: large scale projects, such as in construction or shipbuilding, have the potential to have a negative impact on the environment if supply chains do not take the following issues into consideration: construction waste management (Ye et al. 2012), demolition waste management (Yuan et al. 2011), carbon emission (Papachristos et al. 2020), and noise reduction (Yao et al. 2011). Papers aiming to analyze or improve the environmental performance of ETO projects are classified into this group, wherein waste management attracts the most attention.

Others: SD was also utilized in other post-delivery activities study besides environmental relevant research. **Maintenance** is critical for ETO products, especially for cargo ships and capital goods, which often require regular maintenance after delivery. In addition, when the products break down, the customer may need support from the original manufacturer. Thus, post-delivery management is also crucial for ETO products. SD is applied to simulate the adverse impact of the machine breakdown and highlights the importance of equipment maintenance. **Dispute:** One of the distinguishing features of the construction industry is the high cost of resolving disputes and conflicts. SD is also adopted in this research topic to simulate the process of dispute resolution.

4.3.6 Cross Phase research

This category includes papers that adopt SD in cross-phase research (See **Table 13**), which contribute the body of knowledge by providing aggregated, multi-level models, and demonstrating the ETO system's cross-phase behaviors.

Table 13 Cross-Phase category

Pre-project planning - Project execution: Three research topics are identified, 1) Process modeling, 2) Adaptive building, and 3) Design-build delivery system, wherein process modeling occupied the most significant proportion. Papers in this group bridge the gap between production and project preparation, depicting the connections and interactions between these two stages.

Aggregate planning – Pro-project planning – Project execution (AP-PP-PE)

Two papers are classified into this group. Dynamic planning methodology (DPM) is combined with discrete event modeling technique and simulates the AP-PP-PE process, demonstrating this cross-phase system's dynamic. Another paper adopts SD to simulate the revolving-fund sustainability improvement program. Compared with the model only focusing on a single-phase, AP-PP-PE simulation provides a macro view of the system dynamics, improving the model's fidelity.

5 Discussion and future research agenda

Figure 7 A summary of discussion findings and future research agenda

Figure 7 demonstrates the structure of this section, wherein four discussion points are proposed based on five main findings. The future research agenda is provided from two perspectives. The first four streams take a more holistic ETO perspective while the fifth is for focused research on each construction phase.

5.1 Stream 1: ETO archetype

Discussion: Is there a need for an ETO archetype?

Compared with the other kinds of production systems, e.g., Make-to-Stock (MTS) (Towill 1982), Make-to-Order (MTO) (Wikner et al. 2007), Assemble-to-Order (ATO) (Lin et al. 2020), the ETO community has not yet developed a recognized archetype to model and benchmark against.

An archetype, which is defined as a typical and general model of a specific system (Batista et al. 2018), could assist researchers in providing generic managerial guidelines from the following perspectives, 1) provide suggestions on aggregated level capacity management (Lin et al. 2017), and assist management to estimate the extra capacity to offset the impact of rework (Zhou et al., 2022). 2) provide a platform for researchers and practitioners to design and test managerial interventions via simulation (Pena-Mora and Park 2001), 3) estimate the aggregated level lead time/delivery time based on Little's Law (Wikner et al. 2007), 4) building a bridge to promote knowledge exchange between PM and SCM, 5) provide a solid quantitative foundation for further dynamic studies, to gain deeper insights into production dynamic behavior (Spiegler et al. 2012), thereby guiding management policies, such as tender decisions, outsourcing and resource management. Following research from the SCM field, a deep understanding of a system's parameters, variables and structures contributes to ensuring system stability and mitigate excess variances effects that contribute to increased costs (Disney et al. 2004). In addition, another finding from this review suggests that research in this arena is scattered but rich in terms of empirical cases. Hence, if there is a unified archetype, it may provide a platform for knowledge pooling to significantly boost the development of ETO SD research.

However, an SD archetype also has limitations, such as, 1) an archetype only represents the general scenario and hence for a specific industry or project, researchers still need to modify and adjust the model to correspond to the real-world scenario (Shafiei et al. 2020), 2) SD as a top-down simulation technique has critique, such as its weakness in capturing disaggregate detail (Ding et al. 2016a).

Even though SD archetypes have some weaknesses, given its advantages, we believe there is still value in developing a general model and the disaggregate modeling weaknesses may be addressed by hybrid modelling, such as Agent based – SD and Discrete Event – SD modelling. In terms of the disadvantages being too general, the development of any kind of model required effort from both practice and theory. We believe with more effort made on model implementation and model adjustment, the archetype will play an important role in ETO field as it has with others in MTS, MTO and ATO.

Future research: How to develop an ETO production system archetype.

An opportunity lies in the fact that there is some evidence of the early stages of an ETO archetype development which may act as a springboard for developing generally recognized archetypes by researchers in the field. We found four papers explicitly using the term archetype, with three in safety management (Mohammadi et al. 2018 ; Mohammadi and Tavakolan 2020; Guo et al. 2015) and one for rework mitigation (Zhou et al. 2022). The safety archetype is only designed for safety management, and the rework archetype is limited in scope to production non-conformances and localized rework. Hence, a well-established ETO archetype is still absent. We believe that the DPM as a maturity model in project management needs further consideration for SCM but may prove to be a significant benchmark reference in ETO archetype development.

5.2 Stream 2: Dynamic analysis

Discussion: Adoption of system dynamics approaches in ETO field is still at its infancy.

The adoption of SD in ETO can be categorized into 1) Demonstrating the causal relationship between variables obtained from survey, interview and literatures sources, 2) Analyzing the causes of a typical problem such as poor productivity, injuries, and cost overrun. 3) Modelling dynamic behavior to have a better understanding of system structure, 4) Testing control policies or newly conceived interventions on an SD platform. In terms of CT applications, only four papers adopted such a technique; wherein two adopted optimal control (Tomiyama 1985;

Handa and Barcia 1986), one adopting multi-input multi-output technique (Laursen et al. 1998), and one adopted classic control theory (Zhou et al. 2022).

Beyond demonstrating the relationship between variables, by modelling dynamic behavior via SD simulation, CT could further understanding of system behavior via transfer function state space representation (Sarimveis et al. 2008). The introduction of such analytical mathematical tools could precisely explain the relationship between each state-variable and demonstrate coefficients' effects on system performance, such as transient responses, stability and chaos (Lin et al. 2020). These tools have long been adopted in supply chain analysis and provide managerial insights from a quantitative perspective, e.g. the bullwhip effect in the supply chain system (Wang and Disney 2016) and stability analysis in Assemble-to-Order systems (Lin et al. 2020).

Moreover, during the last decade, research has adopted hybrid modelling techniques in the ETO field, helping to analyze the link between ETO phases. Such a development gives more opportunities in detecting how a low-level change or short-term disturbance affects the overall system, and how the aggregated level decision affects low-level variables.

Future research: How to adopt dynamic analytical tools for ETO.

As discussed above, adopting CT in ETO system can give us a deeper understanding of the system's dynamics, while there are several barriers to overcome, 1) what variables and coefficients should be included in the CT model, 2) how to transform an ETO production system into CT model representation, 3) how to explain quantitative result from CT model into meaningful management information.

5.3 Stream 3: Dynamic Planning Methodology

Discussion: How to integrate design and production.

A well-established and analyzed SD model for construction was identified. The Dynamic Planning Methodology (Pena-Mora and Park 2001), has shown its capability to capture major features in construction projects. Ten papers were found to adopt SD in the research, with five in the Project Execution stage and five in the Pre-Project cross Project Execution phase. Dynamic Planning Methodology is developed based on stock and flow diagram, which includes key variables like work-to-do, rework, work completed et al. Because of its excellent scalability, considerable research has expended its adoption in design (Han et al. 2013), rework (Han et al. 2012), change management (Motawa et al. 2007) and quality management (Lee et al. 2005) by adding new variables. Due to it covering several variables which are also crucial in the ETO supply chain, Dynamic Planning Methodology has vital reference significance for ETO archetype development. However, the main barrier for establishing DPM in the supply chain is transforming it from project-orientated to a supply chain-orientated model.

Future research: Integrated design and production system.

As per the definition of ETO system, design is a core process for ETO project, while only few papers include design into their consideration(Lee et al. 2005; Park et al. 2009; Parvan et al. 2015)). This problem could be attributed to the difficulties in soft system modelling and designing workload measuring. Therefore, further research could reference the DPM structure as the production sub-system, and combine it with the designing sub-system, to provide a holistic and general archetype for ETO.

5.4 Stream 4: model generalization

Discussion: The need for greater breadth of empirical study and cross-sector research.

As mentioned in Section 4.2's descriptive analysis, most of the research pays attention to applications in construction (94%), shipbuilding (3%), and capital goods (2%) with only 2% exploring generic characteristics.
While most of the research sampled in this review came from construction field, other industries applications are also fruitful area to be investigated, such as capital goods (Größler et al. 2008) and ship panel production (Laursen et al. 1998). These production lines often require both project and supply chain knowledge to combine aggregated planning with project execution. ETO system researchers could broaden their research interest from individual sectors, such as construction, to the other ETO systems, thereby enriching good practices for a generalized ETO model.

Moreover, the wealth of case-orientated research in the construction field provides a solid foundation for further SD studies in the ETO field. This research could contribute to the development and knowledge sharing in the ETO supply chain and project management.

From this review, we identified four hybrid techniques 1) SD-ABM modelling: SD was used as a decision-making engine for an agent, and an agent representing ETO orders or project participants. (Khanzadi et al. 2018; Barbosa and Azevedo 2019) .2) SD-DES: DES models reproduce the project process itself by simulating the activities in the process (a bottom-up approach) while SD has advantages to simulate the feedback mechanism in the PM process (a top-down perspective). Such combinations enable researchers to study the cross-phase system, and broden the application area of both methods (Peña-Mora et al. 2008). 3) SD-ABM-DES; combines the advantages of these three techniques, enabling users to capture the interaction between agents, reproduce the system's dynamic and replicate the discrete events. In Lee et al. (2006c), SD was used to design the agent's engine, the agent representing project participants, and DES used to simulate the project's process. 4) Game theory-SD: this hybrid technique exploits SD to simulate the gaming process between players. Such a combination enables researchers to identify the main factors that affect the players' decisions (Zhang et al. 2022; Wang et al. 2022). We believe further exploration of hybrid modelling will broden the application area of SD, as well enrich the toolbox for ETO and PM modelling.

Future research: How to adopt hybrid techniques modelling and cross-phase modelling to improve model fidelity.

Limited by the top-down feature of SD, researchers often model a single project phase and assume linearity. While, in the ETO archetype development, cross-phase corporation (e.g. design with production) and non-linearities (e.g. capacity limitations) are essential elements that should be considered (Park 2005; Shevchenko et al. 2020).Thanks to developments in hybrid modelling, we now have more tools which may enable us to simulate the cross-phase system at a detailed discrete level. Even though hybrid modelling's development and adoption in ETO field is still in the initial stages, there is existing research that has provided a solid theoretical background and examples for hybrid modelling.

5.5 Stream 5: project phases.

Discussion: SD is widely adopted in each phase

As we can summarized in Table 9-13, SD has been adopted in a wide range of research topics, in total 24 topics were identified. The wide application of SD builds a solid foundation for further PM and ETO system study, especially for the system modelling and simulation. However, due to the research topics being relatively scattered, a general future research agenda can hardly cover enough details, therefore, in the following paragraph, we provide a research agenda for each phase.

Future research: research agenda for each phase

For the **Aggregate planning** phase, further research could focus on capacity and resources planning model development, which could contribute to organizational level decision making and capacity adjustment. In the **pre-project stage**, hazard causes are diverse and scattered, which could be attributed to most of the research being case-orientated. Thus, further research should focus on the generalization and categorization of safety causes and match them with suitable intervention policies. In the **Project execution** phase, further research could adopt the dynamic planning methodology into the ETO scenario and shift the scope from single phase project modeling to the aggregated level modeling, with a special focus on design and production integration modelling. Thereby enhancing our understanding of the ETO system's dynamic. In the **Post-delivery** stage, waste management has not been thoroughly studied, this research gap leads to the lack of guidelines and strategies in the implementation. SD could be used as a platform to simulate the waste management system, analyse the critical factors of success or failed cases, and test the newly designed strategies, thereby providing theoretical guidelines to the partitioners.

6. Conclusion

Table 14 Research question and how they were addressed.

This paper contributes to the body of knowledge by reviewing, categorizing, and analyzing the status of SD and CT application in the context of ETO, although there are several literature reviews for ETO, there has been no review conducted with focus on system approaches. The research questions and findings are summarized in **Table 14**. At the same time, this paper summarized the existing ETO dynamics models in Section 4, which enables readers to see the match between existing models and specific topics. This creates a potential toolbox for industrial partitioners to seek reference models for good practice, for researchers to benchmark against existing models and further develop models for future research.

However, this paper is limited to in its method as it is exploring a subject matter that lacks unified terminology. An ETO is still an emerging, cross-disciplinary research endeavor, its terminology has not been unified across disciplines. This problem results in some papers that may study ETO type products but may not have been identified with the key words selected. Thus, future research should seek to extend keywords as well as enhancing the screening process, thereby having a much more comprehensive review.

Data Availability Statement

No data, models, or code were generated or used during the study

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Table List

Table 1 Research Objectives and questions

Objectives	Research Questions
Review and classify SD and CT models or simulations according to Aggregate planning, Pre-project Planning, Project Execution, and Post-Delivery ETO phases.	What has SD or CT-based research been developed in each phase of the ETO supply chain?
Match emerging topics with specific research, thereby identifying SD or CT clusters and topics.	In what sub-topics, SD and CT have been adopted?
Develop a future research agenda for SD or CT application in the ETO field.	What are the gaps and shortcomings of existing research, and how should they be addressed?

Table 2 Keyword setting process.

Keywords combination	**Reasons for choosing**	**Reasons for changing**
"engineer to order" AND ("system dynamics" OR "control theor*" OR "control engineer*")	1. Narrow down the scope to ETO and SD. 2. Control theory is the mathematical foundation for SD.	1. Sample size is too small because the terminology has not been unified in ETO fields.
("construction industry" OR "construction management "OR shipbuilding OR "engineer to order") AND "supply chain" AND "system dynamics. "	1. Construction and shipbuilding belong to the ETO field. 2. Adding the Keyword "supply chain" because we want to limit the search to the supply chain management field.	1. ETO is Interdisciplinary; limited scope on the supply chain will miss the process-oriented nature of ETO products.

Table 3 Final version of searched keyword combinations.

Application or Problems	**Methods**
construction sector	system dynamics
construction industry	system dynamic
shipbuilding sector	project dynamics
shipbuilding industry	control theory
engineer to order	control engineering
one of a kind	

	first of a kind

Table 4 Keywords Combination used for searching databases

("construction sector" OR "construction industry") AND ("system dynamic" OR "system dynamics" OR "project dynamics" OR "control engineering" OR "control theory")
("capital goods") AND ("system dynamic" OR "system dynamics" OR "project dynamics" OR "control engineering" OR "control theory")
("shipbuilding sector "OR "shipbuilding industry") AND ("system dynamic" OR "system dynamics" OR "project dynamics" OR "control engineering" OR "control theory")
("engineer to order" OR "one of a kind "OR "first of a kind") AND ("system dynamic "OR" system dynamics" OR "project dynamics" OR "control engineering" OR "control theory")

Table 5 Coding table

	Code	***Description***	***Reason for using***
Descriptive analysis	ID	Identification number	To ensure all papers identified were coded
	Title	Title of the paper	Convenient for coding in spreadsheet
	Authors	Who wrote this paper	To identify any groups of papers by the same author
	Journal	Journal of final publication	To identify the distribution of the papers in different journals
	Publication Year	The year paper publication	To enable a longitudinal view of the sample to be made
	Industry	In which ETO field the paper focus.	To assess the application of SD in each ETO field.
Phase Categorization	Phases	For which stage are models simulating.	Used for phase categorization
	Modeling Methods	Modeling techniques used in this research	To distinguish between different modeling methods and analyze its distribution over phases
Topics Categorization	Topic	The research focuses on which topic?	Identify the primary research direction in the current stage
	Purpose of the model	The purpose of the model, what are objectives of building this model	To evaluate the applicability of the different models across different scenarios.
	Contribution	How this research contributes to the existing ETO modeling technique:	To identify how this research contributes to the existing structure of ETO supply chain modeling

Table 6 Sample distribution across journal

Journal's name	Percentages
Journal of Construction Engineering and Management	11%
Construction Management and Economics	6%
International Journal of Construction Management	5%
Automation in Construction	4%
Accident Analysis and Prevention	3%
Environmental Science and Pollution Research	2%
International Journal of Environmental Research and Public Health	3%
Construction Innovation	2%
Engineering, Construction and Architectural Management	2%
Journal of Cleaner Production	2%
Journal of Computing in Civil Engineering	2%
Journal of Management in Engineering	2%
Journal of Safety Research	2%
Mathematical and Computer Modelling	2%

Resources, Conservation and Recycling	2%

Table 7 Publication distribution over phase

Phases	Total	Proportion
Aggregate Planning (AP)	28	20%
Pre-Project Planning (PP)	37	26%
Project Execution (PE)	34	23%
Post-Delivery (PD)	36	25%
PP-PE	8	5%
AP-PP-PE	2	1%
Grand Total	145	100%

Table 8 Publications distribution over methods and project stages (DES: Discrete Event Simulation; ABM: Agent Based Modelling)

Row Labels	CT	SD	SD-ABM	SD-ABM-DES	SD-DES	Game theory-SD	Grand Total
Aggregate Planning (AP)	2	26					28
Pre-Project Planning (PP)		33	1	1	1	1	37
Project Execution (PE)	2	28	1		3		34
Post-Delivery (PD)		32				4	36
PP-PE		5		2	1		8
AP-PP-PE		1			1		2
Total Number	4	125	2	3	6	5	145
Percentage	3%	86%	1%	2%	4%	3%	100%

Table 9 Aggregate Planning category

Topics	Innovation	Financial	Marketing	Others	***sum***
What system has been studied	**Innovation system** Describes how project managers' attitudes, team members and organizational climate impact the innovation. (Park et al. 2004) The authors model the innovation system and highlight government incentives' importance. (Suprun et al. 2018) **Innovation transition** Modelling the innovation transition pathway (Suprun et al. 2019). Pasqualino et al.(2021) present a model to display the dynamics of innovation, inequality and inflation, within the context of Industry 4.0.	**Cost management**. This paper demonstrates the causes for cost overrun and its interrelations. (Asiedu and Ameyaw 2020) Kim et al. (2020) simulates the income and cost system of the Korean studio apartment. Lou and Guo (2020) modelled various factors' impact on the prefabrication construction Tang and Ogunlana (2003b) built an SD model to evaluate the performance of several construction projects in Malaysia from a financial perspective. Asiedu and Ameyaw (2021b) develop a model to demonstrate how cost overrun is caused and illustrate the interaction between variables.	**Construction market**. Dangerfield et al. (2010) adopted the SD illustrate the interactions among competitiveness factors. In 2013 competitiveness model was further developed and modeled the process of contracts allocation in a stylized market. (Gilkinson and Dangerfield 2013) Huang and Wang (2005) develops a model to forecast the supply sides units Choi et al. (2017) analyse the core mechanisms of brand management. Tang and Ogunlana (2003a) investigated how the market change influences the organization or companies' financial, technical, and managerial capability. Kim et al. (2021) developed a SD based profit model as a foundation for a statistical model which can be used to simulate the income and cost of studio apartments. **Shipbuilding market** Wada et al. (2018) develops a forecasting model for Ship building market. Based on this paper,Wada et al. (2022) improve the shipbuilding capacity adjustment model by developing a ship price prediction model. Kim et al. (2021b) Develop a market forecasting model which is composed of two SD model, one aims at simulating the grassroots construction market, the other demonstrate operation, maintenance, and demolition market system.	**Supplier management** Smets et al. (2013) simulate in the new product development (NPD) process, emphasized the importance of manufacturers' simultaneous control to correct NPD errors (non-conformance) and the necessity of providing training programs to the newly hired engineer. Supplier management. Bajomo et al. (2022) Present and analyse a construction material supply chain SD model, in Engineer procurement and Construction field. Luo et al. (2022) Analysed how additional cost of passive building is created, from a supply chain perspective.	**21**
What intervention has been studied	**Innovation Performance** Investigating the effect of Borrowing, Joint venture, and Training policies on Innovation performance (Ogunlana et al. 2003).	**Cash flow policies.** Cui et al. (2010) investigate the Overbilling and underbilling, Trade credit, and subcontracting policies' influence on project cash flow.	**House market** Park et al. (2010) Investigate the 831 policy's impact on Korean house market. Hwang et al. (2013) analyse the existing and suggested policies regarding the imbalance of demand, supply, and vacancy in the housing market. **Capital good market** Größler et al. (2008) demonstrates that decreasing the price or the product enhancement may lead to counter-intuitive effects on sales revenue.	**Prefabrication diffusion** Park et al. (2011) provide an insight into policies regarding prefabrication construction diffusion to the private sector. Li et al. (2022) Predict the trend of prefabrication construction diffusion.	**7**
Sum	***5***	**6**	***12***	***5***	***28***

Table 10 Pre-project category

	Safety & health	*Training and learning*	*Risk Management*	*Others*	*sum*
What system has been studied	**Unsafety causes:** Investigate how the production pressure affects the safety culture (Mohammadi and Tavakolan 2019) Han et al. (2014) explored the negative effect of schedule and productivity on safety performance (incident rate). Goh and Askar Ali (2016) applied SD-ABM-DES to simulate the safety performance system for an earthmoving project. **Safety enablers and policies:** Mohamed and Chinda (2011) investigate how safety enablers influence the safety culture. This paper investigates the core mechanism and the effect of how Behavior-based safety programs improve safety (Guo et al. 2018). Woolley et al. (2020a) adopted Systems Theoretic and Accident Model and Processes (STAMP) to model safety management in construction. **Worker's health:** Lingard and Turner (2017b) illustrated the determinants and their interactions of workers' health. Vitharana and Chinda (2021) adopted SD to investigate the causes of lower back pain and the interaction between key factors. Wu et al. (2016) simulate how the work-family conflict influence workers' satisfactory. Mohammadi et al. (2018) develop four safety archetypes with due consideration of delay in design, a number of sub-contractors, project cost, and supervisors' impact on the safety performance. Huang et al. (2022) developed a simulation model for Construction workers unsafe behaviour evolution. Ni et al. (2022) Demonstrate how factors affect the unsafe behaviours, with special focus on new generation construction workers. Nordin et al. (2021) To analyse the safety management system and root causes of accident	**Training** Bajracharya et al. (2000) investigate the causes and remedies for inefficient training activities in Nepal. **Learning.** This paper visualizes the concept of knowledge management capacity and simulates the evolution of such a process. (Chen and Fong 2013) Lê and Law (2009) simulate the experience transferring process in Architecture, Engineering, and Construction industry organizations.	**Risk management** Mhatre et al. (2017) established SD with the interpretive ranking process, modeling the critical factors in construction; the result suggested that the risk dimension "construction management" has a high possibility to occur. Tavakolan and Etemadinia 2017) mixed Delphi, SD, and Fuzzy logic to analyze critical risk factors and their interactions. Finally, 63 crucial risk factors were identified. By developing a risk identification feedback chart and risk flow chart. Li et al. (2017) identified investment risks in prefabrication projects. Nasirzadeh et al. (2008) developed an integrated Fuzzy-SD model to assist risk management. Purushothaman and Kumar (2022) SD is used to explore the relationship between Supply chain risk with the resilient capability.	**Information management:** Middleton and Golay (2008) introduced Shannon entropy into the construction project uncertainty management. Tatari et al. (2008) studied the applicability of the Construction ERP system in PM and identified the critical variables for the system development. **Construction Performance** Soewin and Chinda (2020) reveal the critical factors for construction performance maturity and its interrelation in Thailand. Sahin et al. (2018) assessed the background of off-site manufacture by SD and identified key factors to the value creation. Soewin and Chinda (2020) *utilize SD to develop a Construction Performance Index* Park (2005) developed SD to study the construction performance dynamics; this paper also demonstrated the trade-off between lead time and the cost of resource coverage.	**27**
What intervention has been studied	**Safety archetypes:** Guo et al. (2015) simulated eight safety archetypes and assessed the side effect of various safety regulations, highlighting the importance of the connection between entities in the system. Based on (Mohammadi et al. 2018), this paper place particular focus on workers, and illustrate how blaming, delay, incentives Programmed, and subcontractors' financial status affects the project safety (Mohammadi and Tavakolan 2020) Liang et al. (2018) assessed three safety management policies to deal with the trade-off between productivity and safety issues. Shin et al. (2014) assessed the effectiveness of incentives for safe behaviors and safety levels. **Lean**: Wu et al. (2019) established SD models to simulate the effect of 5 lean tools on construction safety performance.	**Learning** Ecem Yildiz et al. (2020a) combined SD with the balanced scorecard and strategy maps demonstrate how selected policies affect organization's learning ability.		**Six Sigma:** Ullah et al. (2017) investigated the implementation status of six sigma in Pakistan; based on an SD simulation of how six-sigma influenced project success. **Information management** Khan et al. (2016) demonstrated vital drivers and their interrelations for absorbing cloud computing for small and medium enterprises. **Labor shortage:** Aiyetan and Dillip (2018) developed SD to model the effect and enablers of labor shortage; this paper also examines the influence of the interventions.	**10**
Sum	***19***	***4***	***5***	***9***	***37***

Table 11 Project Execution category (DEMATE: Decision-Making Trial and Evaluation Laboratory)

	Design	*Production*	*Quality*	*sum*
What system has been studied	**Design process modeling:** Chapman (1998) simulate the new staff's design process and learning curve and evaluate the risk of the change of key project personnel during the design stage. **Design errors:** The design non-conformances dynamic impact was assessed in the Dynamic Planning Methodology (**DPM**) model (Han et al. 2013). **Design sharing:** Minami et al. (2010) tested several SD-based policies and concluded that design sharing could mitigate the cost overrun problem.	**Production system modeling:** Handa et al. (1986) adopted optimal control theory to optimize the earthmoving process. Peña-Mora and Li (2001) apply **DPM** in fast-tracking techniques research, and proposed methods can absorb the impact from changes. Han et al. (2012) upgraded **DPM**, enabling it can quantify and identify the non-value adding activities caused by non-conformance and changes. Alvanchi et al. (2011) developed a SD-DES model to combine the operational-level (physical activities like equipment capacity and a number of labors) with the context-level (non-physical activities, like labor skill level and organizational policies). This model is further upgraded by Alzraiee et al. (2015), with consideration of strategic-level management. Tomiyama (1985) developed a capital goods production system with a time lag and adopted optimal control theory to calculate the optimality condition for this two-stage system. **Productivity:** Khanzadi et al. (2018) integrated ABM with SD to predict the value of labor productivity. Mawdesley and Al-Jibouri (2010) develop a series of equations to descript and evaluate how control, motivation, planning safety, and disruption affect productivity. Gerami Seresht and Fayek (2018a) developed a Fuzzy SD model, which can be used for predicting the productivity of the equipment-intensive project. Palikhe et al. (2019) utilized SD and fuzzy logic to identify root causes for poor productivity in Nepal. Parchami Jalal and Shoar (2019) combined SD with a decision-making trial and evaluation laboratory method distinguished several factors that most influence and influence labor productivity. **Rework:** Lee et al. (2005) introduced an enhanced **DPM** that can control the system under uncertainty and protect the system from vicious negative iterative caused by non-conformance or change. Love et al. (1999) developed several SD models to provide an insight into the causal nature of rework. Love et al. (2002) simulate how change and rework of construction impact the project management system. **Schedule:** Jalal and Shoar (2017) investigate the factors relevant to project delay and identified the most influencing factors and the most influenced factors by delay through combining SD with the (DEMATEL) method. Jing et al. (2019) evaluated Iraq's local construction project's cost level and time performance by SD. Laursen et al. (1998) adopted CT, the multi-input and multi-output (MIMO) technique, into the ship panel production system, which could be rescheduled and optimize the production sequence in real-time. **Prefabrication:** Li et al. (2018) adopted SD-DES to simulate and evaluate the effect of risk factors on the prefabrication schedule performance. Nguyen and Ogunlana (2005) utilize stock and flow diagrams and simulate the infrastructure construction process.	Shafiei et al. (2020) firstly, identified the factors affecting the cost for quality from literature and established an SD model to analyze the policies which are proposed to reduce the cost of quality Riaz et al. (2022) *Demonstrated how key factors affected the TQM implementation in construction sector.* Mohammadrezaytayebi et al. (2021) Introducing a system dynamic based model of quality estimation for construction industry subcontractors' works Bajracharya et al. (2021) To investigate why there is a recurring failure in the construction industry.	**26**
What intervention has been studied	Ko and Chung (2014) developed a lean design process that enables the process to be more pliable to the customers' needs and validate it on a SD model.	**Production system modeling** Peña-Mora et al. (2001) introduce the Dynamic Planning methodology (**DPM**) to analyze the negative effect of fast-track techniques (a technique in project management where activities are performed in parallel) and modify control policies to minimize the adverse consequence of parallel execution. Javed et al. (2018a) proposed that productivity should be perceived as a latent entity underpinned by five parts. Management should seek solutions from a systemic perspective. Shafieezadeh et al. (2020) investigated the effectiveness and robustness of change management policies, which can model the rework cycle and analyze the ripple and knock-on effect in construction. Zhou et al. (2022) Present a model demonstrate the structure of ETO and assesses the stability of such a system. Ajayi and Chinda (2022) Demonstrated a workflow model, this model is used to assess the impact from project delay variables. SD-DEMETAL is used to estimate the influence weight of each variable Ajayi and Chinda (2022b) Investigate delay-controlling parameters' impact on project schedule. Rachmawati et al. (2022) Develop a model which can forecast Work rate, and optimize the time and cost performance of a project		**8**
Sum	***4***	***26***	***4***	***34***

Table 12 Post Delivery category

	Environmental performance	*Others*	*sum*
What system has been studied	**Waste management:** Yang et al. (2020)adopted SD to detect the root causes of waste behavior. Suciati et al. (2018) investigate the relationship between material waste and workers' behaviors and attitudes. Hua et al. (2022) develop a model to investigate the subsidy and environment tax's impact on C&D waste recycling. This research also studies the proper range of tax and subsidy. Yuan et al. (2022) present a stock and flow diagram illustrate how prefabrication contribute to the waste reduction in the designing stage. Liu et al. (2021) first, develop compensation model of evolutionary game for Waste management and then authors adopt SD to analyze the equilibrium point of this game Hao et al. (2007) apply SD to simulate the demolition waste chain. Yuan et al., (2011) undertake cost-analysis in a construction demolition system simulation, deepening our understanding of the impact of landfill charges on demolition waste. Ye et al. (2012) developed an evaluation system to measure the performance of construction waste management. Li Hao et al. (2008) verified the effectiveness of the on-site sorting strategy by developing SD simulation. Liu et al. (2020) simulated the construction and demolition waste recycling chain. Li et al. (2014) developed a model to quantify the impact of the adoption of prefabrication to waste reduction in China. Yuan (2012) identified major variables affecting the social performance of construction waste management; this paper also depicts the interrelation underlying the system. Ding et al. (2016) combined SD with theory of planned behavior and investigate the effect of different construction waste management measures on environmental performance. Cheng et al. (2022) analyse how incentives and punishment affect resources utilization of construction and demolition waste in China. **Carbon emission:** Papachristos et al. (2020) Investigating the low carbon building performance indicators' interaction by combining operation management with the SD. Du et al. (2019) Investigated the CO2 emission of construction under different economic situations Kim et al. (2013) developed a model which able to calculate the CO2 emission under all stages. Wang et al. (2022) present a game-SD model, demonstrate the low carbon practice's effect, within the prefabrication supply chain context **Remanufacture:** Papachristos (2014) simulated the remanufacturing process in the capital goods supply chain and its difficulties in practice. Mostert et al. (2022) simulate the building material flow in the future, highlight the importance of concrete recycling. **Sustainability:** SD was also applied in developing KPI for sustainability measurement (Wang et al. 2014). Liu et al. (2022) SD was used to construct and analyse the sub system of comprehensive benefit analysis of prefabricated building. Ghufran et al. (2022) present how circular economy enablers affect the sustainable development. Highlight the policy support and organizational incentive schemes are two most effective enablers. Zhang et al. (2022) Combine SD with Game theory and simulate the interaction between government, contractors, on greenhouse application this paper took wemedia (wechat, a social application like Whatsapp and instagram) ,which reflect public opinion , into consideration. **Value co-creation:** Zhang et al. (2016) study the impact of environmental force on Value co-creation in an enterprise.	**Dispute** Menassa and Peña Mora (2010) presented a model that simulates dispute resolve ladders (DRL, which is used to solve arising issues between participants), enabling participants to monitor the occurrence and resolutions of the claims and change orders. Ansari et al. (2022) use SD to predict the construction performance projects based on the reason for the claims. **Maintenance:** Prasertrungruang and Hadikusumo (2008) developed an SD model to capture the dynamic of machine downtime in the context of small or medium highway contractors. Prasertrungruang and Hadikusumo (2009) shifted their focus to the large contractors and highlighted the mitigation function of balancing cycles which is used to simulate the machine dealers' maintenance service.	**29**
What intervention has been studied	**Waste management**: Yuan et al. (2012) evaluated three environmental improving management scenarios by SD and provided decision-makers with the management level's effect on the mitigation of construction waste caused by environmental impact. Yuan and Wang (2014) apply SD in parameter adjustment to assist managers in determining the appropriate waste disposal charging fee in construction. **Noise reduction:** Yao et al. (2011) evaluated the impact of policies, tested the noise level reduction policies under different pricing strategies, considering financial, waste, and safety levels. Tam et al. (2014) simulated different policies and their effectiveness on waste management. Marzouk and Fattouh (2022) testing investment policies' effects on environment Indicators. **Green Building** Li et al. (2022b) study on Green Building Promotion Incentive Strategy Based on Evolutionary Game between Government and Construction Unit	**Dispute** Ng et al. (2007) combined dispute avoidance and resolution technique (DART) with SD simulation to present a solution to manage disputes and conflicts, which provides an insight into the nature of these challenges. This model can also be used for conflicts or dispute forecasting and serves as a testing platform for different scenarios.	**7**
Sum	***31***	**5**	***36***

Table 13 Cross-Phase category

	Pre-project planning - Project execution	*Aggregate planning – Pre-project planning – Project execution*	*Sum*
What system has been studied	**Process modeling** Lee et al. (2006b) proposed several hybrid models that can be used in whole life-cycle simulation. **DPM** was also applied to study the impact of information technology in the multi-layer system. Lee et al. (2006a) integrated **DPM** with several existing methods and implement this integrated method into a web-based system. Peña-Mora et al. (2008) bridges the gap between practice and theory by simulating the cross-level planning process in an earthmoving project. Motawa et al. (2007) adopted **DPM** in the change management field, and the authors developed a change prediction model which can combine with the original **DPM** model. Barbosa and Azevedo (2019) proposed several ETO/MTO performance determinants and developed a hybrid SD-DES-ABM model to assess the system's performance.	**Process modeling** Lee et al. (2009) further developed the **DPM** model to simulate production covering AP-PP-PE phases by integrating SD with DES. In this paper, the authors firstly introduced the Pipeline installation model.	**6**
What intervention has been studied	Wan et al. (2013b) developed an SD model to analyze the inefficiencies of the construction process in subcontractors; in the meantime, the impact of various project settings was also investigated. **Adaptable building** Gosling et al. (2013) investigated drivers for building's adoptability and identified the enablers for adaptable building. SD was utilized to illustrate the building adaptation model and rationalize the concepts. **Design-build** Park et al. (2009) presented an SD model to analyze the Korean design-build delivery system's characteristics and test previous suggestions and initiatives.	**Sustainability** Hessami et al. (2020) designed a model which simulates the revolving-fund sustainability improvement program. The model indicates that if appropriate program management and prioritization strategies were adopted, revolving funding could leverage small initial investment into a significant benefit improvement.	**4**
Sum	**8**	**2**	**10**

Table 14 Research question and how them were addressed.

Research Questions	How are the questions addressed?
What has SD or CT-based research been developed in each phase of the ETO supply chain?	This research reviewed, categorized, and summarized sampled papers into four phases, comprehensively demonstrating the distribution of SD or CT-based research across the ETO field. The results are presented in Section 4.
In what sub-topics, SD and CT have been adopted?	We adopted an inductive approach, grouped sampled papers into 24 topics, matched the research with emerging topics. The result is shown in Table 9 to13.
What are the gaps and shortcomings of existing research, and how should they be addressed?	This question is addressed in section 5.

Figure caption list

Figure 1 Causal loop diagram of a make-to-order system (based on Wikner et al. 2007)

Figure 2 Literature review material collection and filtering process (based on Lin et al. 2017))

Figure 3 Citation network produced by Vosviewer

Figure 4 Publications trend

Figure 5 Research topic distribution against phases

Figure 6 Dynamic Planning Methodology (reproduced from Lee et al. 2005)

Figure 7 A summary of discussion findings and future research agenda