

Universidade do Minho
Escola de Engenharia

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Contributions to the Industrialization Process in the Construction Industry

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Contributions to the Industrialization Process in the Construction Industry

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Work done under the guidance of
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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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ABSTRACT

The construction sector urgently needs to embrace industrialization to meet growing demands for efficiency, sustainability, and innovation. This thesis aims to explore the development process of the Construction Industrialization (CI) phenomenon, driven by the need to improve CI practices. Academic discussions consistently portray CI as a complex and ambiguous topic, with fragmented interpretations and a lack of comprehensive research on the challenges surrounding its adoption. An analysis of the literature reveals important gaps in the body of knowledge to support this effort.

The core focus of this Doctoral Project is the conceptualization and process characterization of Construction Industrialization. It aims to contribute to both theory and practice by offering: (1) a new definition of the CI phenomenon, (2) a framework that conceptualizes the phenomenon, capturing its complex nature and providing practical guidance for Practitioners in shaping their CI initiatives, and (3) a transformation model to support the implementation process of CI.

A comprehensive research approach was employed, combining systematic literature reviews with a two-year exploratory multiple case study. Perspectives from both Practitioners and the Academy on the CI conceptualization and its associated process were examined. This study introduces a novel theoretical lens grounded in Organizational Change and Change Management theories, applying it to the CI context to support construction Managers in understanding and planning a transformational change. A new conceptualization of Construction Industrialization is established: as a socio-technical transformation process. The findings position CI as a profound organizational, human, and social transformation that simultaneously transforms structures, workflows, business models, and production systems, while also reshaping competencies, behaviors, leadership practices, organizational cultures, and individual mindsets. The study shows that Construction Industrialization cannot be reduced to productive or technological innovation alone. The findings of this study show that the primary challenge to Construction Industrialization is social rather than technical. By identifying novel approaches and examining the social and contextual factors influencing CI, this research also provides a strong foundation for future studies in the field. Ultimately, this thesis is a cornerstone for ongoing CI thinking, reducing ambiguities and ensuring a structured and efficient transition from traditional construction to industrialized construction.

Keywords: Case Study; Concept; Construction Industrialization; Framework; Process; Transformation Model.

RESUMO

A Industrialização da Construção surge como um processo revolucionador para combater os baixos níveis de produtividade, eficiência, sustentabilidade e inovação da indústria da construção. Esta tese pretende assim explorar o processo de implementação deste fenómeno da Industrialização da Construção. Tendencialmente, os Académicos tendem a retratar o fenómeno como um tema complexo e ambíguo, com interpretações ainda fragmentadas.

O foco deste projeto de Doutoramento passa pela conceptualização e caraterização do processo de Industrialização da Construção, contribuindo para a teoria e a prática através do desenvolvimento de (1) uma nova definição para o fenómeno, alinhada com (2) uma framework que conceptualiza o fenómeno, captando a sua natureza complexa e fornecendo orientação prática para os Gestores na elaboração dos seus esforços, e com (3) um modelo de transformação para apoiar o processo de implementação.

Foi utilizada uma abordagem de investigação abrangente, que incluiu revisões sistemáticas da literatura e um estudo exploratório de casos múltiplos ao longo de 2 anos. Durante este período, foram estudadas as perspetivas dos Praticantes e dos Académicos relativamente à conceptualização do fenómeno e ao processo a ele associado. Este estudo introduz uma nova lente teórica, fundamentada nas teorias de Mudança Organizacional e de Gestão da Mudança, aplicando-a ao contexto da Industrialização da Construção. É proposta assim uma nova conceptualização da Industrialização da Construção como um processo de transformação sociotécnica. Os resultados posicionam a CI como uma transformação profunda de natureza organizacional, humana e social, que transforma simultaneamente estruturas, fluxos de trabalho, modelos de negócio e sistemas de produção, ao mesmo tempo que reformula competências, comportamentos, práticas de liderança, culturas organizacionais e mentalidades individuais. Este estudo mostra que o principal desafio da Industrialização da Construção é de natureza social, mais do que técnica. A identificação de novas práticas e de fatores sociais e contextuais que influenciam a adoção do fenómeno constitui também um contributo relevante desta tese, fornecendo uma base sólida para estudos futuros. Em síntese, esta tese contribui para clarificar o fenómeno, reduzindo ambiguidades e apoiando uma transição mais estruturada e eficaz da construção tradicional para a construção industrializada.

Palavras-chave: Definição; Estudo de Caso; Framework; Industrialização da Construção; Modelo de Transformação; Processo.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEC - Architecture, Engineering, and Construction

CI – Construction Industrialization

DFMA – Design for Manufacturing and Assembly

IBS – Industrialized Building System

IEM - Industrial Engineering and Management

IPD – Integrated Project Delivery

MC – Modular Construction

MIC – Modular Integrated Construction

OC – Organizational Change

OSC – Off-site Construction

OSM – Off-site Manufacturing

OT – Organizational Transformation

PC – Prefabricated Construction

PPVC – Prefabricated Prefinished Volumetric Construction

SCM – Supply Chain Management

SLR – Systematic Literature Review

Chapter 1

Introduction

This Chapter provides the context for the research subject explored in this thesis. It begins by explaining the motivation and rationale behind focusing on Construction Industrialization, followed by an outline of the theoretical context and existing gaps. The main objectives and contributions of the thesis are then highlighted, along with an overview of the research methodology and research questions. Finally, the chapter concludes by defining the overall structure of the thesis.

1.1. Research Motivation

This Doctoral Project is focused on exploring the phenomenon of Construction Industrialization (CI) – a phenomenon that in the media is referred to as *"the next normal for construction"* (McKinsey Global Institute Report, 2020) or the *"future of construction"* (Deloitte, 2021); and in the academic literature as the new reality for an industry grappling with long-standing productivity issues (Durdyev & Ismail, 2019).

Such long-standing productivity issues have been widely reported in both literature and practice. Previous research suggests that productivity improvement in the construction industry has lagged behind that of other industries (Kenley, 2014). According to the McKinsey Global Institute Report from 2017, the construction industry's productivity has seen minimal growth, averaging only 1% per year over the past two decades, a rate three times lower than that of the manufacturing industry.

The challenges of productivity within the construction industry can largely be attributed to its labor-intensive nature, which significantly relies on human effort (Hu et al., 2019). Additionally, the persistent use of on-site construction methods often leads to various challenges, including poor

performance, high costs, inadequate safety management, long construction times, and substantial resource usage (Goh & Loosemore, 2017; Zhang et al., 2022).

Both academia and industry acknowledge that, relative to other sectors, the construction industry has substantial opportunities for modernization and enhancement of its operational practices (Kamali & Hewage, 2017). Despite being a fundamental pillar of economic development, the construction sector has historically lagged in adopting innovative technologies, streamlined processes, and digital transformation. Low investment levels in technology, innovation, and digitalization (García de Soto et al., 2018; Razkenari et al., 2020) severely limit the industry's potential to thrive in an increasingly volatile and competitive market.

Moreover, the traditional temporary and fragmented supply chain has proven to be a significant challenge (Razkenari et al., 2020), particularly exacerbated by the disruptions caused by the recent pandemic and subsequent conflicts, leading to material availability and cost issues. Adding to this crisis is a dire global housing shortage that requires urgent action (Sutrisna et al., 2019). The industry also faces a pressing shortage of skilled labor, a diminishing workforce, and an aging workforce (Hasan et al., 2018).

Construction Industrialization has arisen as a potentially transformative force within the construction industry. According to Ågren et al. (2014), this force stands as a cornerstone of prosperity, offering significant cost and time efficiencies. Wuni & Shen (2020) stated that its benefits are *"no longer esoteric but overt"*, underscoring its importance for contemporary builders.

Nowadays, this phenomenon has captured the attention of the world. As evidenced in reports from the McKinsey Global Institute Report (2020) and Deloitte (2021), consulting companies are actively contributing to its widespread dissemination. Extensive academic literature also reflects a significant surge in scholarly interest, as evidenced by numerous studies and publications (Qi et al., 2021). Additionally, Architecture, Engineering, and Construction (AEC) companies worldwide are particularly interested in its promising potential, as shown in the works of Sutrisna et al. (2019) and Rong et al. (2020).

From a business perspective, this new reality is fueling a revolution in the industry, prompting businesses to explore innovative construction solutions, build new factories, and develop modular buildings (Mostafa et al., 2016). Currently, construction companies are competing vigorously in the traditional construction market, and at the same time, in a new one: the market for industrialized construction. This pivotal transition signifies that companies are not just adapting

and evolving their operational and building execution methods, but also actively adapting and enhancing commercial and management practices (Larsson et al., 2014; Goulding et al., 2015; Lessing, 2015; Sabet & Chong, 2019; Zhang et al., 2020; Wuni et al., 2021).

Governments worldwide, including those of China, India, Australia, the United States, and the United Kingdom, are actively promoting and supporting the transition to Construction Industrialization (Das et al., 2020). Scholars across the globe have been actively acknowledging the critical role of Governments in promoting and embracing the CI phenomenon (Gan et al., 2018; Ayinla et al., 2019). They act not only as supporters but also as promoters for companies' initiatives, thereby delivering considerable benefits.

In Portugal, the Portuguese Government is also actively promoting a transformation within the construction industry toward the phenomenon of Construction Industrialization. A Governmental Funding Agenda has been allocated to the Construction Group where the thesis Author works professionally, with the specific aim of facilitating the anticipated change in this topic.

A global revolution is currently in progress, with the Portuguese government standing out for its active participation, strategic initiatives, and the introduction of incentives aimed at facilitating this transformative change. This incentive is critical for addressing the industry's complex challenges. Embracing this initiative offers a significant opportunity for positive advancements, benefiting industry and society.

Despite CI's current prominence as a top priority today, its historical roots stretch back several decades (Ågren et al., 2014). History, however, has not always been replete with triumphs (Barlow, 1999; Crowley, 1998; Gann, 1996; Tatum, 1989; Gibb, 2001; Ågren et al., 2014; Xu et al., 2020). Some of the first attempts were unsuccessful, and Scholars in those days warned that lessons were learned and myths were dispelled (Gibb, 2001). Such days go back to the 90s (Gann, 1996).

Decades have passed, yet the widespread adoption of CI faces significant challenges, as evidenced by persistently low global adoption rates (Liu et al., 2019) and various implementation challenges highlighted in the literature (Wuni & Shen, 2020a). Managers worldwide have expressed reservations about transitioning towards the Construction Industrialization phenomenon, often citing concerns over perceived high costs and associated risks linked to its adoption (Dang et al., 2020). Nonetheless, embracing CI is advantageous and vital for the industry's future success and prosperity.

Therefore, the transition from traditional construction to industrialized construction represents a critical evolution for the entire industry and the world. Nevertheless, Scholars, including Hosseini et al. (2018) and Peltokorpi et al. (2018), have acknowledged a significant issue: a lack of a solid theoretical basis to support this transition. To bridge this gap, Scholars have also expressed an urgent need for comprehensive knowledge about developing a CI process to assist construction Managers' decision-making.

Ayinla et al. (2019) and Luo et al. (2020) state that much of the misunderstanding about CI development arises from a lack of a systematic framework detailing its broader knowledge agenda. Additionally, Liu et al. (2019) argue that the understanding of the Construction Industrialization phenomenon is still underdeveloped, both in practical and theoretical terms, which raises serious concerns about its feasibility and success. This highlights the urgent need for focused attention and action from all stakeholders involved.

Accordingly, the motivation underlying this Doctoral Project began when the Author personally experienced a desire to contribute to the phenomenon adoption. In exploring this topic, the Author identified a lack of comprehensive knowledge recognized by academia and industry to implement the phenomenon of CI effectively. This challenge presents a valuable opportunity for impactful academic research and a distinctive contribution to the evolving CI field. As a result, this Doctoral Project has represented a period of personal development, professional contribution, and academic discovery.

1.2. Theoretical Context and Research Gaps

There has been a surge in interest in Construction Industrialization in recent years, driven by its practical and academic significance. Much has been written about the phenomenon, and Scholars worldwide have been dedicating substantial efforts to enriching its body of knowledge (Hu et al., 2019; Thai et al., 2020; Wuni & Shen, 2019; Ghalenoei et al., 2022; Saad et al., 2023).

While there has been a significant amount of research on CI, some Scholars have raised concerns about the theoretical foundations and the overall direction of CI research. Hu et al. (2019) have acknowledged that the current understanding of CI has been perceived as immature, sluggish, and with blurred boundaries. Additionally, there are discussions about the CI's current definitions being

unclear, hazy, and fragmented (Ayinla et al., 2019). The phenomenon of Construction Industrialization has yet to be comprehensively understood.

In summary, four gaps were found that collectively emphasize the lack of academic support in assisting construction Managers in the CI development process:

(1) The lack of a common understanding of CI.

One of the most critical issues in the CI field is the lack of a consensual, well-accepted definition of CI (Lessing et al., 2015; Peltokorpi et al., 2018; Liu et al., 2019). Despite extensive research, Scholars such as Luo et al. (2020) have consistently advocated for a unified understanding of CI in both theoretical and practical contexts. The varied terminology that fits under the umbrella of CI is a good indicator of the many misunderstandings and divergent interpretations of the CI phenomenon (Hussein et al., 2021). Because of such diversity, various reviews have employed a broad range of keywords that characterize the research landscape of CI (Qi et al., 2021). It is also widely accepted that different countries use their own terms and definitions for CI study, even though CI is a global phenomenon. As acknowledged by Ayinla et al. (2019), this diversity leads to confusion and frustration among those seeking clarity. As Wacker (2004) argued, ambiguous and unclear definitions can lead to other measures of the phenomenon, ultimately hindering theories' development. Dubious understanding can also lead to increased implementation costs. The realities of CI adoption underscore the necessity for a clear understanding; without it, the effectiveness and consistency of implementation are likely to be compromised.

(2) The lack of a comprehensive conceptualization of the CI phenomenon and its theoretical basis.

According to Stock & Boyer (2009), a clear definition is imperative for understanding the concept, achieving acceptance of its fundamental components, and applying it in practice. The existing lack of consensus on what constitutes CI has resulted in widespread misunderstandings and has hindered its consistent adoption within the industry, according to Hosseini et al. (2018) and Luo et al. (2020). While some definitions primarily focus on changes in products and processes through modularization and off-site prefabrication, respectively, others offer a broader perspective. To the Author's best knowledge, a study has yet to be conducted to conceptually develop a structured and

comprehensive conceptualization of the CI phenomenon. In the absence of such research, CI remains a messy and ambiguous issue with incomplete meanings and under-researched complexities despite the evolution in the research on CI, according to Nabi & El-adaway (2020). Stock & Boyer (2009) pointed out that the absence of valid constructs and a generally accepted definition of a phenomenon hinders the development of sound theory, resulting in theoretical ambiguity — an issue that continues to affect the CI field today.

(3) The lack of a framework that can effectively capture the complex nature of CI and guide Practitioners in their CI efforts.

A roadmap (Goulding et al., 2015), a few maturity models (Wang et al., 2020; Suliman & Rankin, 2021), a readiness model (Bendi et al., 2020), and conceptual frameworks (Dang et al., 2020) have significantly contributed to the development of theory in the field of CI. However, some criticisms have been pointed out about these tools. Some tools are mostly incomplete in terms of what CI means to the organization; others do not provide a comprehensive view of the concept (Wuni & Shen, 2020b; Qi et al., 2021). Additionally, some Scholars (such as Wang et al., 2020) have focused on the operational aspects of construction projects. In contrast, others, such as Bendi et al. (2020), have directed their attention to the company level. This variety in focus leads to differing interpretations and results in a fragmented understanding of the CI transition. As a result, Liu et al. (2019) characterized the understanding of the CI transition as underdeveloped, fragmented, and poorly structured, which has led to a high level of misunderstanding. This misunderstanding exists both in the academic field and in the Practitioner communities. Further, it also becomes difficult to find a tool to support Managers in the Construction Industrialization development when the meaning of the *"Construction Industrialization process"* has not received the attention needed. Consequently, confusing, ambiguous, and vague characterizations of the CI transition, with current approaches lacking a comprehensive understanding of CI's organizational implications, and frameworks that support construction Managers creating holistic CI development, need to be improved.

(4) The lack of empirical studies that provides a greater understanding of the CI process.

Empirical evidence is crucial for developing theories, yet there is a shortage of studies that explore CI from the perspective of those actively engaged in the field. As stated by Whetten (1989), empirical evidence is a fundamental input for theorizing. According to Stock & Boyer (2009), only when Practitioners' experiences and perspectives are integrated into the body of research can a discipline consider what a specific phenomenon is and what it is not. Consequently, this Doctoral Project seeks to bridge the significant gap between theory and practice, thereby enhancing the scientific credibility of the literature and its relevance in supporting construction Managers in their CI efforts. Although the importance of CI is widely recognized, literature and practice remain largely disconnected in their approaches to defining and conceptualizing CI and its developmental process. Addressing this disconnect is essential to fully unlocking the potential of CI within the industry.

These four gaps provide sound theoretical arguments to support this research. Thus, an urgent need is identified: to develop a detailed and comprehensive approach that can guide Managers in the Construction Industrialization development process and converge theory and practice. By delving into these four gaps and acknowledging this urgent need, there exists a significant opportunity to effectively tackle the central research question of this Doctoral Project: *"How to assist construction Managers in a comprehensive Construction Industrialization development process?"*.

1.3. Research Aim and Contributions

The overall aim of this Doctoral Project is to explore the phenomenon of Construction Industrialization to enhance clarity and support for construction Managers throughout the CI process. Five research objectives emerge as contributions to knowledge:

1. To develop a structured and comprehensive definition of the phenomenon of Construction Industrialization;
2. To develop a framework that helps capture the complex nature of CI and can provide the necessary guidance to Practitioners when crafting their efforts;
3. To develop a transformation model to support the transition towards the Construction Industrialization phenomenon;

4. To develop an empirical study to explore the perspectives of Practitioners on the CI development process;
5. To integrate Practitioner and Academic perspectives on the phenomenon of the CI development process for a greater understanding of it.

By achieving these research objectives, a new understanding and a new approach can help companies in their implementation efforts by giving them a broader and deeper understanding of Industrialization and what it entails, allowing them to adapt their practices, principles, and habits accordingly.

The new understanding and a new approach will lead to a greater understanding of the true nature of CI and potentially promote the sustainable development of the phenomenon in practice. Therefore, the ambiguity and misperceptions surrounding the CI definition are addressed, and the misunderstandings associated with the process are clarified. Furthermore, the theoretical gap between theory and practice is bridged. The fragmentation often described by Scholars is also attended.

The aforementioned research objectives are related to one another since they contribute to developing the theoretical underpinnings of the other research objectives. Part of the novelty of this Doctoral Project lies in the integration of these contributions, which both individually and ultimately collectively have yet to be addressed in literature.

On the novelty of this project, this Doctoral Project stands out for the relevance it brings to literature and practice about the Construction Industrialization development process in four dimensions:

(1) For its relevance in conceptualizing the phenomenon and characterizing the transition process from traditional construction to the phenomenon of Construction Industrialization;

(2) For its relevance to bring the practical voice, from the field, of those who are actively involved in the phenomenon of Construction Industrialization and their perspectives, to enrich and refine theory and practice in terms of understanding the phenomenon;

(3) For its relevance to bringing the new theoretical lenses from the Organizational Change and Change Management theories to assist in the substantive understanding of the phenomenon and the change process toward Construction Industrialization;

(4) For its relevance in consolidating the practice and academic perspectives in a transformation model for a Construction Industrialization development process, providing

Scholars and Managers with a comprehensive perspective on the complexity associated with the phenomenon in a condensed illustration and explication.

1.4. Research Methodology Overview and Research Questions

Building on the argument that little research has been settled about the CI development process, this Doctoral Project represents an exploratory research project. Embracing a positivism paradigm, this thesis employs an abductive research approach consonant with this study's ontological, epistemological, and methodological orientations. This thoughtful choice is considered particularly suitable for addressing the research question while effectively addressing the thesis's research objectives.

For a comprehensive understanding of the methodology guiding this thesis, a detailed explanation is provided in Chapter 2, outlining the rationale and research methods employed throughout the study.

Figure 1.1 summarizes the three parts of the Research Methodology followed in this Doctoral Project.

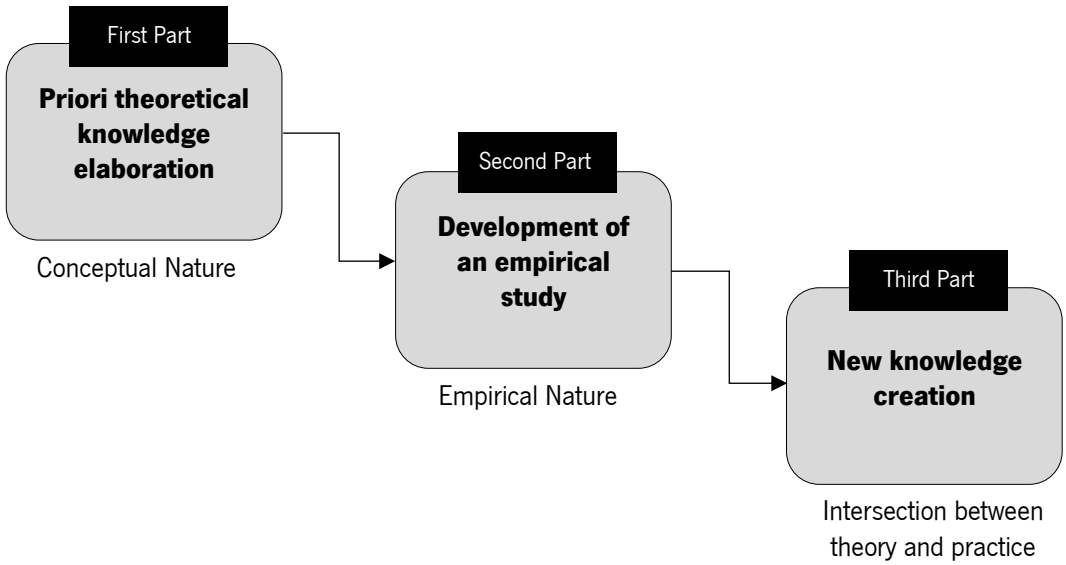


Figure 1.1: Research Methodology

As shown in Figure 1.1, the first part of the Research Methodology is conceptual in nature, in which a priori theoretical knowledge is elaborated. Subsequently, the second part, empirical in nature, explores the Practitioners' perspectives on the CI phenomenon and CI process – the two perspectives about the phenomenon under study. A multiple case study is conducted to provide an in-depth analysis of how CI is perceived and implemented across different contexts (sectors). In the third part of this study, the prior theoretical knowledge established in the first part is revisited in light of the empirical findings from the second part toward a greater understanding of the CI phenomenon. The objective is to refine and enhance existing theoretical knowledge by incorporating empirical insights and addressing real-world nuances. Additionally, abductive research aims to uncover novel and overlooked insights into existing literature, making an original contribution to knowledge and fostering a unified understanding that bridges the gap between theory and practice.

Following the established Research Methodology, three conceptual studies and one empirical study were conducted to address the central research question:

> ***"How to assist construction Managers in a comprehensive Construction Industrialization development process?"***

Four secondary Research Questions (RQ) were formulated for this Doctoral Project, and their relevance is discussed below.

RQ1: How has research defined and operationalized the concept of Construction Industrialization to date?

RQ1 was formulated to critically review the existing literature about the phenomenon of CI to (i) reach a deep understanding of its conceptual scope and (ii) make a prior theoretical contribution to the CI definition and CI development process.

To drive the advancement of the CI development process, four sub-questions have been formulated:

RQ1.1: What are the key Design Principles referred to as pillars of Construction Industrialization?

RQ1.2: What Changing Initiatives must organizations undertake to promote the development of Construction Industrialization?

RQ1.3: What Elements of influence may positively or negatively impact the decision to implement a CI development process?

RQ1.4: What are the research gaps in the Construction Industrialization topic?

The first sub-question (RQ1.1) examines Design Principles, which, in this study, are considered general and unique guiding principles for a CI transformation applied universally across diverse contexts and countries. These principles encapsulate the fundamental nature of the phenomenon under study and establish a shared knowledge of it, helping to maintain coherence and clarity across various implementations.

Subsequently, the second sub-question (RQ1.2) emanates from the initiatives that introduce the organizational dimension to the research and articulate a set of actions that organizations must undertake to promote the effective Industrialization of the construction industry. In this respect, while the Design Principles provide a vision of an evolving industry, the initiatives offer a perspective of a company that must adapt.

The third sub-question (RQ1.3) is associated with the influencing factors that introduce the context and encompass critical factors that may positively or negatively impact the decision to implement and develop such a transformation. Studying influencing factors provides a comprehensive understanding of the phenomenon occurring and evolving within an open-system environment.

The fourth sub-question (RQ1.4) was formulated to identify the current gaps in the literature on CI and guide the study to understand the Construction Industrialization development process. By answering this sub-question, the Author realized that using only the literature on CI could lead to an undue bias in the sense of being theoretically conservative and not reflecting the complex and comprehensive nature of the phenomenon under study. The current CI theoretical scenario is characterized by fragmented development rather than a unified and comprehensive understanding of the CI phenomenon. In this regard, a new research direction emerged in this Doctoral Project that seeks to expand the theoretical boundaries of the CI field by applying the theoretical lens of Organizational Change and Change Management theories.

Liu et al. (2019) were one of the first Scholars who called for research on the effects of organizational change on CI literature, prompting other Scholars to recognize the need to advance even more on such robust and well-established theories to foster a comprehensive understanding of the CI development process. Nevertheless, this call has not yet been adequately addressed, presenting an interesting gap to be explored in this research.

As Construction Industrialization remains a pivotal goal, the exploration of effective pathways to achieve this goal must be reflected in both academic literature and practical contexts. In any industry transformation, a well-conceived change plan is crucial for maximizing the associated benefits (Al-Haddad & Kotnour, 2015). Understanding how to plan and manage construction companies to succeed in this phenomenon can be considered one of the key modern issues in both literature and practice.

Therefore, this Doctoral Project employs the theories of Organizational Change and Change Management as a theoretical framework to comprehensively enhance the understanding of the CI phenomenon and its development process. In this way, Research Question 2 was formulated to enrich the a priori theory (continuing to align with the first part of the Research Methodology depicted in Figure 1.1):

RQ2: How can Organizational Change and Change Management theories assist a comprehensive CI development process?

The purpose of formulating the RQ2 is to bring the literature on Organizational Change and Change Management into discussion, understanding how theory and practice can extend their knowledge for a more complete and comprehensive understanding of the Construction Industrialization development process.

As such, this Doctoral Project contributes to theory and practice with RQ2 through the application of a new theoretical lens to the field of CI. It aims to develop a greater understanding of the true nature of CI and potentially promote the building of sustainable development. The ultimate goal is to enrich the conceptual formulation of a CI definition and CI development process so that both can be elaborated with the empirical study.

Two sub-questions have been formulated:

RQ2.1: How has CI literature been approaching Organizational Change and Change Management theories?

RQ2.2. How can the unique and complex nature of CI be exhibited, and what can be learned from Organizational Change theory?

The first sub-question (RQ2.1) will explore how CI literature has approached organizational change and change management theories. Specifically, it aims to assess the maturity of CI research concerning change theories and to establish a foundation for a CI transformation model.

The second sub-question (RQ2.2) will examine established models for planning transformative change, seeking valuable insights that can enhance the understanding of what CI literature can learn from these theories.

By addressing these two pivotal research sub-questions and integrating their findings, the Author intends to develop a more comprehensive understanding of the CI phenomenon as a process of change. This effort will contribute to creating a transformation model that promotes sustainable development in practice.

With prior (conceptual) knowledge about the CI concept and the CI process development process, a third research question is formulated to capture the perspectives of Practitioners. Therefore, Research Question 3 emphasizes the necessity for empirical research, as illustrated in the second part of Figure 1.1.

RQ3: How has the Construction Industrialization phenomenon been perceived in practice, both in terms of its definition and its development process?

RQ3 aims to bring practical experience to academic literature. The empirical context for the Case Research is a Government Funding Agenda involving Practitioners from different sectors (Architecture, Engineering, Traditional Construction, and Manufactured Construction) and different countries (England, Spain, and Portugal). This context has been intentionally selected to provide a comprehensive understanding of the real-world environment in which the CI process is developed, where dedicated teams collaborate towards shared objectives while navigating contemporary challenges and uncertainties.

Two interconnected perspectives are presented in this RQ3: the definition of CI and the CI development process. Appendix A provides a detailed and comprehensive overview of the evolution of both the CI definition and the CI process model throughout the chapters. The subsequent five sub-questions arise directly from this evolution.

RQ3.1: What Rationale has led to the implementation of a Construction Industrialization development process?

RQ3.2: What Design Principles do Practitioners identify as necessary for the implementation of a Construction Industrialization development process?

RQ3.3: What Organizational Changes need to be embraced to assist in the implementation of a Construction Industrialization development process?

RQ3.4: What Elements of influence have shaped or hindered the implementation of a Construction Industrialization development process?

RQ3.5: What anticipated Results are expected from the implementation of a Construction Industrialization development process?

Through this empirical study, the Author aims to achieve a more accurate reflection of the practical realities and perceptions that emerge along these five sub-questions.

Aligned with the abductive research approach adopted in this thesis, the last part of the Research Methodology integrates academic and practical perspectives, ultimately facilitating a deeper and more comprehensive understanding of the CI phenomenon. Consequently, literature can refine its discussions and expand its conceptual boundaries. This expansion is particularly driven by Research Question 4, which corresponds to the third part illustrated in Figure 1.1:

RQ4: How can the phenomenon of Construction Industrialization be conceptualized to fill the current gaps in the literature and advance its understanding by linking theory and practice?

RQ4 intends to integrate theory and practice into a CI definition and a CI process model, which pushes forward a new perspective on how construction Managers should plan the phenomenon under study. By intersecting insights from both theoretical discussion and practical applications, this study not only contributes to academic knowledge but also offers practical implications regarding the understanding of the CI concept and CI process. Additionally, RQ4 intends to identify new insights that emerge empirically that the literature has not yet paid attention to. A strong foundation for further theorizing and research in the CI phenomenon is offered that will enrich and unify theory and practice.

1.5. Thesis Structure

This document comprises a total of six chapters. Through these chapters, the Author intends to explain the work developed in this research. Five articles were developed during the Doctoral Project to answer the research questions raised earlier in this chapter.

Figure 1.2 introduces the research questions formulated in this Doctoral Project and their relations to the five developed papers, also locating them in the structure of the thesis.

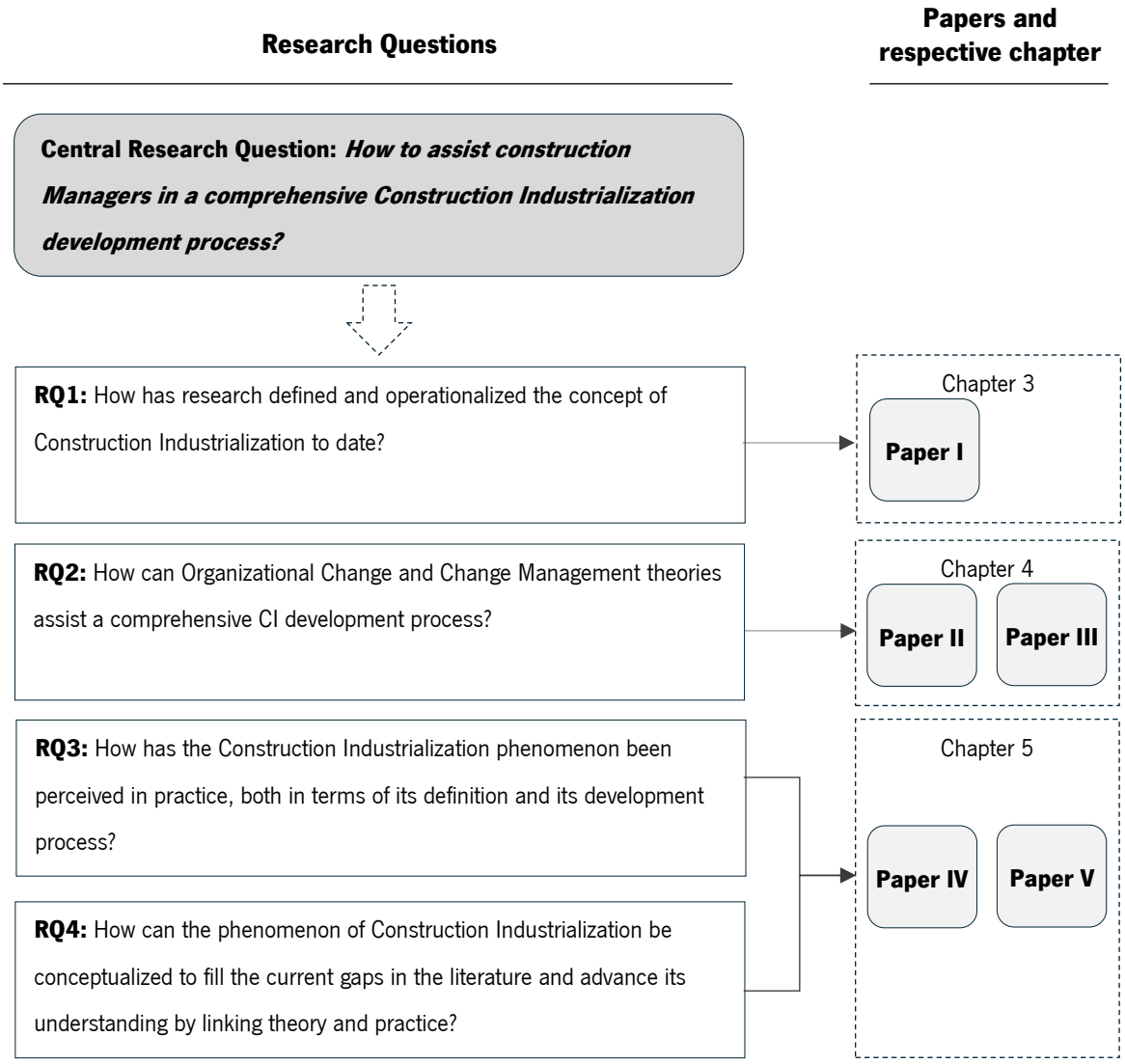


Figure 1.2: Research questions of this thesis and their relations to the five appended papers

A brief explanation of each chapter is provided next.

This introductory Chapter 1 provides the background and significance of the research project, along with the research objectives, an overview of the research methodology, and research questions.

Chapter 2 develops the research methodology used in this Doctoral Project. It starts with a brief overview of the philosophical fundamentals. This is succeeded by an explanation of the rationale behind selecting Case Research as the research strategy and its intended purposes. The Chapter concludes with a discussion of the research quality and ethical considerations.

Chapter 3 addresses the first research question of this Doctoral Project *("How has research defined and operationalized the concept of Construction Industrialization to date?")* through a Systematic Literature Review (SLR). A threefold contribution is offered with this review. Firstly, it proposes a comprehensive definition of Construction Industrialization to address existing ambiguity and fragmentation identified by numerous Scholars. Secondly, it introduces a conceptual framework that presents CI as a new way of operating a business, emphasizing the need to align and manage five main areas - Strategy, Organization, Processes, Planning, and Resources - to achieve a competitive advantage. The framework also delineates ten design principles, five influencing factors, and nineteen initiatives to define and represent the CI phenomenon. Thirdly, it presents a holistic view of the phenomenon, which blurs pluralistic understandings of CI and establishes a view of Organizational Change. This holistic view serves as a starting point for reflection on the phenomenon under study throughout the remainder of the Doctoral Project. The reference that supports Chapter 3 is as follows:

Paper I: Costa, Sara; Carvalho, Maria Sameiro; Pimentel, Carina; Duarte, Cláudia. (2023). **A Systematic Literature Review and Conceptual Framework of Construction Industrialization.** *Journal of Construction Engineering and Management*. 149(2); https://doi.org/10.1061/(ASCE)CO.1943-7862.0002410

Chapter 4 addresses the second research question *("How can Organizational Change and Change Management theories assist a comprehensive CI development process?")*. As shown in Figure 1.2, two papers have been developed to address this specific research question (Paper II and Paper III). Conference Paper II conducts a primary review analyzing some organizational change models published in different journals and the grey literature. The goal of this paper is to extract lessons learned regarding the content of change, thus providing insights that can inform a comprehensive approach to CI transition. The first reference that supports Chapter 4 is as follows:

Paper II: Costa, Sara; Carvalho, Maria Sameiro; Pimentel, Carina; Duarte, Cláudia. (2022). **Lessons From the Organizational Change Literature Towards a Transformational Model for the Construction Industrialization**. Proceedings of the 5th International Conference on Production Economics and Project Evaluation, ICOPEV 2022, pp 369-382

Paper III provides an in-depth examination of Organizational Change and Change Management theories within the context of this Doctoral Project. Two systematic literature reviews were conducted. The objective is to produce a deeper understanding of the complex nature of CI and to explore new approaches for planning change towards the CI process. As an output, Paper III presents a comprehensive transformation model that encompasses the fundamental changes inherent in the CI process across diverse spheres and their interplay. To the best of the Author's knowledge, this study represents the first attempt in CI literature to provide a comprehensive model of CI transformation. So, the second reference that supports Chapter 4 is as follows:

Paper III: Costa, Sara; Carvalho, Maria Sameiro; Pimentel, Carina; Duarte, Cláudia. (2024). **Analyzing Construction Industrialization: A Theoretical Model Including the Perspective of Organizational Change Theory**. (Out for Review in the Engineering Management Journal)

Chapter 5 tackles the third and fourth research questions *(RQ3: "How has the Construction Industrialization phenomenon been perceived in practice, both in terms of its definition and its development process?"; RQ4: "How can the phenomenon of Construction Industrialization be conceptualized to fill the current gaps in the literature and advance its understanding by linking theory and practice?")*. The empirical part of the research is established through a multiple case study that empirically explores the CI phenomenon. The findings of the within- and cross-case analyses across four sectors (Architecture, Engineering, Traditional Construction, and Manufactured Construction) are presented, offering valuable insights. One paper has been developed to address the concept (Paper IV) and another, the CI process (Paper V).

Paper IV contributes to the conceptualization of CI by challenging the initial conceptualization from Paper I, refining the theory and practice, and providing a structured approach to advancing the understanding of CI by identifying similarities and differences within and across cases. An improved CI definition is developed in this paper. So, the first reference that supports Chapter 5 is as follows:

Paper IV: Costa, Sara; Carvalho, Maria Sameiro; Pimentel, Carina; Duarte, Cláudia. (2024). **Conceptualizing the Phenomenon of Construction Industrialization: Linking Theory and Practice Through a Cross-Sector Case Study**. *International Journal of Construction Management.* https://doi.org/10.1080/15623599.2024.2389583

Paper V tackles the third and fourth research questions regarding the CI development process, within the same empirical context. By exploring each facet of the CI process and delineating similarities and differences within and across cases, Paper V provides a structured opportunity for a theory to be advanced. An improved CI process model is developed in Paper V. Novel and unique insights for both Scholars and Practitioners interested in CI are provided. This should be used to systematize, inform, and inspire future research. So, the second reference that supports Chapter 5 is as follows:

Paper V: Costa, Sara; Carvalho, Maria Sameiro; Pimentel, Carina; Duarte, Cláudia. (2024). **The Construction Industrialization Process: Results of an International Cross-Sector Case Study.** *Engineering, Construction, and Architectural Management Journal.* https://doi.org/10.1108/ECAM-04-2024-0521

Chapter 6 ends this document by summarizing the main findings of the study. It reviews the main contributions, answers the four research questions, and discusses theoretical and managerial implications. Additionally, it highlights research limitations and suggests future research directions.

To help readers better understand the structure of this thesis, Table 1.1 closes Chapter 1 by presenting a list of the five papers developed to answer the four research questions. The correspondence between the papers, their research design, and their current publication status is also provided in Table 1.1.

Table 1.1: List of the five papers developed

RQ	Chapter	Paper	Title	Research Design	Publication Status
RQ1	3	I	A Systematic Literature Review and Conceptual Framework of Construction Industrialization	SLR	Published in an international journal*
RQ2	4	II	Lessons from the Organizational Change Literature Towards a Transformational Model for the Construction Industrialization	LR	Published as an international conference paper
		III	Analyzing Construction Industrialization: A Theoretical Model Including the Perspective of Organizational Change Theory	SLR	Under review in an international journal
RQ3; RQ4	5	IV	Conceptualizing the Phenomenon of Construction Industrialization: Linking Theory and Practice Through a Cross-Sector Case Study	Multiple case study	Published in an international journal
		V	The Construction Industrialization Process: Results of an International Cross-Sector Case Study	Multiple case study	Published in an international journal

*Fifty citations to date – update March 2026

Chapter 2

Thesis Methodology

This Chapter is designed to delineate the methodological approach employed in this thesis. Such clarification is crucial to explain the decisions made in this research to create and communicate new knowledge regarding the CI phenomenon. Consequently, Chapter 2 begins with a brief delineation of the philosophical fundamentals, followed by an explanation of the research approach and research design. An explanation of the case study selection as a research strategy follows this. Topics of research quality and ethical considerations are also discussed.

2.1. Philosophical Fundamentals

Philosophers of science and Scholars have been engaged in a long-standing debate about how best to conduct research (Karami et al., 2006). Philosophical fundamentals represent the backbone of a viable research design, or as succinctly stated by Solem (2003):

> *"Maturity in a discipline can be judged by its Practitioners' capacity for philosophical reflection on the fundamental assumptions they make about reality, i.e., ontology, and the process of learning about it, i.e., epistemology, to use two of the main concepts from the Theory of Science or Philosophy of Science."*

The basic argument is that the Philosophy of Science plays a significant role in the way theories, in general, are elaborated and tested, and in the shape and form of the subsequent knowledge that is generated. According to Karlsson (2016, p.53), contributing to knowledge requires being mindful of the philosophical assumptions of meaning and knowledge.

Neglecting the philosophical part of research can considerably affect the quality of findings that support scientific studies (Dubé & Paré, 2003). For the present study, a deep consideration of

philosophical fundamentals helped to form a coherent link between the phenomenon, the research questions, the research design, the data, and the findings.

The following sections discuss the present research's ontological, epistemological, and methodological positions. Ontology and Epistemology are concerned with questions of *"being"* and *"knowing"*, respectively. Methodological positions represent a third concept from the Philosophy of Science; it deals with *"how we gain knowledge about the world"* (Ketokivi & Choi, 2014).

2.1.1. Ontological Positions

Each research process can be carried out under different ontological assumptions. Ontology leads with an assumption of the nature of reality and social beings, concentrating on *"what's out there to know?"* (Karlsson, 2016).

Different interpretations of reality may be undertaken, and consequently, different ways of expressing ontological positions exist (Ketokivi & Choi, 2014). In the literature, typically two main positions can be found: realism, which considers "*reality"* to be investigated as objective, external, and independent of human knowledge and beliefs; and nominalism, which understands "*reality"* as a product of individual consciousness (Solem, 2003). In this research, realism is adopted to study the CI phenomenon.

2.1.2. Epistemological Positions

Ontology and Epistemology are inextricably linked, with each ontological assumption influencing the researcher's epistemology definition (Karlsson, 2016). Epistemology deals with how *"reality"* is perceived (Näslund, 2002). Ultimately, the fundamental epistemological assumptions govern how the research will be done and how knowledge is produced and communicated (Langley & Abdallah, 2011).

In a nutshell, two commonly known research paradigms have been portrayed in the research literature as the significant philosophical foundations (Dubé & Paré, 2003; Solem, 2003; Karlsson, 2016): positivism and interpretivism. At one extreme, positivism assumes the existence of an objective *"reality"* that exists independently and externally. This paradigm emphasizes that knowledge can and must be developed objectively based on the experience of sense through direct measurements and careful observations of the phenomenon. In contrast, interpretivism assumes

that *"reality"* is socially constructed, and knowledge is inherently subjective, culturally and contextually situated, and shaped by individuals' interpretations, meanings, values, and beliefs (Azungah, 2018).

Based on such distinction, and aligned with the ontological position, this thesis follows a conscious path of positivism as it aims to have a real, objective picture of the Construction Industrialization development process, where the knowledge can be transmitted tangibly and can be replicable across different contexts (Solem, 2003).

2.1.3. Methodological Positions

Ontological and epistemological assumptions consequently influence methodological positions (how knowledge about the *"reality"* is acquired) (Näslund, 2002). This debate is often framed in terms of two methodologies: quantitative and qualitative (Eisenhardt & Graebner, 2007).

The quantitative methodology is focused on measuring and quantifying a phenomenon in terms of amount, intensity, or frequency, thereby enabling researchers to hypothesize and test theories through empirical validation (Ketokivi & Choi, 2014). In contrast, qualitative methodology prioritizes an in-depth understanding of phenomena over measurement and quantification (Wacker, 2004). This methodology uses words, meanings, and observable data to capture a comprehensive understanding of the phenomenon from the perspective of those who experience it (Langley & Abdallah, 2011).

The existing literature frequently associates positivism with a quantitative methodology, particularly when research employs predetermined and highly structured data collection methods such as surveys and statistical analyses (Larsson, 1993; Naslund, 2002; Solem, 2003). This direct association stems from a fundamental principle of the positivism paradigm: its emphasis on objectivity and the pursuit of knowledge that is independent of subjective interpretations.

In the context of the CI field, and as discussed in Chapter 1, the theoretical foundation underlying CI conceptualization and the CI development process remains underdeveloped, presenting significant challenges to the immediate application of quantitative methodologies. The Author contends that the CI field has yet to achieve the necessary theoretical rigor to support large-scale empirical testing through quantitative methods. Furthermore, at this stage of theoretical development, quantitative methodology may struggle to capture more holistically the complexities

of a contemporary phenomenon and its interaction within different contexts (Handoko et al., 2018), potentially leading to superficial insights rather than substantive theoretical advancements (Näslund, 2002).

Some Scholars advocate for a more nuanced perspective on methodological positions, arguing that ontological and epistemological positions are not rigidly or exclusively linked to specific methodological approaches (Ahrens & Chapman, 2006; Saunders et al., 2019). This perspective allows for a broader exploration of qualitative methodologies within the context of this thesis.

The application of qualitative methodology within positivist studies has been strongly endorsed as a means of obtaining richer, more comprehensive, and objective descriptions of phenomena (Azungah, 2018). As highlighted by Näslund (2002) and Edmondson & McManus (2007), qualitative methodology is particularly suitable when the phenomena in question are not well understood, and the research seeks to uncover and explore novel perspectives on emerging topics. Additionally, qualitative methodology offers the flexibility and depth necessary to examine complex phenomena across diverse contexts, allowing for the examination of patterns that can be generalized or applied to specific contexts, while also being responsive to unexpected or emerging findings (Edmondson & McManus, 2007).

Positivist and interpretivist studies differ in research design when applying qualitative methodology. Positivist studies emphasize the use of theoretical constructs to explain phenomena, aiming for generalizability and theory development (Whetten, 1989; Edmondson & McManus, 2007). In contrast, interpretivist studies prioritize capturing nuanced, context-dependent interpretations of social phenomena from participants' perspectives. Rather than imposing pre-existing theoretical constructs or frameworks, interpretivist research seeks to understand meaning as it emerges within specific social and cultural contexts (Azungah, 2018).

According to Suddaby (2010), constructs are robust categories that are considered the precise language to capture, as effectively as possible, the essence of a phenomenon. In positivist studies, these constructs must be explicitly defined and refined as empirical evidence is gathered and analyzed (Barrat et al., 2011). While these constructs are subject to modification as research progresses, qualitative methodologies also allow for the emergence of new, unanticipated findings (Awuzie & McDermott, 2017).

Given these considerations, qualitative methodology emerges as the most appropriate choice for this research. It enables a deeper exploration of the CI phenomenon, providing insights that may

not be attainable through quantitative methodology. By adopting a qualitative methodology, this study can contribute to the development of a more comprehensive theoretical framework for CI and facilitate a richer understanding of the phenomenon under study.

2.2. Research Approach

The previous philosophical decisions have a strong influence on the research approach selected, and consequently, on the shape and form of the subsequent knowledge that must be developed in this thesis.

The literature points out three research approaches to theory development: the deductive, the inductive, and the abductive approach (Saunders et al., 2019). However, the distinctions between these approaches are not always clearly defined, leading to ambiguity in scholarly debate (Kovács & Spens, 2005). This lack of clarity raises concerns about the rigor of research designs and challenges the validity of conclusions drawn from them, according to Spens and Kovács (2006). One example of this ambiguity is the predominant use of deductive or inductive approaches in some scholarly works, often neglecting abduction (see, for instance, the review developed by Barratt et al., 2011).

Although the abductive approach is gaining recognition, Scholars emphasize that it tends to be underutilized, and it is frequently confused with other research approaches (Fisher & Aguinis, 2017; Saunders et al., 2019; Elliot et al., 2020; Conaty, 2021). Particularly, Kovács & Spens (2005) and Borgström (2012) highlight that abduction is often confused with the deductive approach, leading to misunderstandings regarding its distinct characteristics, objectives, and research designs.

Scholarly work also diverges regarding the role and purpose of abductive studies. Some argue that abduction serves as a combination of deductive and inductive approaches (Awuzie & McDermott, 2017); while others assert that abduction is not an alternative to these approaches but rather serves distinct research purposes: deduction for theory testing, induction for theory building from data, and abduction for theory elaboration (Fisher & Aguinis, 2017; Conaty, 2021; Saunders et al., 2019). This explanation forms the basis of the distinction adopted in this thesis.

Therefore, deductive studies are applied to test a prior theory by validating or disconfirming whether the empirical evidence supports the theoretical propositions/hypothesis (Hillebrand et al., 2001;

Barratt et al., 2011). According to Kovács & Spens (2005), deduction is not intended to generate new theories. Instead, Saunders et al. (2019) argue that the development of new theories requires an inductive or abductive approach. However, when a theory is not yet mature enough, Scholars advise against going ahead with formulating and testing hypotheses.

Particular attention was given to this thesis to avoid the deduction of a testable hypothesis; a practice commonly associated with the positivism paradigm. The Author has consistently highlighted the ambiguities and gaps in understanding the CI phenomenon and its development process in this thesis. CI research currently lacks a well-defined, comprehensive framework that can effectively capture the complex nature of CI and guide Practitioners in their CI efforts. These concerns reinforce the need for additional research to develop theoretical frameworks and enhance empirical insights on this topic. Therefore, after careful consideration of the deductive approach's purposes and its implications for research design, it has been determined that this research strategy may not align closely with the context of this study.

As another approach to research, inductive research is used to explore unknown phenomena based on subjective interpretations (Golicic & Davis, 2012; Gammelgaard, 2017). The inductive approach generates theories systematically from data, predicated on the assumption that no prior theory exists (Dubois & Gadde, 2002; Ketokivi & Choi, 2014).

In this thesis, the absence of a comprehensive framework does not invalidate the existing models and studies published in the literature, which explore the implementation of the phenomenon through its components and from various perspectives. This suggests that the inductive precondition of *"whenever theory does not exist"* does not apply to this thesis. Instead, this study seeks to engage with existing literature and enrich it through empirical data, aligning more closely with an abductive approach.

Abductive studies, according to Kovács & Spens (2005), seek to identify theories suited to empirical observations and refine them accordingly. Fisher & Aguinis (2017) define abduction as:

> *"(...) the process of conceptualizing and executing empirical research using pre-existing conceptual ideas or a preliminary model as a basis for developing new theoretical insights by contrasting, specifying, or structuring theoretical constructs and relations to account for and explain empirical observations."*

When applied within a positivism paradigm, abductive reasoning enables the elaboration of theories that remain grounded in the intersection of the empirical observations, the existing framework, the

theory, and the case (Dubois & Gadde, 2002). Abductive studies prioritize theorization through continuous reflection on empirical data, assessing its alignment with prior theory to refine and expand theoretical constructs (Dubois & Gadde, 2002; Borgström, 2012).

As mentioned earlier, a prior specification of constructs must be developed as the basis for this type of research approach (Borgström, 2012). Particularly, within the positivism paradigm, following an abductive research approach, well-defined constructs prove to be fundamental elements as the study progresses to empirical exploration, ensuring the internal validity of abductively derived explanations (Eisenhardt, 1989; McCutcheon & Meredith, 1993).

One significant distinction between abduction and other research approaches is the role of prior theoretical knowledge. Rather than testing pre-existing theories (as in deduction), abductive studies iteratively modify and refine the theoretical constructs in answer to unexpected empirical findings. This iterative confrontation between theory and empirical findings allows for novel insights that would not emerge through deduction or induction (Meredith, 1998; Solem, 2003; Karami et al., 2006; Bitektine, 2007).

Additionally, abductive research fosters the development of contextual knowledge by reaching a deep understanding of specific phenomena while determining which constructs are generalizable and which are context-specific (Towers et al., 2020), which aligns with the fundamental principles of the positivism paradigm mentioned earlier. This contextual knowledge is particularly valuable for CI research, as it enhances the comprehensive understanding of the CI phenomenon from a broad industry perspective while addressing the central research question of this thesis *("How to assist construction Managers in a comprehensive Construction Industrialization development process?")*.

Therefore, the iterative refinement of initial theories, the openness to unanticipated findings, and the examination of CI across different contexts all align with the philosophical underpinnings of abduction. Consequently, an abductive approach is deemed the most appropriate methodological choice for this study.

2.3. Research Design and Outcomes

This section outlines the research design followed in this thesis, ensuring coherence and rigor in aligning philosophical positions, the chosen research approach, the process of gathering and elaborating knowledge about the CI phenomenon, and the outcomes of this research (how the newly generated knowledge is transmitted).

Literature, however, does not always provide a clear delineation of the abductive research process, particularly in comparison to deductive and inductive approaches. To strengthen the research design, this thesis draws on the contributions of Kreye & van Donk (2021), Do et al. (2022), and Gomes et al. (2023), along with the study by Fisher & Aguinis (2017).

This thesis begins with its motivation, which serves as the foundational basis of the study (Chapter 1). Particularly, this beginning follows the recommendations of Spens and Kovács (2006), who argue that an abductive study within a positivism paradigm, employing a qualitative methodology, typically originates from the researcher's direct interaction with a complex real-world phenomenon and the realization that the current literature is still insufficient for explaining it.

As outlined in Chapter 1, this thesis is motivated by direct interaction with real-life challenges in CI implementation, particularly the practical challenges encountered in CI implementation, where the current body of knowledge does not provide adequate theoretical support for effective implementation. A review of the literature reveals that existing studies offer only a fragmented and narrow understanding of CI, failing to capture its full complexity. Furthermore, prior theoretical contributions to CI development lack coherence, making practical implementation even more challenging. This practical motivation, combined with the theoretical gaps identified in Chapter 1, informs the first part of this research—the conceptual part of the research design.

Figure 2.1 shows the abductive research design structured in this thesis. It explicitly links each research question to the corresponding part and chapter where it is addressed in this thesis. Each part addresses one or more research questions. Additionally, Figure 2.1 synthesizes the main research outcomes of this thesis in the form of a CI definition and a CI transformation model. Through these outcomes, the central research question of this thesis *("How to assist construction Managers in a comprehensive Construction Industrialization development process?")* is answered.

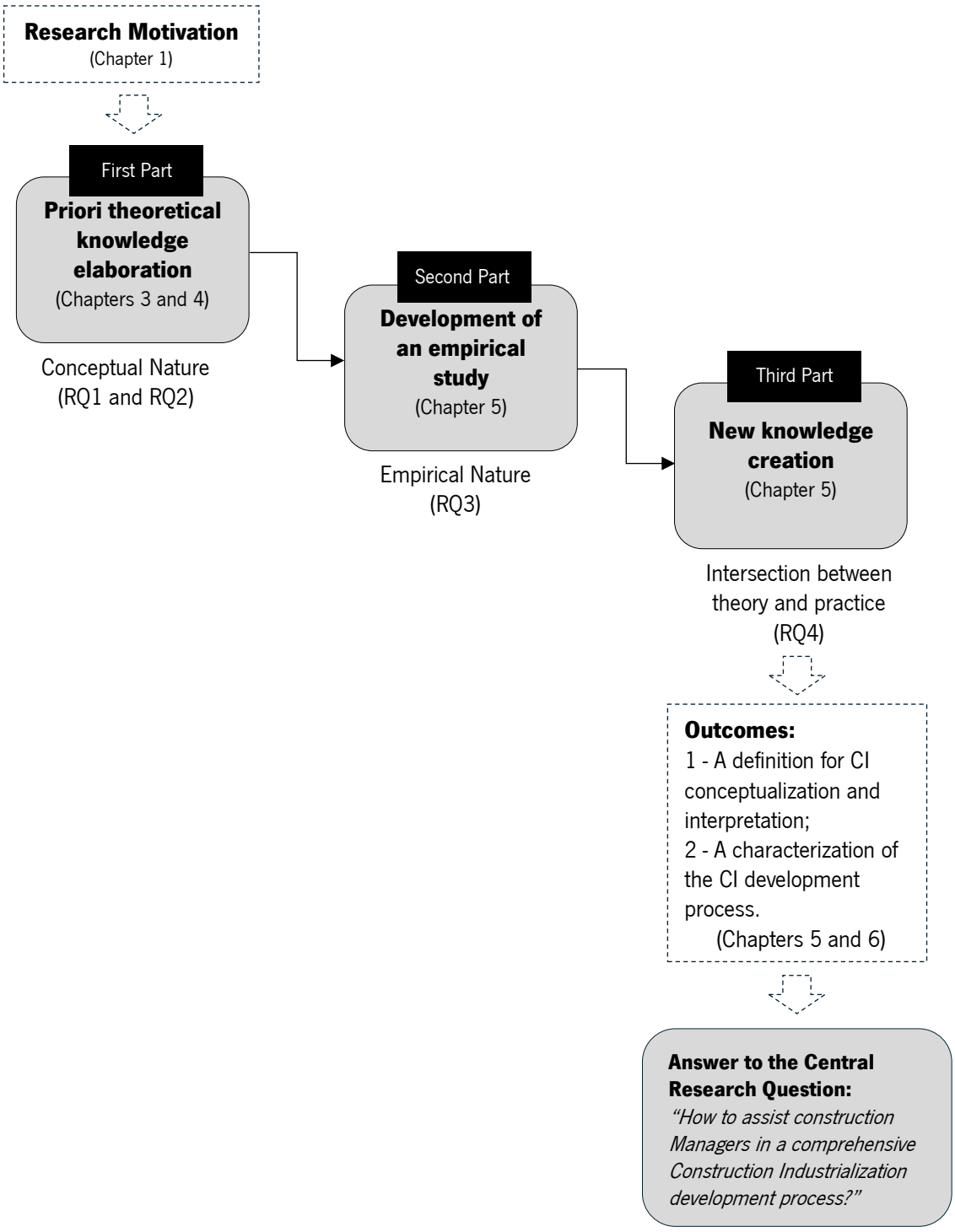


Figure 2.1: Schematic diagram of the research

Three sequential parts are outlined in Figure 2.1: the first part is conceptual, the second part is empirical, and the third part intersects theory and practice. The rationale for this sequence is that the CI phenomenon must first be theoretically conceptualized and further elaborated, revised, and enriched through empirical study.

By following this structured approach, this thesis ensures that the CI phenomenon is examined from both theoretical and practical perspectives. This integration enhances the contribution to existing literature and industry practices, fostering a comprehensive understanding of the Construction Industrialization process.

Two significant outcomes are expected from this research design, both of which aim to enhance scholarly discourse, inform policymakers, and support industry Practitioners in their transition toward the CI phenomenon. They are:

1. **The development of a structured and comprehensive definition of the phenomenon of Construction Industrialization.**

   This definition aims to offer a clear, broad, and widely applicable conceptualization of the CI phenomenon. A unified definition is crucial for fostering consistency in academic discourse, addressing the call in the literature for a more rigorous conceptual foundation. Moreover, by clarifying the complexity and scope of CI, this definition aims to guide policymakers and support industry Practitioners in adopting CI practices. This definition is intended to serve as a cornerstone for future debate, reducing ambiguities and ensuring a common interpretation for analyzing CI across different contexts and regions.

2. **The characterization of the CI development process through a transformation model that helps to capture the complex nature of CI and can provide the necessary guidance to Practitioners when crafting their CI efforts.**

   This model aims to offer a tool for Scholars, Policymakers, and industry Practitioners as essential guidance for stakeholders in planning, implementing, and improving their CI practices. By framing CI as a paradigm shift that influences both project-level processes and broader organizational strategies, the model aims to provide a comprehensive perspective on its adoption. Additionally, it aims to highlight the multifaceted and multilevel interactions within the construction industry, ensuring a more structured and effective transition toward the CI phenomenon.

The objective of both outcomes is to provide a more systematic, clear, and coordinated approach to the adoption of CI practices, integrating both theory and practice in an improved understanding of the phenomenon.

To achieve this, the first part of the research design is dedicated to establishing a theoretical foundation for CI conceptualization and its development process. As suggested by Miles and Huberman (1994, p.17), no empirical data were collected in this part. Two literature reviews were conducted: the first examining the construction management literature (Chapter 3), and the second, using the theoretical lens of Organizational Change and Change Management for a deep understanding of the true nature of CI and its development process through a transformation model (Chapter 4). According to Kovács & Spens (2005), it is rather common that abductive studies borrow theories from other scientific fields. This takes advantage of leading to new insight into existing phenomena by examining the phenomena from a new perspective.

By adopting a structured approach as a systematic literature review, this thesis aims to establish a stronger theoretical basis for CI and address the theoretical gaps discussed in Chapter 1. A CI definition and a CI framework are developed in this first part; however, the Author considers that these elements do not fully explain the phenomenon under study (in line with the abductive reasoning). Rather, they serve as a research framework for empirical exploration (Coughlan et al., 2016). The utility of these elements as constructs aligns with abductively led qualitative research (Awuzie & McDermott, 2017). Their subsequent refinement enhances construct validity and expands the theoretical scope of this research, contributing to theory elaboration (Fisher & Aguinis, 2017).

In the second part of the research design, an empirical study is conducted to explore the perspective of Practitioners from different sectors involved in the construction industry regarding the CI phenomenon and its development process (Chapter 5). Empirical evidence, therefore, aims to reveal insights into how CI is applied in practice and how it can enrich the overall development process—insights that may not be fully captured through purely conceptual analysis.

Case Research is the research strategy chosen to gather and analyze the empirical perspectives in this thesis (further detailed in the next chapter). A multiple case study approach is employed (detailed in Chapter 5), enabling a comparative analysis of similarities and differences in CI conceptualization and development processes across different sectors. This comparative

approach, fundamental to theory elaboration, aligns with the concept of horizontal contrasts as defined by Fisher & Aguinis (2017).

This second part of the study also incorporates a practical understanding— or *phronesis* —which, according to Conaty (2021), is most effectively achieved through in-depth, direct engagement with the individuals involved in the phenomenon being studied. This direct involvement is facilitated by the Author's proximity to the phenomenon under study while maintaining self-awareness and vigilance to mitigate potential biases (discussed in the next section).

In this thesis, a rigorous Case Research process, which incorporates multiple data sources and gathers insights from various hierarchical levels, sectors, and professional backgrounds, contributes to a more comprehensive and practical agenda for advancing CI adoption. Therefore, this research strategy not only strengthens the validity of the research but also enhances the robustness of the findings. By integrating diverse data sources, it ensures a well-rounded perspective. The inclusion of multiple hierarchical levels allows for an in-depth exploration of both strategic and operational aspects of CI development. Additionally, the cross-sectoral perspective facilitates the identification of common themes, sector-specific challenges, and variations in the conceptualization and implementation of CI across different sectors.

The third part of the research design emphasizes the need to confront theoretical frameworks with empirical fieldwork, bridging the gap between theory and the empirical world. This process facilitates the reflection and potential redirection of the evolved theory in abductive studies. Dubois and Gadde (2002) refer to this approach as *"systematic combining"*, while Coughlan et al. (2016) call it *"theory matching"*. This iterative process of revisiting and refining the framework, data sources, and analysis is central to this third part.

Empirical data is confronted with prior theoretical knowledge, enabling the refinement, adaptation, and enhancement of prior theoretical constructs. This alignment process may reveal previously unanticipated or conceptually related constructs. Meredith (1998) emphasizes that the purpose of theory elaboration through Case Research often extends beyond the initial theoretical framework, particularly when addressing exceptions or unexpected findings, aligning with the discussion outlined in the previous section. Scholars argue that data collected empirically should not be forced to fit preconceived or preexisting constructs. Instead, these constructs should evolve from the data itself. The data collection process must be defined in this regard (as proved in Chapter 5).

The concepts of creativity and intuition are often linked to the abductive research process, which is associated with a critical approach to theory, especially in relation to anomalies or outliers. Borgström (2012) refers to the abductive research approach as a *"mystery methodology"*, emphasizing its role in explaining unexpected phenomena that cannot be explained using an established prior theory.

In this thesis, and from the perspective of an abductive research approach - aimed at enriching the literature - the Author seeks to refine the theoretical foundations by providing a revised CI definition and CI transformation model. These outcomes, as shown in Figure 2.1, serve to develop novel knowledge for the scientific community. Furthermore, new insights derived from empirical findings are presented as a list of constructs that not only provide new perspectives but also stimulate further academic and practical discussions.

Collectively, these contributions bridge theory and practice, intending to foster future scholarly debates while offering valuable guidance to Practitioners. The aim is to provide a more structured and effective framework for transitioning from traditional construction methods to industrialized approaches, thus supporting the planning and implementation of CI practices.

2.4. Research Strategy

The importance of articulating the philosophical foundation and taking a holistic approach to research design stresses Case Research as the selected research strategy to bring the empirical perspective about the CI phenomenon in this thesis. Therefore, this section clarifies the rationale behind this choice and subsequently addresses research quality—a matter that the Author believes merits significant attention. Additionally, the section ends with ethical considerations that warrant further discussion.

The research process associated with Case Research is detailed in Chapter 5. Two papers have been authored to present the findings of the empirical study: one addresses the CI conceptualization, while the other explores the development process of the phenomenon. These papers offer comprehensive insights into the empirical basis, research design, case selection, data collection methods, and data analysis.

2.4.1. Case Research Choice

According to Conaty (2021), the abductive research approach lends itself to the Qualitative Case Research strategy by its advantages in the researchers being in close proximity to the phenomenon under study and the source of the data in its natural context. Studies developed by Ahrens & Chapman (2006) and Conaty (2021) employed Case Research within abductive studies. This research strategy aligns with abduction, as it facilitates a deep interaction between the Researcher and the field, as well as between the data and theory, enabling richer insights and a more nuanced understanding.

Yin (1974) compared Case Research with other research strategies. The type of research question posed, the extent of control an investigator has over actual behavioral events, and the degree of focus on contemporary, as opposed to historical events, sustain the choice for the most appropriate research strategy to employ in this thesis (Table 2.1).

Table 2.1: Relevant aspects for different research strategies (based on McLachlin, 1997)

Research Strategy	Form of the research question	Requires control over behavioral events?	Focus on contemporary events
Experimentation	How, Why	Yes	Yes
Survey	Who, What, Where, How Many, How Much	No	Yes
Case Research	How, Why	No	Yes

In the context of this thesis, Case Research particularly fits the purpose of answering the "*how"* question (*"How to assist construction Managers in a comprehensive Construction Industrialization development process?"* is the central question of this Doctoral Project). It also fits the purpose of examining a contemporary phenomenon, and the relevant behaviors cannot be manipulated (under the philosophical assumptions outlined in Section 2.1).

Over the years, Scholars have been justifying the importance of using Case Research in contemporary and complex phenomena. Similarities are found between the following justifications.

For Voss et al. (2002), Case Research is a deemed strategy when the phenomenon is not at all understood, and Scholars do not know what issues may emerge from the data. Along the same

line, Edmondson & McManus (2007) state that Case Research is increasingly accepted as a research strategy, especially for studying a phenomenon where the theory is in a nascent stage.

Compared to the deductive research approach, when little or no prior work related to a research question exists, a (quantitative) Survey is unlikely to be as informative as (qualitative) Case Research, according to Edmondson & McManus (2007). As stated by Näslund (2002), *"the complexity of methods, the large sample sizes needed, and the difficulty in understanding and interpreting the results from complex quantitative studies"* are three notable objections to the use of survey research for contemporary phenomena.

Dubé & Paré (2003) defend that Case Research is particularly useful where the existing body of knowledge is insufficient to advance with a hypothesis and causal relations, when a holistic, in-depth investigation is needed, and when a phenomenon cannot be studied outside the context in which it occurs. This is especially relevant given that proponents of case studies further suggest that surveys may not be the most appropriate research strategy if the research is about a change in organizations (Handoko et al., 2018).

Case Research strategy is widely and increasingly being used in organizational research (vom Brocke et al., 2021). For Noor (2008), Case Research is particularly useful in capturing organizations' emergent and immanent proprieties of life, and for Azungah (2018), Case Research is uniquely suited to *"opening the black box"* of organizational processes.

Case Research also leads to covering context-rich data from bounded real-world settings, believing that they might be highly pertinent to the phenomenon under study (Yin, 1974). A key feature of Case Research widely cited by Scholars is that such research strategy relies on multiple sources of evidence, with data needing to converge in a triangulation fashion while investigating contemporary phenomena in-depth and within their real-life settings (Yin, 2018). Scholars often rely on the applicability of Case Research for capturing more holistically the complexities of a contemporary phenomenon, and its interaction across contexts (in line with the positivism paradigm).

Therefore, beyond the philosophical positions and the research approach selected, the combination of the abductive approach, the position of this thesis in the previous three conditions presented by Yin (1974), and the many advantages of Case Research in qualitative studies, reinforces the selection of Case Research as the preferred research strategy for data collection and analysis of the CI phenomenon.

2.4.2. Research Quality

Regardless of philosophical assumptions and research approach, four tests are commonly used to establish the quality of empirical research, these are: construct validity, internal validity, external validity, and reliability (McCutcheon & Meredith, 1993). The typical definitions are the following (based on Yin, 2003):

- **Construct validity:** establishing correct operational measures for the concepts being studied;
- **Internal validity:** establishing a causal relationship, whereby certain conditions are shown to lead to other conditions;
- **External validity:** establishing the domain to which a study's findings can be generalized;
- **Reliability:** demonstrating that the operations of a study, such as the data collection procedures, can be repeated, with the same results.

However, the need for a thorough examination of research quality within an abductive approach has produced considerable debate. Primarily, internal validity is not applied to exploratory and descriptive studies, but only to causal (or explanatory) case studies, according to McCutcheon & Meredith (1993) and Yin (2003). For this reason, such a test was not considered in this thesis. Secondly, the integration of different philosophical and methodological paradigms—such as realism, positivism, abduction, and qualitative research—raises concerns regarding methodological rigor. Scholars point out that careful consideration should be given to uphold fundamental principles such as objectivity, generalizability, and replicability. According to the literature, addressing these concerns is essential for maintaining the credibility and robustness of the research process.

Table 2.2 summarizes eighteen case study tactics to ensure the construction of construct validity, external validity, and reliability. The presented summary is developed based on Case Research works (Eisenhardt, 1989; Voss et al., 2002; Yin, 2003; Gibbert & Ruigrok, 2010), as well as the particularly abductive studies developed by Kovács & Spens (2005), Gibbert & Ruigrok (2010), Dubois and Gibbert (2010), Fisher and Aguinis (2017), Awuzie & McDermott (2017), Folger & Stein (2017), Song et al. (2020), Towers et al. (2020), Conaty (2021) and Gomes et al. (2023). Table 2.2 also shows where each case study tactic is addressed in this document.

Table 2.2: List of criteria to ensure case study quality

Criteria	Case Study Tactic
Construct Validity	I. Formulate a prior model explicitly derived from the literature, which especially determines the key constructs (Chapter 5 and Appendix F); II. Adopt different angles from which to look at the same phenomenon (Chapters 3, 4, and 5); III. Establish a chain of evidence from raw data from the data collection process through summary tables and conclusions (Appendix I); IV. Adopt Researcher triangulation through two Researchers collecting data (Appendix F); V. Discuss the emergent findings and theoretical framework with construction Practitioners (Appendix I); VI. Develop a construct specification approach, which involves the identification or refinement of theoretical constructs so that they more accurately reflect empirical realities (Chapter 5 and Appendix F); VII. Develop a case study in a context that embraces the CI process in a real setting (Chapter 5); VIII. Develop methodological triangulation through collecting data using different data collection instruments (Appendix I); IX. Ensure horizontal contrasting (contrasting observations across different contexts) to improve logical and empirical adequacy (Chapter 5);
External Validity	X. Provide a clear rationale for selecting multiple case studies, particularly the four construction sectors involved in the study. This will help frame the study in a geographical and sectoral context that allows for a comprehensive view of the industry (Chapter 5 and Appendix F); XI. Develop a theoretical sampling approach that allows the adoption of replication logic to elaborate theory (Chapter 5); XII. Conduct a first-order/second-order analysis that offers transparency in the data analysis process (Appendix I); XIII. Conduct a thematic analysis that makes explicit the exercise in moving from raw data to interpretations (Appendix I); XIV. Ensure that empirical findings are connected to prior theory (Chapter 5 and Appendix I);

Table 2.2: List of criteria to ensure case study quality *(continue)*

Criteria		Case Study Tactic
Reliability	XV.	Use a case study protocol to guide field research and analysis (Appendix F);
	XVI.	Develop a case study database including interview transcripts and notes, Funding Agenda reports, internal documents, and site visit reports (from Appendix I);
	XVII.	Include numerous and highly knowledgeable informants who view the focal phenomena from diverse perspectives to reduce any potential bias (Chapter 5);
	XVIII.	Ensure constant self-awareness and vigilance on the part of the researchers about their own practical understanding of the phenomenon, throughout the process of collecting and analyzing data (Section 2.4.3 of this Chapter 2 and Chapter 5).

2.4.3. Ethical Considerations

Ethical and moral norms must be exposed, especially in the context of an empirical study being conducted under a Government Funding Agenda where the Author is professionally involved.

In Portugal, a Government Funding Agenda is driving a transformative empirical study within the construction sector, with the Author's company taking a leading role. This ambitious initiative aims to establish a Living Lab—a visionary mini-city that will feature five distinct building types in Braga. The design of these five buildings is integral to this crucial transition, representing a considerable advancement from conventional practices to an industrialized construction process. Approximately 50 diverse entities are collaborating on this Agenda, which prioritizes the development of new materials and products, advanced services, digital innovations, and enhanced knowledge sharing.

As outlined in Chapter 5, an international team is actively engaged in conceptualizing this groundbreaking construction system, while the Author oversees its implementation. Moreover, new automated factories are being designed to revolutionize the organization of the construction production process, playing a crucial role in this initiative. This comprehensive agenda, rich in potential and complexity, highlights the collaboration and commitment of all parties involved. Together, this effort is poised to fundamentally reshape the construction industry in Portugal, advancing industrialization and establishing the Author's company as a pioneering leader in this vital field.

In light of this context and the Author's close association with the Governmental Funding Agenda, ethical considerations must be prioritized. The research conducted in this Doctoral Project was carried out with a strong commitment to professionalism, adhering to the highest standards of rigor and integrity. To achieve this:

- In developing the Governmental Funding Agenda, the Author was excluded from the decision-making process, which seemed crucial to prevent her input from impacting the outcome. It should be noted that the Author only became involved after the Governmental Funding Agenda incentive had been approved.
- During the empirical study, a clear distinction was established between the roles of the Author and the Worker. To maintain impartiality and contribute to unbiased research, the Author adopted a passive observational role instead of actively participating in the meetings. Although this decision posed a significant challenge due to the Author's close relationships with colleagues and the nature of the topics being discussed, it was a deliberate step taken to address ethical and moral concerns.
- The Author made noteworthy contributions to the Governmental Funding Agenda following the completion of the empirical study, drawing upon her extensive knowledge and experience along the several dimensions of change that are outlined in Chapter 5.

Associated with the data collection process, there are two crucial observations to be made regarding the ethical issues, especially:

- To foster a collaborative environment while safeguarding intellectual property, ethical regulations on privacy (see Appendix H), and detailed writing guidelines were developed, along with an interview protocol. The Author has successfully obtained official consent from all Practitioners, using a form that ensures their participation in the research while guaranteeing the utmost confidentiality for their company affiliations and personal identities.
- Chapter 5, which examined Practitioners' perspectives, gathered data directly from primary sources to uphold data confidentiality and ensure its secure preservation throughout the research process, thereby safeguarding the data's integrity.

Finally, the Author thoroughly addressed potential sources of bias in the Doctoral Project research:

- Based on the literature, the Author developed the framework of reference before starting the empirical part of the study. Despite the practical experience, the Author confined the drafting of the interview protocol (Appendix G) to the themes and constructs found in the literature.
- Once again, given the practical experience, the ideas that the Author considered to be new or worth exploring depended on the framework of reference, which was influenced by the literature. It is worth mentioning that the Author's framework of reference remained constant throughout the interview process so that all Practitioners look at the same basis for reflection. It was deliberately asked that Practitioners reflect on their experiences rather than talk about ideas in the literature.
- It is also worth mentioning the potential bias in the data analysis process, where the Author could be influenced by the ideas of certain respondents more than others. This fact was considered through the chain of evidence so that its interpretation remains unbiased (in line with the previous research quality topic).
- The choice of the Practitioners was a source of potential bias addressed in Chapter 5.

Chapter 3

State-of-the-art Review

This third Chapter reports on the first systematic literature review developed in this Doctoral Project. It was carried out to get a picture of the state of the art of the Construction Industrialization phenomenon and offer a systematic perspective of CI in terms of definition and development process. One of the key findings of this Chapter is a list of gaps in the field of Construction Industrialization, highlighting the need for a more comprehensive understanding of the CI concept and the CI process. Additionally, a conceptual definition and framework are thoughtfully provided. The chapter concludes with a summary of the main contributions and research opportunities, including the potential for further research in extending the organizational change theory as a basis for the development of this Doctoral Project.

A Systematic Literature Review and Conceptual Framework of Construction Industrialization

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ABSTRACT

Construction industrialization (CI) has dramatically altered how Architecture, Engineering, and Construction (AEC) companies design, manufacture, build, operate, and manage. Despite its growing relevance in academia and companies in the last few decades, the CI field has been considered unclear, fragmented, and with a high level of misunderstanding. To address this knowledge gap through a systematic literature review, this paper provides a holistic and comprehensive conceptualization of the phenomenon and its theoretical basis for the global engineering and construction management community. In total, 102 articles from the last 11 years (2010–2021) from the Scopus and Web of Science databases were collected and analyzed. So, one primary contribution of this paper is the establishment of a definition for the CI concept. Another important contribution is the definition of a conceptual framework that introduces industrialization as a new way of operating the business, where five major areas, namely strategy, organization, processes, planning, and resources, need to be aligned and managed simultaneously for competitive advantage. Furthermore, design principles, five influencing factors, and initiatives are presented to provide an integrated and holistic view of the concept. This article gives businesses a better understanding of what industrialization in the construction industry actually means, enabling them to move forward with this transformation. Finally, the research provides a basis for improving future contributions in CI and adjacent management disciplines.

Keywords: Industrialized Construction; Organizational Change; Industrial Engineering; Conceptual Framework; Systematic Literature Review.

3.1. Introduction

After several decades of low productivity (Durdyev & Ismail, 2019), under-digitization (García de Soto et al., 2018), and limited appetite for innovation (Xue et al., 2018), the Architecture, Engineering, and Construction (AEC) industry is taking bold steps in a new era. Today, there is a common understanding among all stakeholders and entrepreneurs around the world about the importance of Industrialization as a fundamental paradigm to survive and thrive in an environment characterized by dynamics and volatile markets (Zakaria et al., 2018; Razkenari et al., 2020).

Although the intention to implement CI is widely spread and the research interest is high, a critical ambiguity regarding the concept remains in the research literature. A lack of consensus about the concept of the CI field and its elements is claimed by several Scholars (e.g., Ayinla et al., 2019; Hussein & Zayed, 2021). Similarly, several Scholars recognize that the adoption of CI is underdeveloped, fragmented, immature, and not well-structured, leading to a great level of misunderstanding. This view is supported by Lessing et al. (2015), Peltokorpi et al. (2018), Liu et al. (2019), Ayinla et al. (2019), and Correia et al. (2020).

Many different terms have been used for essentially the same research area. Concerned with some of the most popular terms associated with CI - Modular Construction (MC), Prefabricated Construction (PC), and Off-Site Construction (OSC) - research has shown a lack of common understanding, and in some cases, some overlap between these concepts, which has caused much confusion and misunderstanding. This is due to the widespread consideration that these terms are interchangeable (Mao et al., 2015; Teng et al., 2017; Luo et al., 2020). However, several Scholars refute this interpretation. Ayinla et al. (2019) believe that the impact of theoretical diversity is such that it inhibits a global view and understanding of multicultural collaboration.

Hitherto, to the best of our knowledge, there is not a universal definition of CI, but there are a few sets of topics that have been on the agenda of Practitioners, Policymakers, and Academics and that have been explored in scientific research group debates (such Customized Industrial Construction Task Group 57 *"Industrialization in Construction"*) (Goulding et al., 2015) and Government initiatives (Kamar et al., 2012; Viking & Lidelöw, 2015; Xu et al., 2020).

Different perspectives of the phenomenon often result from partial views of the phenomenon. Some studies focus on products (modularization) (see O'Connor et al., 2014; Choi et al., 2019), others on processes (new construction mode/modern methods of construction) (see Rahman, 2014; Liu

et al., 2018), and still, others focus on a new business model (see Lessing, 2015; Wuni & Shen, 2020a).

The truly strategic and holistic nature of CI thus becomes widely recognized by Practitioners, Policymakers, and Academics. Several Scholars claim that CI not only forces companies to learn and innovate but also requires new organizational and operational models. An effective CI development process also requires changes, not only managerial, but also cultural and behavioral, structural, physical (facilities and machinery), and technological (Goulding et al., 2015; Lessing, 2015; Sabet & Chong, 2019; Zhang et al., 2020).

In the context of the CI development process, the literature shows the growing concern for improving the performance of production systems towards greater efficiency and better customer service levels simultaneously, which has led to a convergence in the study along with separate areas of the discipline of Industrial Management (Salvendy, 2001). Management, manufacturing, and operations are the main areas studied in the recent literature as companies have triggered a change in their manufacturing procedures, construction technology, and production systems (Jonsson & Rudberg, 2015; Altaf et al., 2018; Luo et al., 2020).

Further, in order to enhance the overall CI transformation, several Scholars also widely recognized the importance of Supply Chain Management (SCM) contribution to improving organizational efficiency and competitiveness. Lambert & Cooper (2000) define SCM as: *"Supply Chain Management is the integration of key business processes from end-user through original suppliers that provides products, services, and information that add value for customers and other stakeholders"*.

Therefore, Prefabricated Construction Supply Chain Management (PCSCM) must be properly configured (Arashpour et al., 2017), planned (Liu et al., 2020), synchronized (Dallasega, 2018), and executed (Hussein et al., 2021). In this context, relational, managerial, market, and technological issues must be properly managed (Hsu et al., 2018; Liu et al., 2020; Correia et al., 2020) to continuously improve the production efficiency and the coordination and integration in the whole supply chain (see Ekanayake et al., 2020).

However, although CI Scholars and Practitioners have been aware of this complexity and evolution of the concept, the scientific literature fails to provide a holistic and comprehensive conceptualization of the phenomenon and its theoretical bases; rather, isolated and fragmented pieces of CI transformation have been explored (as stated by Hosseini et al., 2018).

Based on a Systematic Literature Review (SLR) this paper attempts to provide a systematic perspective of CI: a clarification of the concept and a structured definition of its core elements including organizational transformation issues, i.e. (i) the crucial design principles that characterize what industrial transformation of CI requires; as well as (ii) the major dimensions that capture the organizational change required to embrace Industrialized Construction, and (iii) a set of structural initiatives that construction companies should develop during the transition process, within an Industrial Engineering and Management perspective of processes and operations management in the context of SCM. All these aspects are integrated into a framework that embraces all the above-mentioned dimensions and aims to support future developments of Practitioners, Policymakers, and Academics.

We argue that this integration is highly required to understand how the phenomenon is established, carried on, and improved in construction companies, where, at the same time, multiple disciplines and players integrate this transformation to provide competitive and compelling value propositions.

The remainder of this paper is organized as follows: in the following section, a preliminary look at previous literature reviews that may, even partially, be relevant to the study of CI is presented. In Section 3.3, the methodology is described. This is followed by the descriptive analysis of the literature (Section 3.4). Section 3.5 discusses the concept of CI, its definition, initiatives, and design principles to build a conceptual framework that is derived from existing literature. A conceptual CI framework is constructed in Section 3.6. In Section 3.7, the relevant gaps found to provide an agenda for future research are pointed out. The conclusions in Section 3.8 close the paper.

3.2. Background

Some literature reviews exist in CI, all of which are connected with Off-Site Construction or Off-Site Manufacturing (OSM). The main insights are presented in Table 3.1 and discussed below.

Table 3.1: Summary table of CI literature reviews

Reference	Purpose	Keywords Selection	Summary of findings
Hosseini et al. (2018)	Generates a comprehensive, objective portrait of the existing state of research knowledge in OSC	Only keywords related to industrialization: (*"Off-site construction"* OR *"Off site construction"* OR *"Prefabricated construction"* OR *"Industrialized building"* OR *"Panelized construction"* OR *"Modular construction"* OR *"tilt-up construction"* OR *"Precast"* OR *"offsite construction"* OR *"pre-cast construction" OR "tilt-up construction")*	✓ *"(...) off-site construction requires a change of practices in a broader sense of people, process, working culture, communication, business models, etc (...) prominent outlets have not been influential in advancing such arguments in OCR."* ✓ *"Incomplete nature of current research as being heavily biased by the 'product' aspects of off-site construction."* ✓ *"There is an endemic problem with OCR in terms of a lack of focus, exchange of ideas, and debate among investigators."*
Jin et al. (2018)	Provides a more comprehensive picture of the current status and research gaps, and proposes research directions for OSC	Only keywords related to industrialization *("Off-site construction"* OR *"off site construction"* OR *"Prefabricated construction"* OR *"Industrialized building"* OR *"Panelized construction"* OR *"Modular construction"* OR *"Tilt-up construction"* OR *"Offsite construction"* OR *"Precast construction"* OR *"Tilt-up construction"* OR *"Off-site manufacturing"* OR *"Prefabrication construction")*	✓ "*It should be noticed that OSC is not an isolated construction concept, but inherently connected with other emerging concepts such as BIM and lean.*" ✓ "*Currently, there have been insufficient integrations of these digital practices into the OSC project delivery process from the practical perspective.*"

Table 3.1: Summary table of CI literature reviews *(continue)*

Reference	Purpose	Keywords Selection		Summary of findings
Ayinla et al. (2019)	Provides knowledge on the broader context of the fundamentals of OSM	Keywords related to industrialization – (*"Offsite construction"* OR *"prefabrication in construction"* OR *"offsite manufacturing"* OR *"offsite fabrication"* OR *"industrialised building systems"* OR *"system buildings", "modern methods of construction"* OR *"modular construction"* OR *"building classification system"*) Other string levels: Definition-related keywords and classification-related keywords.	✓	"*There is a significant lack of consensus on OSM classification approach, thus leading to a misunderstanding on what should be regarded as part of OSM and what is not.*"
Liu et al. (2019)	Offers a broad understanding of the trending topics and themes in OSC research	Only keywords related to industrialization *("Prefabrication construction"* OR *"Prefabricated construction"* OR *"Prefabricated building"* OR *"Precast concrete"* OR *"Semi-prefabricated concrete"* OR *"Off-site construction"* OR *"Off-site manufacturing"* OR *"Modular construction"* OR *"Modular building"* OR *"Industrialized building"* OR *"Industrial housing"* OR *"Modern construction method")*	✓	"*Despite OSC benefits and countries' commitments, the application of OSC remains stagnant, limited, underdeveloped, immature, sluggish, and small (Marjaba and Chidiac, 2016). This may be attributed to the lack of understanding of principal issues in OSC*".
Liu et al. (2020)	Determines the status, trends, priorities, and gaps of Prefabricated Construction Supply Chain Management (PCSCM)	Keywords related to industrialization: *("off site" OR "offsite" OR "tilt up" OR "precast" OR "prefabricated" OR "prefabrication" OR "modular" OR "industrialized" OR "modular" OR "penalized")* Other string levels: Supply Chain related keywords ("*supply chain*" OR "*supply network*" OR "*industrial chain*" OR "*logistics*") and Industry related keywords ("*construction*" OR "*building*" OR "*housing*")	✓	"*For PCSCM, no matter in research or practice, enterprises are still trying to improve their interests through internal integration but ignore the overall interests of the supply chain.*"

1. **CI definition**. Existing reviews do not address the CI concept clarification. This gap, in turn, has hindered the theoretical and practical development in this field of research, as several Scholars have pointed out.

2. **Keyword analysis**. All reviews employed a vast number of interchangeable keywords to essentially refer to research concerning CI, as illustrated in Table 3.1. Each of the keywords used may have different interpretations for different Scholars, and/or even for different countries (Jin et al., 2018; Liu et al., 2019). This, in turn, leads to scattering and ambiguity of the literature, which makes the comparability of research results difficult. There is a need for a single, universally accepted concept.

3. **Object of analysis**. Reviews appear to address Industrialization-related perspectives only partially, instead of using the phenomenon as a whole. OSC and PC terms are quite common, as shown in Table 3.1. This results from the fact that CI research focuses primarily on product aspects (Hosseini et al., 2018). Consequently, although these interchangeable terms represent a central theme in the applicability of the phenomena, they do not holistically define the concept. Most studies have also been integrating process and business model-related issues. This evolution consequently leads to a strong need for cultural, relational, technological, production, and management changes toward industrialization in the construction sector. There is an urgent need for a holistic system-level approach to explaining how companies do business in the CI paradigm.

4. **Industrial Engineering and Management Domain.** From the previous reviews, the design, improvement, and management of systems composed of people, materials, equipment, financial resources, information, and energy, which execute processes for the production and delivery of products and services, play a critical role in CI. This viewpoint leads to the discipline of Industrial Engineering and Management. However, little is explored in the construction area, and it can be the trigger to leverage the knowledge and practice of this transition.

5. **Transformation understanding.** From the summary in Table 3.1 is also possible to identify the need for holistic and comprehensive studies in this area due to the lack of knowledge/understanding about the different elements (organizational dimensions of CI transformation, CI design principles, as well as CI initiatives and influencers) that contextualize and explain the concept of CI as an evolving paradigm and as an overarching

concept. This, in turn, is becoming an important requirement for Scholars as well as Practitioners to formulate and implement an Industrialization strategy.

3.3. Methodology

A Systematic Literature Review has been adopted i) to develop a contemporary, systematic, and comprehensive overview of the existing research on CI by identifying patterns and themes; and ii) to identify the conceptual content of the field and contribute to theory development (Seuring & Müller, 2008).

Overall, this paper aims to provide an insightful conceptual framework as a comprehensive contextualization of the CI concept. It is therefore constructed with the elements deemed relevant to the Scholars (dimensions, design principles, initiatives, and influencers) in order to clarify and enhance the understanding of the Construction Industrialization development process. Hence, our SLR aims to answer two crucial questions[1]:

RQ1: How has research defined and operationalized the concept of Construction Industrialization to date?

RQ1.1: What are the key Design Principles referred to as pillars of Construction Industrialization?

RQ1.2: What Changing Initiatives must organizations undertake to promote the development of Construction Industrialization?

RQ1.3: What Elements of influence may positively or negatively impact the decision to implement a CI development process?

RQ2: What are the research gaps in the Construction Industrialization topic?

To ensure replicability by using transparent procedures and steps, a four-step approach based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) approach (Fargnoli & Lombardi, 2020) was followed and complemented by the articles Kitchenham et al. (2009), Seuring & Müller (2008), and Thomé et al. (2016). Figure 3.1 provides a simplified

[1] RQ1 in this paper corresponds to the research question formulated as RQ1 in Chapter 1, while RQ2 aligns with RQ1.4 of this thesis.

overview showing the PRISMA flowchart applied to this research. Many research Scholars in both the CI research field (see Nabi & El-adaway, 2020; Hussein et al., 2021; Hussein & Zayed, 2021; Wuni & Shen, 2019) and in different areas within Industrial Engineering and Management (see Bueno et al., 2020) have also applied the PRISMA approach.

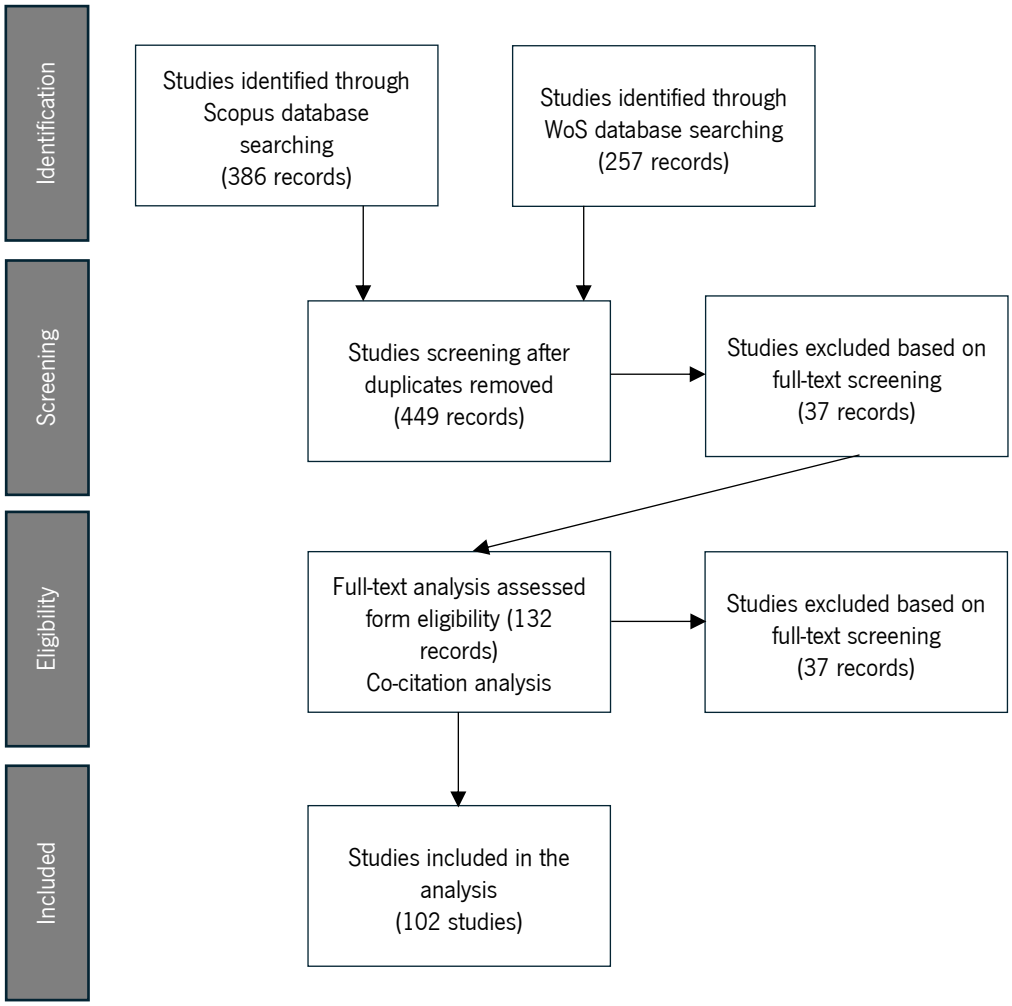


Figure 3.1: PRISMA Flowchart

Data Identification

In Stage I – "*Data Identification*", a preliminary search around recent literature reviews on the topic under study was developed aimed at two objectives: (1) establish the most relevant keywords; yet, specific enough to bring only studies related to the topic, as suggests Thomé et al. (2016) and (2) determine the search databases, as developed by Hussein & Zayed (2021).

From the selected papers, the search process was conducted on Scopus and Web of Science (WoS) scholarly databases under the fields *"title, abstract, keywords"* (consistent with Jin et al., 2018, and Liu et al., 2019), with a final string built in three levels of keywords (see Table 3.2). Both databases are commonly used for the screening of data sources and are proven to provide reasonably comprehensive results (Ghadge et al., 2020).

Table 3.2: Keywords used in the literature search

Level	Keywords
Industrialization keywords	"*Manufact* construction*" OR "*off-site* construction*" OR "*prefab* construction*" OR "*onsite industrialization**" OR "*industry 4.0*" OR "*construction 4.0*" OR "*industrial* building*" OR "*modular* construction*" OR "*industrial* construction*" OR "*construction industrial**"
Supply and Production Planning Keywords	"*supply chain*" OR "*planning*" OR "*control*" OR "*operations*" OR "*production*" OR "*manufacturing*"
Industry keywords	"*construction industry*" OR "*building industry*"

The first level of keywords is related to the range of interchangeable terms that have been used in CI literature. The second level of keywords outlines the focus on the Industrial Engineering and Management perspective of processes and operations in the context of the Supply Chain. In the third level, the search concentrates on the Construction Industry, also referred to as the Building Industry in some articles. The asterisk "*" was used at the end of the search keyword to cover a broader range of results.

Screening

The Screening stage requires clarity concerning boundaries to frame the research (Seuring & Müller, 2008) and to generate high-quality knowledge (Ghadge et al., 2020). In this context, four important boundaries were established: the search was narrowed (i) to journal papers (ii) published and written in English, and (iii) from January 2010 until December 2021 (in line with Jin et al., 2018, and Liu et al., 2019). Conference papers, book chapters, white papers, company reports,

and magazine articles were excluded from the study (Ghadge et al., 2020). Also, publications focusing on Government policies, ethical and payment issues, as well as those focusing on mechanical or technical aspects of the civil engineering discipline, were not included.

Then, to ensure a holistic view of CI, the Scholars conducted a preliminary screening by assessing the retrieved papers' titles and abstracts to investigate whether or not the collected articles fall within the scope of this paper (Thomé et al., 2016). With this goal, the search was narrowed only to studies that discuss the CI concept or related terms. In this context, two exclusion criteria were applied to the selection (Seuring & Müller, 2008; Thomé et al., 2016): (i) publications where the concept was merely mentioned were not considered; (ii) publications with a focus on peripheral subjects of CI were considered out of scope. In some cases, the abstract did not clarify if the paper fulfilled the inclusion criteria. Those papers were kept for stage III. Consequently, a total of 132 papers were selected for full assessment (as shown in Figure 3.1).

Eligibility

In stage III, a full-text analysis was conducted to select which articles would be included in the study sample. Only articles with definitions that meet two requirements simultaneously were accepted: (A) the article clearly defines the CI concept or related terms, and (B) highlights the relevant elements that represent the Construction Industrialization development process. Furthermore, *"snowball"* backward and forward searches (Thomé et al., 2016) were incorporated in this SLR to locate additional relevant articles that could be missing in our research. Thus, in this study, we used 102 articles (listed in Appendix B) as the basis for this paper's literature review, from which the results are presented in the next section.

Analysis and Synthesis

In the fourth stage, the descriptive information was analyzed (number of publications over time and per international peer-reviewed journal, citation analysis, and keyword analysis). Further, a content analysis was conducted to explore the nature and evolution of CI in the current construction literature. Four main research elements were set – CI definitions, CI design principles, CI influencers, and CI transition initiatives – in order to analyze and understand the richness and complexity inherent to a CI transformation (Table 3.3). The major findings of these analyses

constitute an important input for a CI conceptual framework by highlighting the various elements that make up the phenomenon and structuring them to lay the fundamental foundation to explain and guide the CI field.

Table 3.3: Detailed description of content type

Number	Level	Keywords
1.	CI Definition	CI definition refers to what is meant by CI in the literature (its scope and content).
2.	CI Design Principles	CI Design Principles cover the general (and unique) principles of a CI transformation that can be applied in any context (or country).
3.	CI Influencers	CI Influencers are a set of critical factors that may have either a positive or negative impact on the decision to implement such a transformation.
4.	CI Initiatives	CI Initiatives are a set of actions that organizations must undertake to promote the effective industrialization of the construction sector.

3.4. Descriptive Analysis

This section is dedicated to the description of the knowledge obtained in the paper sample, bringing an initial overview of the literature analyzed.

Distribution across the time period and main journals

The allocation of the publications in the researched period (2010 – 2021) shows a peak of published papers in 2014 (see Figure 3.2). This was also verified by Hosseini et al. (2018). According to the Scholars, the publishing of a research roadmap for off-site production and manufacturing in 2013, by the CIB Task Group TG74, was a trigger for articles in the CI context. In Figure 3.2, there appears to be a significant increase in the number of published papers from the year 2018 onwards.

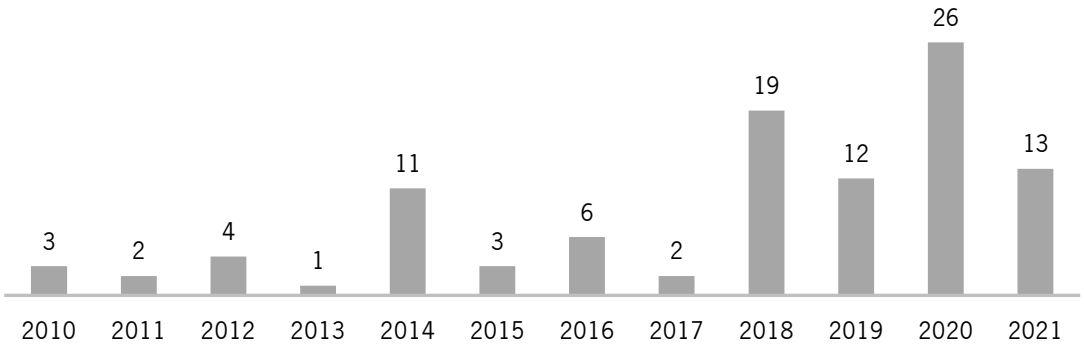


Figure 3.2: Number of publications per year

Table 3.4 shows the main journals that published the highest number of papers contained in our final sample. Five journals - Journal of Cleaner Production (14); Construction Management and Economics (10); Construction Innovation (10); Engineering, Construction and Architectural Management (8); and Journal of Construction Engineering and Management (7) - accounted for 51% of the publications. The remaining percent of articles is "*thinly*" spread over the rest of the 19 journals, of which 11 have only one paper on the topic under review. Journals on Construction Management or Sustainability issues list the maximum number of published papers over the time window considered (78 papers – 92%). This shows the relevance of these areas.

Table 3.4: Distribution of the top 10 cited journals

Journal	**Number**	**%**
Journal of Cleaner Production	13	14%
Construction Management and Economics	12	13%
Automation in Construction	11	12%
Construction Innovation	10	11%
Engineering, Construction, and Architectural Management	9	9%
Journal of Construction Engineering and Management	7	7%
Architectural Engineering and Design Management	7	7%
Journal of Management in Engineering	5	5%
Sustainability	4	4%
Habitat International	3	3%
International Journal of Construction Management	3	3%

Citation analysis

Table 3.5 presents the ten most cited papers in the CI literature. Here, the Scopus database was used as it is the largest abstract and citation database of peer-reviewed research literature. The most cited paper was published by Li et al. (2014) with 236 citations and presents a systematic summary of the research developments in the management of prefabricated construction (MPC). Furthermore, three out of four of the most cited articles are reviews addressing some of the perspectives of CI.

Table 3.5: The 10 most cited papers in the Construction Industrialization literature

R	Title	Reference	TC
1	Critical review of the research on the management of prefabricated construction	Li et al. (2014)	236
2	Critical evaluation of off-site construction research: A Scientometric analysis	Hosseini et al. (2018)	195
3	Barriers to promoting prefabricated construction in China: A cost-benefit analysis	Hong et al.(2018)	174
4	A holistic review of off-site construction literature published between 2008 and 2018	Jin et al.(2018)	116
5	Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall	García de Soto et al. (2018)	116
6	Making a case for offsite construction in China	Arif & Egbu (2010)	112
7	Exploring the Challenges to Industrialized Residential Buildings in China	Zhang et al. (2014)	110
8	Barriers to implementing modern methods of construction	Rahman (2014)	109
9	Integrating resource production and construction using BIM	Čuš-Babič et al. (2010)	107
10	New offsite production and business models in construction: priorities for the future research agenda	Goulding et al. (2015)	106

Keyword Analysis

Each article identified was further analyzed, both manually and via keyword analysis, performed with VOSviewer, to map how research on CI is organized by research clusters. Results are shown in Figure 3.3 and Table 3.6.

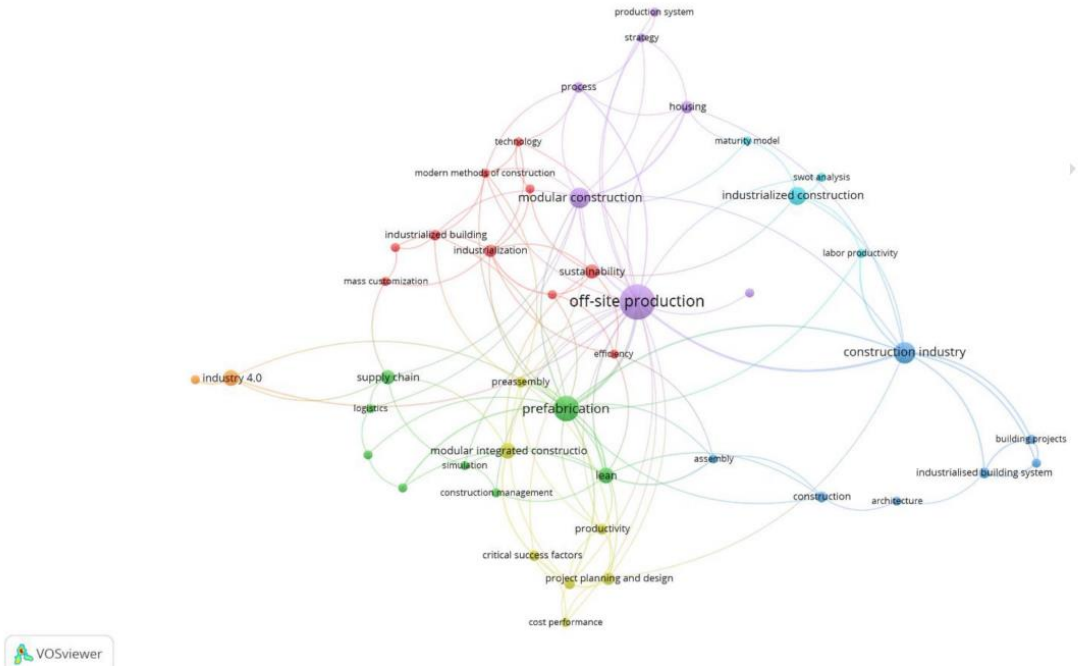


Figure 3.3: Keywords analysis by VOSviewer

Table 3.6: Top 10 cited keywords in CI literature

R	Keyword	Research Stream	Keywords that also represent
1	*"Off-site Production"*	Process	*"OSM", "PC"*
2	*"Prefabrication"*	Process	*"Preassembly"*
3	*"Modular Construction"*	Product	*"Modular Integrated Construction"*
4	*"Lean"*	Business Model	*"Lean Construction"*
5	*"Construction technology"*	Process	*"Industry 4.0", "Digitalization", "Building Information Modelling", "Automation"*
6	*"Supply Chain"*	Process	*"Logistics"*
7	*"Sustainability"*	Business Model	n.a.
8	*"Project Planning and Control"*	Process	n.a.
9	*"Production System"*	Process	*"Industrialized Building System"*
10	*"Modularization"*	Product	n.a.

In Figure 3.3, the bigger the circle of a keyword, the more frequently that keyword occurs in the respective sample. The colors correspond to the various clusters identified by the software. The image reflects a large dispersion of topics around 4 concepts (OSP, Prefabrication, Modular Construction, and Industrialized Construction).

A closer examination of the top ten keywords presented in the final sample (Figure 3.3) reveals that the papers included therein match the perspectives previously identified: Process, Product, or Business model focus. Table 3.6 shows the clustering analysis of the keywords: i) a new way of design (Product Research Stream), ii) of managing the processes and relations (Process Research Stream), and even, iii) of doing business (Business Model Research Stream) in the Construction Sector.

The Product Research Stream is essential for construction companies to initiate the industrial transformation. At the heart of this industrial transformation, a remarkable advance is modularity in product and production, represented by *"Modularization"* and *"Modular Construction"*, respectively, as keywords.

The importance of integrated management approaches, incorporating both the focal company and the network of suppliers and customers, has been amplified by the literature. Concerning the innovation in the production process, *"Off-site Production"*, prework ("Prefabrication"/"Pre-assembly"), *"Construction Technology",* and *"Production System"* are the critical keywords. The truly strategic nature of the CI concept thus becomes apparent with the representativeness of the *"Supply chain"* keyword.

Finally, the organizational strategy planning and execution have a significant influence on the CI adoption. Table 3.6 reveals four additional keywords that have revolutionized the way of doing business, namely, *"Lean"* philosophy, *"Sustainability"* issues, *"Digital"* transformation, and *"Project Planning and Control"*. They suggest managerial, cultural, behavioral, and technological changes in the construction industry to meet the requirements of a complete transition.

Added to these three major research streams, a knowledgeable interpretation of what the scientific evidence says about the conceptualization and operationalization of the CI concept is suggested by the Scholars. Consequently, five major dimensions of an industrial transformation from an organizational change perspective are implicit, i.e, (1) Organizational Strategy, (2) construction companies must align Organizational Restructuration, (3) Resources redefinition, (4) Business Processes, and (5) Supply Chain planning and execution with Organizational Strategy.

Thus, it is clearly depicted from the literature that the CI transformation has the goal of improving organizational excellence, thus improving the operational performance of the supply chain. The proposed decomposition approach provides an initial avenue for further research on the Industrial transformation of construction business organizations. Especially in this paper, this decomposition forms the basis for developing a CI transformation conceptual framework highly focused on organizational change.

This leaves another finding in this keyword analysis: although there is no clear identification of research directions for the discipline of Industrial Engineering and Management, the various keyword arrangements and their interpretation (performed by the Scholars) reinforce the importance of this discipline as a basis for an understanding and operationalization of a CI development process.

3.5. Construction Industrialization: Definitions, Design Principles, Influencers, and Initiatives

This section provides a discussion regarding how research to date has defined the concept of CI (Section 3.5.1) and how it has been operationalized (Section 3.5.2). This knowledge, gathered from the literature, allows for establishing the common features among various studies to build a unified and integrated conceptual framework of CI.

3.5.1. Defining Construction Industrialization

A detailed analysis of the articles was carried out to determine how Scholars describe Construction Industrialization. This analysis is presented in three areas: (1) definitional analysis, (2) conceptual framing analysis, and (3) constructs analysis. This analysis follows the work of Burgess et al. (2006).

Definitional analysis

Three categories were formed, i.e., whether the content addresses (1) only the phenomenon of Construction Industrialization, (2) uses related terms to study the phenomenon, or (3) has both perspectives (the study refers to the phenomenon yet studies it through its term) (see Table 3.7).

The majority (68 percent) of the articles introduced CI based on related terms, while about a fifth (19 percent) refer to both perspectives. A smaller proportion (14 percent) investigated Construction Industrialization as a broader concept. This can be explained, in part, by the emergence of different terms[2] for the same concept adopted by different players (Scholars, Practitioners, and multicultural Policymakers) for a long period. Still, the above results confirm the insufficient attention given to the CI phenomenon, as several works acknowledge (see Luo et al., 2020).

Table 3.7: Approaches to the phenomenon of Industrialization

Approach	Some references
Construction Industrialization phenomenon (Perspective 1)	Čuš Babič et al. (2010); Eriksson et al. (2014); Jonsson & Rudberg (2014) ; Wang et al. (2020); Qi et al. (2021); Ekanayake et al. (2021);
Industrialization-related terms (Perspective 2)	Bildsten (2014); Mao et al. (2016); Jin et al.(2018); Bendi et al. (2021a); Das et al. (2020); Patrucco et al. (2020); Liu et al. (2020)
Both (Perspective 3)	Nadim & Goulding (2011); Larsson et al. (2014); Peltokorpi et al. (2018); Innella et al. (2019); Li et al. (2020); Hammad et al. (2020)

Conceptual Framing Analysis

Evaluation of the literature review on CI indicated that while Scholars offer various understandings of CI, sometimes similar, and other times, fragmented, no widely accepted definition exists. To this end, and according to the previous statements and an in-depth analysis of each definition, four conceptual framings appear:

- **Product** - a change in the design and conception of the building as a modularizable product.
- **Process** - involving a restructuration of the production process aiming at increased efficiency (for instance, Larsson et al., 2014; Bildsten, 2014; Ayinla et al., 2019; Qi et al., 2021); as construction *"mode"*, *"approach"*, *"technique"*, *"method"* or *"manufacturing process"* are some of the main framings employed for the concept.

[2] Appendix C provides an overview of the various terms used interchangeably as CI and the existing definitions associated with each one. Appendix C also clarifies the distinctions made between those terms.

- **Business process** - a deeper level of organizational analysis that leads to a reformulation of the business strategy model is investigated (see Nadim & Goulding, 2011; Lessing et al., 2015; Razkenari et al., 2020; Wuni & Shen, 2020a).
- And even, a **new way of looking** at the Construction Industry as a whole, thus encompassing all players as well as reinforcing the multidisciplinary nature of this transformation (see Wang et al., 2020; Wuni & Shen, 2020b; Liu et al., 2020).

Therefore, successful CI requires an integrated and evolutionary change in the product, process, and business model, underscoring the need for organizational change. However, this holistic perspective has been neglected in both breadth and depth of research. Still, these are the starting points for analyzing the relevant literature and thus for systematizing the main findings in the following analysis.

CI Constructs

There exists a general idea in both academia and industry about the operational focus, as a starting point for the initial development of CI, but not sufficient to define or describe industrialization, as argued by Lessing et al. (2015) and as it is confirmed throughout this literature review.

A detailed analysis of different scientific contributions establishes that the CI not only challenges companies' capacity to learn and innovate in their products and production systems (Wuni et al., 2021), but also requires new organizational models (Taylor, 2010; Girmscheid & Rinas, 2012; Goulding et al., 2015; Lessing, 2015; Sabet & Chong, 2019; Zhang et al., 2020) and organization-wide changes. For instance, it includes holistic strategies (Kedir & Hall, 2021), supply chain operations and relations (Čuš-Babič et al., 2010; Ekanayake et al., 2020), automation techniques (Li et al., 2014; Hammad et al., 2020; Qi et al., 2021), and leadership (Woodhead et al., 2018). These are just some of the many individual (but interrelated) constructs that can be found in existing definitions.

In the absence of a consensus on a common set of CI constructs, this study contributes to the literature on CI by proposing a more comprehensive definition of CI. So, CI, in our view, "*is a new form of production and management, driven by the adoption of several individual (but interrelated) construction and industrial engineering and management innovations whose objective is to improve the productivity and the sustainable development in the construction industry".*

This definition is distinctive for the following reasons. First, overall, this definition provides a clear understanding of *"what is Construction Industrialization", "what it entails",* and *"to what end".* This integrated view is sometimes omitted from the literature.

This definition leads to the perception of an organizational transformation. This perception is consistent with other Scholars such as Wang et al. (2020) and Wuni & Shen (2020b). For instance, a new *"form of modern manufacturing, transportation, installation, and scientific management of construction"* was mentioned by Wang et al. (2020). Wuni & Shen (2020b) introduce Industrialized Construction as a *"new way of working and thinking within the modular (off-site) construction sector"*.

Second, over the last decade, *"production"* (a change from traditional *"construction"*) and *"management"* were continuously part of several CI (and related terms) definitions; however, they rarely appeared together, with some exceptions. For instance, Liu et al. (2020) argued that the biggest difference between PC and traditional site construction is that the process and scope of construction management extend into production.

Finally, the CI definition refers to the goals and objectives when implementing a CI development process. Consequently, as several Scholars have stated, an effective CI transformation has the potential to help industry meet the productivity challenge (Jiang et al., 2018; Liu et al., 2019; Qi et al., 2021), while embracing the characteristics of green, environmentally friendly, energy saving (Hong et al., 2018), and providing the necessary level of customer satisfaction (Larsen et al., 2019). Accordingly, the sustainable development of the Construction Industry is attributed to this definition.

3.5.2. Operationalization of Construction Industrialization

The CI design principles, CI influencers, and CI initiatives are summarized and analyzed to classify the key findings of the reviewed literature, which, later, will be part of the proposed conceptual framework.

Design Principles of the CI concept

Regarding the design principles identification, which is essential to the establishment of the operational bases of the CI concept, prior literature has invested considerable efforts. A good

starting point is the works of Larsson et al. (2014), Lessing et al. (2015), and more recently, Razkenari et al. (2020) and Li et al. (2020).

These Scholars have shown that *"repetition"*, *"standardization"*, "*continuous improvement*", *"integrated design & production"*, *"planning for efficient production"* and *"automation"* have been associated with the adoption of industrial production in the context of the construction industry (Larsson et al., 2014; Razkenari et al., 2020; Li et al., 2020), similarly to the keyword analysis developed in this article.

For Larsson et al. (2014), *"standardization of products and processes"* is the single most important element of industrialization. Other Scholars provide a similar interpretation of CI. For instance, Razkenari et al. (2020) only added "*experience feedback*," yet they remain within the sphere of product and process. The research by Lessing et al. (2015) makes an important contribution by adding the strategic positioning of the CI development process. And, Li et al. (2020) propose a new industrialized construction method, Onsite Industrialization (OSI), which includes five basic principles (Sustainability, Lean, Modularization, Standardization, and Prefabrication).

Despite these contributions, a comprehensive and contemporary analysis is still lacking to explicitly identify the set of principles associated with CI that can be applied in any context. The integration of these design principles can provide an effective means to ensure a complete implementation of the CI development process.

Based on the analysis carried out and in the context of an evolving and holistic concept, ten distinct design principles are compiled and described next:

1. Adopt a Factory-based Production Process. Industrialization transforms the way buildings are produced. Based on this foundation, literature suggests a number of strategies to achieve an effective transition to industrial processes, including off-site production and prefabrication (the two most cited keywords) in order to promote a product-oriented manufacturing process (Yu et al., 2013; Larsson et al., 2014; Goulding et al., 2015; Lessing et al., 2015; Hsu et al., 2018; Gan et al., 2018). Many studies employ modular production in factories as an important part of the CI development process (Wuni & Shen, 2019; Peltokorpi et al., 2018). This involves the production using different modular product architectures (Hsu et al., 2018; Peltokorpi et al., 2018). Working in a controlled environment means faster delivery and improved production quality while reducing safety risks (Jonsson & Rudberg, 2014; Li et al., 2018). According to the Modular Building Institute, most modular projects can reduce 30%–50% of the construction schedule (Razkenari et

al., 2020). The integration of these two changes (Prefabrication and OSP) depends, among other factors, on the level of product and process standardization (and repetition) (Čuš-Babič et al., 2010; Nawari, 2012; Larsson et al., 2014; Bildsten, 2014), the degree of offsite production allowed, and the modularization strategy (Jonsson & Rudberg, 2014). For Larsson et al. (2014) and Liu et al. (2020), standardization is the symbol of the industrialization level. Studies suggest that automation is the natural consequence of Standardization (Nadim & Goulding, 2011) (developed further).

2. Produce Modular Products. The basic principles of modular design (modularization) also foster a radically new way of looking at construction. The emphasis on modularization, as a way to decrease the complexity of systems, by building them from smaller subsystems (or modules) that can be designed independently (Peltokorpi et al., 2018), accompanies the entire evolution of the research in the CI field (O'Connor et al., 2014; Peltokorpi et al., 2018). Some Scholars even point to Modularization as a core element of the Industrialization concept (Li et al., 2020). Furthermore, because of its intense and growing interest in this topic (Modular Construction is the third most cited keyword based on Table 3.6), this article presents it as an isolated design principle. Modularization not only explains the architecture of products and the modular-sized design options, but also the product-oriented production of mass-customized buildings (Yu et al., 2013; Larsson et al., 2014; Goulding et al., 2015; Lessing et al., 2015; Hsu et al., 2018; Peltokorpi et al., 2018) and the supply chain design organization (Doran & Giannakis, 2011; Hussein & Zayed, 2021). The modular products produced in a factory (Qi et al., 2021) are typically volumetric modules, components, or elements (Larsson et al., 2014).

3. Focus on the Automation. The Construction Industry is experiencing a new form of production and communication through automation. Instead of relying on manual labor to work on-site (craft production), the traditional methods, which are slow, expensive, and non-coordinated, are being changed in a way that gives birth to a justifiable level of mechanized, automated, or robot-supported industrial processes (Čuš-Babič et al., 2010; Nadim & Goulding, 2011; Jonsson & Rudberg, 2014; Jin et al., 2018)**.** This transformed the whole course and idea of construction in a fundamental way. CI also underwent radical process changes by adopting digital technologies to improve quality and productivity (Woodhead et al., 2018). The digitalization of products and processes (Arif et al., 2012) confers the ability to support and complement off-site construction (Yin et al., 2019; Sabet & Chong, 2019; Tang et al., 2019) and fulfill its potential once applied in practice (Sabet & Chong, 2019). Furthermore, recent studies increasingly try to probe the relationship between digital technologies (such as Building Information Modelling - BIM), OSC, and

lean principles and their performance in terms of productivity and operational performance (Gbadamosi et al., 2019; Sabet & Chong, 2019; Lekan et al., 2020). More recently, Construction 4.0 (C4.0) has been presented to achieve the automation goal in construction (Lekan et al., 2020). This explanation exposes the fifth most cited keyword in the literature as it relates to Larsson et al. (2014), Lessing et al. (2015), Razkenari et al. (2020), and Li et al. (2020) studies that also identified principles of the Industrialization concept.

4. Implement a Lean transformation. Lean manufacturing has been demonstrated to be a critical part of the construction firm's success in times of time - and quality-based competition (Hussein & Zayed, 2021; Innella et al., 2019; Yin et al., 2019). For instance, Lean Construction is the second largest prefabricated construction-related knowledge cluster in the review developed by Luo et al. (2020) and the fourth most cited keyword in our review (Table 3.6). Stable and Standardized processes, Waste Reduction, Customer Focus, Continuous Improvement, and Just-in-time (see Meiling et al. 2012; Jonsson & Rudberg, 2014; Innella et al., 2019; Wuni et al., 2021; Hussein & Zayed, 2021) are five of the most comprehensive elements and techniques of lean manufacturing that have been highly applied in CI literature. More recently, some works studied the application of lean construction and Industry 4.0 to improve construction processes and resource management (see Lekan et al., 2020). Furthermore, the various research streams to date have established the shift in the very culture of an organization. Lean Culture and management's long-term commitment can support the vital "*soft*" people-centered transition (Yu et al., 2013; Zhang et al., 2020; Hussein & Zayed, 2021). However, it remains one of the main problems and is still strong and hard to change (Innella et al., 2019).

5. Manage an Efficient Production System. The Construction Industry has learned valuable lessons from the manufacturing industry (Nadim & Goulding, 2011). How the production system should be planned and controlled is one of the lessons. This is reflected in the fact that the production system is the ninth keyword most cited in the literature.CI is a complex process, mainly because it includes several integrated structural decisions that influence operational performance (Liu et al., 2018) in a temporary onsite organization. As CI competition increases, it becomes more evident that production system efficiency can only be achieved by better designing the organization of production and operations management (Mehrotra et al.,2005; Hammad et al., 2008; Liu et al., 2018). In fact, mass production processes (Arif & Egbu, 2010) of prefabricated components in the off-site factory and subsequent on-site construction/assembly can have various forms of non-value-added activities (Mostafa et al., 2020). Jonsson & Rudberg (2015) argue that the most appropriate

production system, which includes the degree of off-site production and assembly, balances productivity and flexibility to match the production system to market demands. On the other hand, Peltokorpi et al. (2018) state that a higher degree of off-site production limits the building's flexibility and innovativeness.

6. Embrace the Mass Customization Paradigm. Construction companies will lose their competitiveness and flexibility if they cannot offer customization, which is why it is considered a design principle in this article. It is decisive, therefore, to provide customized products without compromising their cost or quality (Li et al., 2020). For instance, OSC is a prerequisite for being able to mass customize (Larsen et al., 2019). Some highly practical and specific fundamentals of CI can be found in the literature : (1) Modularization not only tackles the architecture of products (Ramaji & Memari, 2016) but also the organization and processes (Isaac et al., 2016; Shafiee et al., 2020) for designing and producing mass-customized buildings (Peltokorpi et al., 2018); (2) the development of a completely new production system (Goulding et al., 2015; Hammad et al., 2019; Luo et al., 2020; Li et al., 2020); and (3) the postponement strategy (Lessing et al., 2015). Consequently, embracing mass customization principles requires a transformation of the business model.

7. Transform the Business Model. Scholars, Practitioners, and Policymakers have realized the massive impact of business model innovation to ensure a successful transformation (Arif et al., 2012; Goulding et al., 2015; Gan et al., 2018; Hosseini et al., 2018; Wuni & Shen, 2020b; Xu et al., 2020). This principle is also important to Lessing et al. (2015). Additionally, a growing number of studies (Brege et al., 2014; Choi et al., 2019; Das et al., 2020) have dealt with the business model transformation concern, partly because of its potential to provide a holistic view of how companies do business, as argued by Girmscheid & Rinas (2012). These design principles involve a process of change that includes new relationships, working culture, communication, skills, technology, products, production strategies, processes, and new ways of working and thinking (Hosseini et al., 2018; Wang et al., 2020; Wuni & Shen, 2020b). Thus, organizational change management driven by an understanding of the organizational strategy and business model is crucial in order to ensure business competitiveness and profitability.

8. Design a Building as a Product. Scholars proclaim that industrialization will revolutionize the way of thinking, constructing, and management (Wuni & Shen, 2020b). When starting to think about buildings as products that can be manufactured and assembled instead of being constructed,

some methodologies are established by looking at the manufacturing industry. The incorporation and diffusion of manufacturing-oriented design approaches are applied to foster a radically new way of looking at a building. The manufacturing-oriented design approaches include Design for Manufacturing and Assembly (DFMA) (along with logistics) (Goulding et al., 2015; Hsu et al., 2018; Gao et al., 2020; Jang et al., 2021) and Concurrent Engineering (Innella et al., 2019; Bendi et al., 2020). Its application enables the achievement of a higher quality of the end product on site, minimizes the complexity of the manufacturing operations, provides significant time and cost savings, and results in fewer construction materials wasted compared to the traditional stick-built method (Arashpour et al., 2018; Hsu et al., 2018; Wuni & Shen, 2020a). Furthermore, Gao et al. (2020) emphasize the synergy of DFMA and Lean construction.

9. Focus on Integrated Project Delivery. Industrialization requires a new approach to project management and, consequently, delivery (Wuni et al., 2021). A fully-integrated approach (Sutrisna et al., 2018) will allow an accurate synchronization of the whole-of-life approach (Zhang et al., 2020) with particular attention to technological, communicational, and managerial aspects (Liu et al., 2020; Luo et al., 2020; Wuni et al., 2020). The close integration and coordination among project stakeholders (Xue et al., 2018) have reconfigured the upstream and downstream relationship of the project delivery system (Lessing et al., 2015; Wuni & Shen, 2020b). The Integrated Project Delivery (IPD) approach is a strong factor in achieving effective collaboration and greater integration potential (Wuni et al., 2020; Muñoz-La Rivera et al., 2020). Also, lifecycle-based management facilitates the effective delivery of IC projects (Wuni et al., 2021). Nevertheless, Jin et al. (2018) found that limited studies have showcased how an appropriate project delivery method can enhance OSC project performance.

10. Focus on Results and Creating Value. Industrialization is a socio-environmental and economic process through which society and business structures change from conventional to industrialized construction. A well-developed CI development process may substantially contribute to the productivity, effectiveness (Lessing et al., 2015), and efficiency of a firm's production-related performance (Wuni & Shen, 2020; Patrucco et al., 2020). Also, results should be used to create and balance value for key stakeholders. With regard to sustainability-oriented performance, CI may lead to more environmentally friendly production and increased worker safety and health (Sadafi et al., 2012; Li et al., 2014).

Influencers of CI transition

Several attempts have been made in the literature to map the emerging decision factors (see Li et al., 2018; Wu et al., 2019; Wuni et al., 2020; Sutrisna et al., 2020; Wuni & Shen, 2020b), enablers and drivers (see Wuni & Shen, 2019; O'Connor et al., 2014), or challenges and barriers (see Rahman, 2014; Mao et al., 2015; Gan et al., 2018) that affect or boost the use of industrialized construction. However, most of them have been focused on the deployment of these factors with a focus on related terms (see Nabi & El-adaway, 2020) or even the decision to use a single construct of the CI phenomenon (see Wuni & Shen, 2019). The systematic review reveals five generic influencers that provide a basis for several Scholars and Practitioners to understand how to improve the Industrial transformation.

Culture & Leadership. Several studies argue that construction Managers' commitment and leadership have a strong impact on CI development (Jonsson & Rudberg, 2014; Goulding et al., 2015; Wuni et al., 2020) as well as on influencing the willingness of participants to cooperate with the CI (Wang et al., 2020).

Collaboration & Cooperation. As another influencer of CI transformation, CI holds a massive potential when external collaboration and cooperative relationships (Wuni & Shen, 2020). For instance, Larsson et al. (2014) considered cooperation as one core element of industrialized infrastructure construction.

Technological infrastructure. Early studies indicate that 'prework' has become more viable in recent decades, given advances in design and information technologies (J. Song et al., 2005). Therefore, the ability to effectively use technological advancements in design and construction systems can significantly influence industrial transformation (Goulding et al., 2015; Lekan et al., 2020; Zhang et al., 2020). These advances (e.g, BIM) (Hammad et al., 2019) are treated as useful tools to support supply chain cooperation, integrated production system (Lessing et al., 2015), technical performance, cross-organizational performance adjustment, and optimization (Lessing et al., 2015; Liu et al., 2018; Wang et al., 2020; Luo et al., 2020).

The worker's Expertise. There is evidence in the literature about human expertise and its positive influence on industrial performance; both expertise embracing the academia (Goulding et al., 2015) once some Scholars noted that the research output of a country has a direct positive influence on its industrial and policy progress (Wuni & Shen, 2019); as well as the presence of sufficiently highly qualified construction workers has strong influence on what a firm has to offer

and its influence on firm performance (Song et al., 2005; Gan et al., 2018; Luo et al., 2020; Sutrisna et al., 2020).

Company Context. Because of the type of construction projects (residential or not residential projects), the size of the company, and its core business (civil, mechanical, electrical, and plumbing installations...), construction companies not only meet customers' existing demands and preferences but also must design a global Industrialization strategy based on the company's core competencies, its motivations, and objectives.

Initiatives to sustain the CI transition

According to Bendi et al. (2020), a main challenge remains: *"How do organizations actually prepare themselves for the transition?"* . As a result, several publications recognize an increasing interest in establishing the body of knowledge in CI for a better comprehension of expected transformations (Wuni et al., 2021). Overall, performance assessment, prefabricated product, prefabricated process, prefabricated material, project delivery process, management practices, and technology application are the main initiative groups based on the literature reviews (see Jin et al. 2018 and Luo et al. 2020).

Current studies that suggest roadmaps, frameworks, and maturity models are still short on unlocking the holistic potential of CI. Beyond that, there are few contributions in this direction. Additionally, depending on the point of view and the level of abstraction, different levels of detail can be attributed to CI initiatives. Some contributions state the influence of People, Process, Technology, Product, Market, and Project initiatives (Nadim & Goulding, 2011; Goulding et al., 2015; Wuni et al., 2021). For instance, the strategy factor was also not considered in the industrialized construction maturity model presented by Wang et al. (2020). This is not the case in the study of Bendi et al. (2020). The Scholars established four key factors in the off-site construction readiness maturity model developed: operational challenges, strategy, planning certainty, and operational impact.

So, despite substantial work ongoing in this area, Scholars do not have unified views of the fundamental initiatives of Industrial Transformation in the Construction Sector. Thus, "*Initiative*" is defined in this article as a set of change management strategies undertaken by a company to promote effective management of its transformation.

With the extension of the literature review, this study discusses nineteen initiatives along the five dimensions of Industrialization identified throughout the paper – Organizational Strategy, Organization, Process, Planning, and Resources - which have shown a close relationship with the performance of an organizational change.

From Table 3.6, it is clear that the literature keeps the focus on three pillars - product, process, and business model - in view of industrial restructuring of a traditionally conventional sector; however, with strong pressure for industrialization of its processes and products. Such initiatives, in turn, are well developed in the Industrial Engineering and Management discipline, and they are recommended to be implemented in construction management. The vast majority of the initiatives presented in Table 3.8 have already been objectively underlined or are implied in the discussion in the previous subsections.

Table 3.8: Initiatives in the Construction Industrialization Process

Reference	Purpose	Keywords Selection
A) Organizational Strategy Structure strategic decision-making around the company's existing business models with the inclusion of the Industrialization paradigm.	1. Organizations must redesign their business model; 2. Organizations must have customer and market knowledge; 3. Application of performance indicators; 4. Organizations must have visionary leaders;	Lessing (2015); Bendi et al. (2020).
B) Organizational Restructuration Introduce deep transformations in the way construction companies are configured and operate their business.	5. Organizations must redesign the supply chain network; 6. Organizations must embrace lean construction practices; 7. Organizations must define the production strategy; 8. Organizations must employ education, training, and development;	Larsson et al. (2014); Arashpour et al. (2017); Hsu et al. (2018); Peltokorpi et al. (2018); Liu et al. (2018); Innella et al. (2019); Zhang et al. (2020); Patrucco et al. (2020); Liu et al. (2020); Jang et al. (2021); Hussein et al. (2021); Kedir & Hall (2021).
C) Business Processes Redesign Define the appropriate industrial practices aligned with their business processes, linked across intra- and intercompany boundaries, and their organizational strategy**.**	9. Organizations must embrace manufacturing-oriented design approaches in product design; 10. Organizations must redesign the manufacturing flow management process;	Larsson et al.(2014); Lessing et al. (2015); Innella et al. (2019); Nabi & El-adaway (2020); Gao et al. (2020); Bendi et al. (2020); Kedir & Hall (2021); Jang et al. (2021).

Table 3.8: Initiatives in the Construction Industrialization process *(continue)*

Reference	Purpose	Keywords Selection
D) Supply Chain Planning Improve the performance of a company's operations, ensuring that the industrialization principles are introduced.	11. Organizations must plan the modular production, prioritizing both the current design process of prefabricated building and the achievement of optimal manufacturing and assembly; 12. Organizations must fully integrate production, distribution, and assembly planning; 13. Organizations must enhance collaboration and coordination among the stakeholders in the whole supply chain;	Goulding et al. (2015); Hsu et al. (2018); Altaf et al. (2018); Gbadamosi et al. (2019);Bortolini et al. (2019); Wuni et al. (2020); Jang et al. (2021); Tsz Wai et al. (2021); Hussein et al. (2021).
E) Resources Rethink, improve**,** and analyze the investment of many different resources**.**	Technological/Automation 14. Organizations must introduce automated design and production, and digitalization; 15. Organizations must identify the automation level/breakeven point in production processes/tasks onsite and off-site (factory); Human 16. Organizations must develop multidisciplinary teams for construction projects; Financial 17. Strategic use of standardized project financial accounting and management systems; Physical 18. Search for innovative and industrial materials; 19. Determine the infrastructure and/or space needed by production onsite or off-site.	Balaguer et al. (2002); Song et al. (2005); Čuš-Babič et al. (2010); Goulding et al. (2015); Liu et al. (2018); Bendi et al. (2020); Hou et al. (2020); Sutrisna et al. (2020); Hussein et al. (2021); Kedir & Hall (2021).

Organizational Strategy. CI is not just confined to prefabrication, production in a controlled environment, or a modular product; rather, it prompts big changes in companies' business models (Goulding et al., 2015; Patrucco et al., 2020) and their strategy (Sutrisna et al., 2020). Business strategy restructuring is commonly accepted in the literature, as stated by Bendi et al. (2020). This also calls for strong strategic leadership from a host of players – construction companies, and leaders at the supply chain level (Arif & Egbu, 2010; Girmscheid & Rinas, 2012). The main finding shown by Lessing (2015) is that product-oriented construction companies should continuously align their offering with the market position and the operational platform.

Organizational Restructuration. The process of change prompts deep changes in companies' strategic planning (Goulding et al., 2015; Li et al., 2018; Patrucco et al., 2020) to implement a cohesive range of improvement initiatives to build a successful industrial transformation. These initiatives should focus essentially on supply-chain network configuration, lean transformation, and production strategy. For instance, production strategy comprises the decision process about *"the processing equipment, factory layout, automation level, organization of the production and planning methods"* (Peltokorpi et al., 2018). The soft skills concerning People, for their competence, experience, and knowledge, as well as their attitude and culture, are a decisive factor in a transformation of the sector (see Qi et al. 2020; Wang et al., 2020). So, providing the necessary intellectual knowledge to the company's human resources is an important step in the industrial transformation, since CI predominantly requires a highly skilled workforce (Bendi et al., 2020) and the investment in human resources skills development and training is needed (Jiang et al., 2018; Hou et al., 2020; Muñoz-La Rivera et al., 2020).

Business Processes Redesign. To deliver customer value and achieve organizational success and sustainability, construction companies need to rethink how they organize the key resources, systems, and business processes to improve the manufacturing flow efficiently (Wang et al., 2020). Also, a focus on the conceptualization of the building as a product and, consequently, its design through the delivery of industrialized building systems planning rather than projects (Wuni et al., 2020) is needed.

Supply Chain Planning. It is very clear from the literature that the interrelationship between the internal processes and supply chain contributes to a competitive advantage in both operations' productivity and performance growth (Wuni & Shen, 2020b; Arashpour et al., 2017; Hussein et al., 2021; Patrucco et al., 2020). Effective coordination and planning, both upstream and

downstream in the supply (Xue et al., 2018), can directly improve customer service and reduce operating costs (Gan et al., 2018; Hussein et al., 2021). Thus, being the cost one of the biggest barriers to a CI transformation (Rahman, 2014; Mao et al., 2015; Hwang et al., 2018), having the right product, at the right time, with the right quantity and with the required quality becomes a competitive advantage for any company. To maximize value in an industrial transformation, a wide variety of supply chain decisions are intertwined. However, although there is a vast amount of literature that reinforces the strategic role of planning in the Industrialization strategy, most Scholars often focus their studies mainly on one tier of the supply chain (on-site construction or off-site production). For instance, Bortolini et al. (2019) report the development of a logistics planning and control model for site assembly, and Hsu et al. (2018) study how factory manufacturing and inventory management should react to variations in the demand on construction sites.

Resources. With its disruptive nature and scope of the CI concept in transforming internally and beyond company boundaries, several contributions offer new insights for companies to rethink, improve, and analyze the investment in many different resources. This article divides them into four main groups: technological, human, financial, and physical. For instance, for the building project level, industrialized construction requires an accurate synchronization of the whole-of-life approach with particular attention to technological, communication, and managerial aspects (Zhang et al., 2020; Liu et al., 2020; Luo et al., 2020; Wuni et al., 2020).

3.6. Conceptual Framework for the Construction Industrialization Development Process

Scholars and construction Managers need to be aware of what industrialization is, and specifically, how to implement an Industrialization Strategy. Consequently, to provide a comprehensive overview of the conceptualization, Figure 3.4 compiles the individual search categories of CI as the foundations of CI and illustrates CI as a whole.

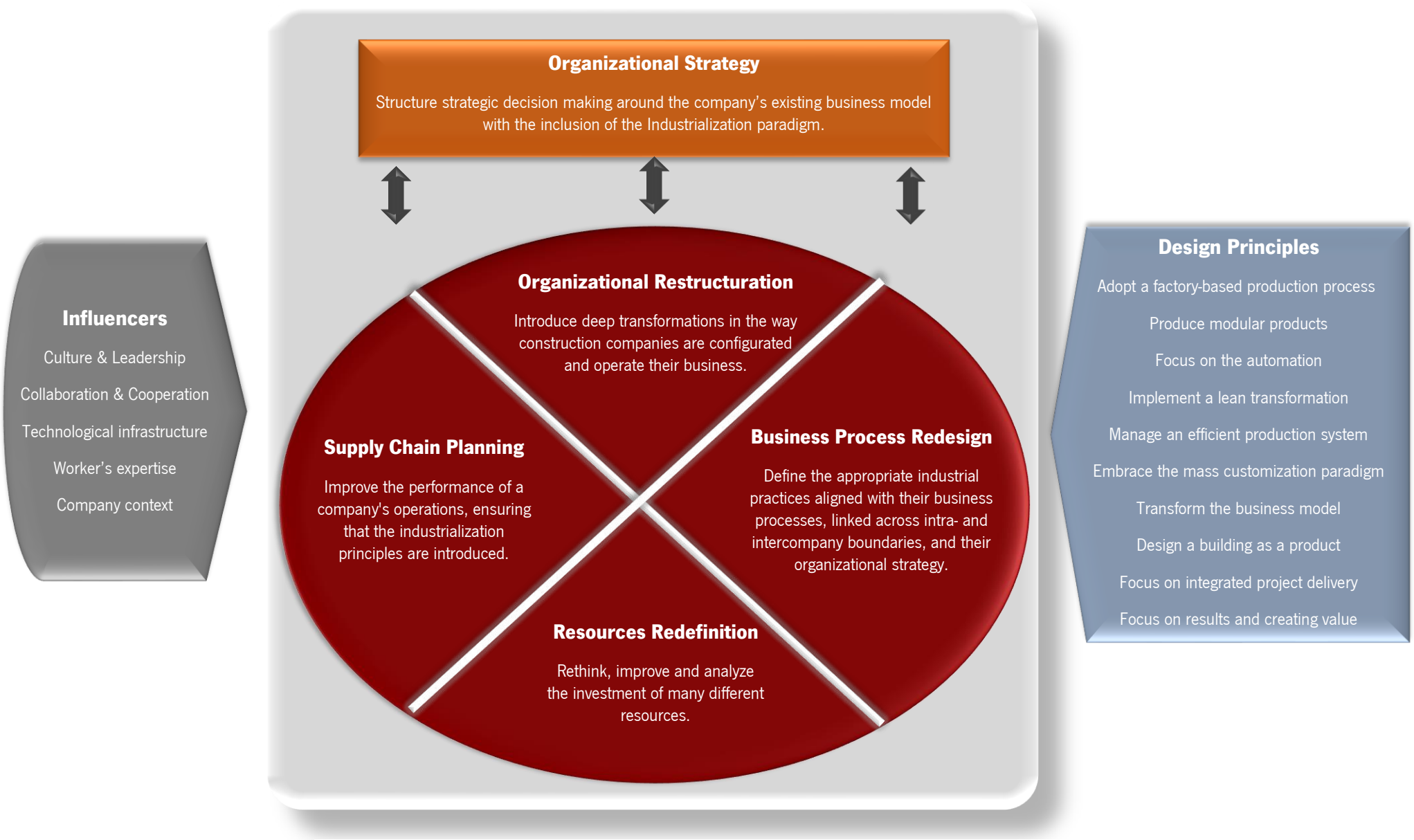


Figure 3.4: Construction industrialization conceptual framework

Among the recent contributions, there may be reasonable agreement that Construction Industrialization is a complex endeavor and poses significant attention to managerial (Jonsson & Rudberg, 2014), technological (Sabet & Chong, 2019), engineering (Jin et al., 2018) and behavioral (Zakaria et al., 2018) issues, as well as strategic (Jiang et al., 2018; Hall et al., 2020) and operational challenges, to Scholars and organizations around the world of all sizes and core businesses. As a result, in the focal construction company, CI not only implies a shift in the way of operating in the business but also implies a new culture.

Throughout this conceptual framework, most construction Managers will be familiar with a step-by-step strategic approach which includes the following main components: (a) assuming the higher-level considerations that constrain and significantly influence the overall performance of the resulting industrial strategy, referred to as *"influencers"*; (b) identifying the key design principles that grant knowledge of what explicitly address the research field of CI; and (c) selecting the essential CI practices that can serve as a simple guide for the development process of CI transition. The relationships between these three components are illustrated in Figure 3.4 through the relative position and flow between them, as indicated by arrows.

The conceptual framework presented in this study claims that successful industrialized construction companies need to include seven major dimensions in their transition quest. There is, then, a precedent challenge to understand the relationships between these dimensions. To overcome this difficulty, the conceptual framework proposes an integrated process—encompassing top-down and bottom-up strategies – since CI implies that construction companies re-design their strategy and operations, considering that top management, as well as middle management and frontline workers, must contribute together across the extended transformation (Yu et al., 2013). However, there are few studies introducing and focusing on these strategies.

This is a challenge for construction companies since they not only need to be able to learn and innovate but also require new organizational models and organization-wide changes (Ekanayake et al., 2020; Muñoz-La Rivera et al., 2020; Zhang et al., 2020) at macro and micro levels. CI transformation can be designed with regard to key practices, as part of the CI paradigm, driving innovation and forcing businesses to reconsider how they can transform their operations and processes to better address the demands of the rising number of Industrial challenges.

It is plausible to conclude that companies need to understand the need to use a holistic and integrative transformation in their business and operations, develop new knowledge, relationships,

and partnerships, rethink the market segments, and change their culture and leadership. Furthermore, to the best of the Author's knowledge, this conceptual framework may be followed up as a roadmap in further works.

3.7. Suggestions for Future Research

The findings of the systematic literature review and the proposed conceptual framework suggest several future avenues for empirical research and theory building. In this section, therefore, the Scholars draw attention to a few important opportunities for future research on CI.

First of all, concerning the descriptive analysis findings, two future research guidelines for literature review work on CI arise. Future research is expected to shed light on contextual and technical differences among countries (or regions) that are dominant in construction and policies in the transition to an Industrialization journey. Another extension opportunity lies in the construction sector from which the samples are drawn. Besides the general studies that cover multiple construction stakeholders or construction projects, we argue that future research is required to explicitly consider the role of these stakeholders and construction companies in an integrated way.

Second, the results of the thematic analysis also guide the Scholars for potential research avenues. So, given the multiple CI-related terms, with different layers and boundaries, Scholars, Managers, and Governments need to build a more holistic, multicultural, and multilevel understanding of CI issues. Hence, the adoption of a consensual definition of CI is of paramount importance to academicians in the development of a coherent discipline and for guiding future research, and to Practitioners as they develop and implement more effective CI transformations.

Then, it is clear that much of the knowledge about CI resides in narrow operational silos such as supplier management (see Liu et al., 2018), synchronization of onsite and offsite schedules, off-site constructing optimization (see Arashpour et al., 2016), technological development (Hou et al., 2020), site logistics, and so on. Likewise, operational and management themes are noticeably neglected in OSC research (Hosseini et al., 2018). Therefore, additional research must integrate the supply chain to ensure that all the functions and activities involved in the chain are working harmoniously together.

Fourth, the conceptual framework developed in this paper introduces five complementary and interrelated dimensions to the CI literature, which involve different (but interconnected) practices.

Therefore, different methods would be required to understand the dimensions in a precise way. The linkages between the different dimensions have not been well defined. Besides this, *"What are the pros and cons, as well as conditions/criteria for implementing these CI practices?"*, *"What are the shortcomings/limitations of those practices in terms of project level, organizational level, and/or country level?"* and *"How to address those limitations?"*. The answer to these research questions might provide very fruitful insights for both Scholars and Practitioners who are trying to understand and operationalize an Industrial Transformation in the Construction Sector.

Fifth, the integrated conceptualization of CI would greatly benefit Researchers' efforts to study the phenomenon of CI and those Practitioners attempting to implement CI. Consequently, research in this field, using the conceptual framework as the basis, should move from theoretical and conceptual development to empirical exploratory studies; hence, this is a timely point at which to reflect on the progress of the field and direct future research. A uniform, agreed-upon definition and conceptualization of CI will be able to advance the theory and practice of the discipline.

Finally, the literature is still missing a strategic roadmap to better visualize and understand each move and decision that companies need to make to facilitate the transition toward the CI development process and how they interrelate and interact with one another. This strategic roadmap will be crucial to both Scholars and Practitioners for a successful transition from traditional manufacturing to the Industrialization Process. Inherent in this structuring of decisions required to move from Conventional Construction to Industrialized Construction, several levels of decision will have to be analyzed (from strategic to operational), and consequently, the relationship between the various decision blocks will have to be analyzed to form the foundation to apply advanced decision support systems.

3.8. Conclusion

Construction Companies are undergoing remarkable and unprecedented enterprise transformations to pursue different avenues for higher productivity, better quality of construction products, and competitive advantage.

Despite the increasing attempts to conceptualize the phenomenon in academic work, however, the diversity of elements essential to the transformation often remains dispersed, and there is no

holistic, contemporary, and comprehensive view of the phenomenon as an organizational change and its supply chain. This article is an attempt to close this gap.

This study, in turn, discusses the process of CI transformation to guide Scholars and industry experts in organizing, conceptualizing, and conducting their research and their organizational change on CI. So, the outcome of this extensive review aims to present a foundation for further research in this field.

In this paper, the topic *"Construction Industrialization"* is introduced to provide a clear understanding of Construction Industrialization as both an evolutionary paradigm and a comprehensive concept. First, in the absence of consensus on a common set of CI constructs, this study contributes to the literature on CI by proposing a comprehensive definition of CI. Then, the aim of the literature was to develop an exploratory framework built with the relevant elements (CI dimensions, initiatives, influencers, and design principles) representing the Industrialization process to support both Scholars and Practitioners in this transformation.

Five major areas – Organizational Strategy, Organization, Process, Planning, and Resources -, ten design principles, five influencers' factors, and nineteen initiatives are identified and incorporated in a conceptual framework. This contextualization attempts to show the potential benefits of an Industrial Engineering and Management perspective in the Construction Sector that can no longer be ignored in its Industrial Transformation.

Consequently, the contributions of this article can be used as a guide to explain and guide the debate in construction companies and their supply chain actors (e.g., suppliers, subcontractors, logistics providers), project stakeholders (e.g., developers, architects, engineers, and contractors), and Customers, but also in academic institutions and policymakers (including planning and government Authorities).

Some limitations of this paper are worth mentioning. First, our review process concerns the inclusion of articles only published in Quartile 1 Journals. While recognizing only selected articles published in the most recognized journals, there is the risk of eliminating articles that could contribute to this research. Second, although our framework was constructed based on a systematic literature review, it is purely conceptual, and empirical validation is required.

Future studies are invited to further investigate one element (or more) of the conceptual framework, taking into consideration, to some extent, also the influence of the other elements presented in practical solutions. Additionally, future studies could examine what the main challenges of

operations planning are covered in operations management literature in the Construction Industry and compare the holistic interactions of the challenges in different production strategies using empirical data. Finally, another suggestion is future empirical investigations on construction companies to validate the framework proposed and to further explore the understanding of how the adoption of CI can push construction companies to achieve better performance.

Chapter 4

The Perspective of Organizational Change Theory

This fourth Chapter applies the theoretical lens of Organizational Change and Change Management theories. Two significant papers support Chapter 4. The first paper outlines important lessons regarding the Content of Change, underscoring that effective planning for transformational change is not a simple task. It requires a comprehensive understanding of core aspects such as the Process, Content, and Context of change. In light of this complexity, two systematic reviews were carefully conducted. The first review examines the maturity of the CI field as it relates to Organizational Change and Change Management theories. The second review explores a wide array of Organizational Change and Change Management models, focusing on the three key aspects previously mentioned. This in-depth study enriches the previous understanding of CI as a transformational process and establishes an organizational transformation-oriented model specifically for the Construction Industrialization development process. Chapter 4 concludes with a thorough summary of the primary contributions and practical implications.

4.1. Lessons from the Organizational Change Literature Towards a Transformational Model for the Construction Industrialization

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ABSTRACT

The intention to industrialize the Construction Sector has put enormous pressure on businesses. Construction companies' primary concern is to define a clear vision that will guide them on the path to a successful transformation. So far, Construction Industrialization (CI) research has provided only limited theoretical guidance, and practical applications frequently lack a systematic approach. Furthermore, while various approaches have been introduced in the literature, a thorough examination of these approaches reveals that none of them comprehensively covers all aspects of CI. Thus, the current review paper is among the first to give specific recommendations for lessons learned from the vast and solid field of Organizational Change, which can provide insights into a comprehensive CI transformation approach. Specifically, the emphasis is placed on the key organizational dimensions as a first effort to investigate how construction companies can implement a CI transformation. Six dimensions for effective CI implementation are presented from a total of twelve lessons learned. These lessons will provide a more in-depth knowledge of the nature of organizational transformation that must be addressed while implementing CI. Moreover, the current study suggests future research topics in the field of CI.

Keywords: Industrialized Construction; Transformation Model; Organizational Change.

4.1.1. Introduction

Although the term "*Construction Industrialization*" (CI) can be interpreted in a variety of ways, it is used here to refer to a critical process of modernizing and transforming the traditional construction industry in order to increase productivity and competitiveness (Bendi et al., 2020; Goulding et al., 2015; Duncheva & Bradley, 2019; Sutrisna et al., 2020).

CI has evolved from a topic of product and process change to one that requires Managers to transform the way they create, deliver, and capture value in order to implement industrial practices while managing their entire value chain (Wang et al., 2020; Wuni & Shen, 2020). While some academics emphasize this systemic and holistic adoption, there is disagreement on the most important question in CI research: "*How to assist construction Managers in a comprehensive Construction Industrialization development process?*"[3]. So far, the understanding of the CI concept and successful CI implementation represents a comparatively young field of research, with still many uncertainties and ambiguities.

The management literature, on the other hand, has grown significantly in its discussion of the best strategies for successfully embracing and managing transitions in specific contexts and for specific purposes (see Sikdar & Payyazhi, 2014; Ifenthaler & Egloffstein, 2020; vom Brocke et al., 2021).

Organizational Transformation (OT), also known as Organizational Change (OC), has received considerable attention, especially in the literature that links organizational theory, industrial engineering, and management (see Al-Haddad & Kotnour, 2015), and its benefits are well understood. Whether aimed at improving culture (Latta, 2009), organizational performance (Parry et al., 2014), or operational efficiency (Imran et al., 2021), the majority of the transformation initiatives seek to significantly change how business is perceived and carried out in order to adapt to a changing environment (Nutt & Backoffz, 1997; Kotter, 2007). Companies that are successful are those that can change and adapt (Colin & Hodges, 2010; Reefke & Sundaram, 2018).

OT has been introduced as a notoriously complex phenomenon. According to some Scholars (Teng et al., 1996; Jacobs et al., 2013; Gallego & Calderón Hernández, 2021), a high percentage of change attempts fail or produce results that fall short of expectations. Furthermore, they contend that there is no one-size-fits-all solution.

[3] The central question of this Doctoral Project (Chapter 1)

So, if Scholars and leaders continue to struggle to successfully transform their businesses, even in a well-established research field like OC (Chen et al., 2006; Al-Haddad & Kotnour, 2015; Basile & Faraci, 2015), the lack of a theory for the transformation towards CI development, with a specific context, subject to typical industry criticism, and with a new purpose of Industrialization, exacerbates this struggle. As a result, connecting the literature on organizational change and change management, and CI is critical as a first step toward ensuring a thorough understanding of what organizational transformation truly entails and how to apply this knowledge in CI. No other study, to the best of the Scholars' knowledge, has looked at CI implementation from this perspective.

The application of this extension theory opens up numerous opportunities for advancement in the CI field, particularly for the future development of a coherent, systematic transformation model that captures the changes that underpin the CI development process, including all of its dimensions and their interaction. These contributions stem from the solid foundations of such theories, as well as well-known practical contributions in this field. When applied to a new context, knowledge of the Construction Industrialization phenomenon in the construction industry will improve understanding of organizational theory. There is also, to the best of the Author's knowledge, a literature gap in the connection between the two fields of study.

The following research questions[4] have been developed to guide the study:

> *RQ1: What transformation models are available in the management literature that may help with the design of a comprehensive CI transformation model?*
>
> *RQ2: What dimensions of organizational change must be addressed to carry out effective planned change?*

To help achieve these goals, the paper is organized as follows. Section 4.1.2 provides a brief review of various perspectives of Organizational Transformation theory. The research methodology is then highlighted (Section 4.1.3). Section 4.1.4 discusses the main lessons found in the OT literature and analyzes their fit in the context of CI. Section 4.1.5 contains the conclusions and suggestions for future research.

[4] RQ1 and RQ2 of this conference paper are connected to RQ2 in Chapter 1 of the Doctoral Thesis. By focusing on the Content of Change, the present RQ2 addresses the dimensions or initiatives of change, ensuring alignment with the previous chapter and enhancing the overall coherence of the research.

4.1.2. Background

4.1.2.1. The Significance of Organizational Transformation

Organizational Scholars have had a fruitful discussion about how to achieve developmental (incremental), transitional, and, most importantly, transformational change, the three most common types of change that occur in organizations (Bartunek & Jones, 2017; Gallego & Calderón Hernández, 2021). While incremental and transitional types are usually completed over a set period of time, an OT is a radical system-wide change with transformational depth (Kotter, 2007; Termeer et al., 2017; Schalock et al., 2018).

OT has an impact on everything from values to routines to the way business is conducted (Gallego & Calderón Hernández, 2021). Transformation, according to Nutt & Backoff (1997), goes beyond fostering growth; it changes the "*rules of the game*" by implementing a paradigm shift that departs from traditional thinking about products/services, markets, and internal operations. According to Gallego & Calderón Hernández (2021), OT changes the firm's assumptions and fundamentals, resulting in an organization that differs significantly in terms of Structure, Process, Culture, and Strategy – a much deeper level of change.

Furthermore, Burke & Litwin (1992), Colin & Hodges (2010), Bartunek & Jones (2017), Termeer et al. (2017) and Gallego & Calderón Hernández (2021) recognize the significance of working with the entire system across multiple organizational domains and at various levels of analysis to an effective change in the way business is conducted, while also incorporating the external environment. This is exactly what the CI phenomenon anticipates and requires from construction companies.

As a new phenomenon in construction, CI dominates the landscape today in terms of how operations are done and managed, as well as how business is conducted (Wang et al., 2020). New products emerge and dominate companies' new offerings, which are characterized by modularization and prefabrication (Shafiee et al., 2020).

The willingness to challenge the traditional Structure, Process, Culture, and Strategy of the construction industry is growing (Larsson et al., 2014; Lessing et al., 2015; Wuni et al., 2021). And, viewing the organization as an interconnected system in which any change in one element affects the others, both internally and externally, particularly in the organization's supply chain, reinforces CI's holistic role (Hu et al., 2019; Liu et al., 2020). Insights from the larger body of

interdisciplinary literature on OT models, which will be discussed next, provide a distinct yet practical lens for gaining a better understanding of a CI transformation.

4.1.2.2. The Models for Organizational Transformation

Many models have been developed in the field of Organizational Change and Change Management research to help organizations improve their ability to change and grow. Concurrently, consultancies successfully launch new organizational change *"products"* that receive some attention in the OT literature (Jacobs et al., 2013).

Anderson & Ackerman (2001) classify current OT models as process models or frameworks. These models appear to be divided into two categories: change process theory and implementation theory, respectively (Latta, 2015).

The change process theory attempts to explain the phases and strategies that occur in organizations over time (the "*how"*) (Self et al., 2007). Representative examples include Lewin's three-step model, Kotter's eight-step model, and Luecke's seven-step model (see Latta, 2009; Al-Haddad & Kotnour, 2015; and Apostolopoulos et al., 2016).

The implementation theory describes the dominant high-intensity management and organizational changes, as well as their interactions, that must occur in order to carry out effective planned change (the "*what"*) (Parry et al., 2014). For example, McKinsey's 7-S Framework and academic Weisbord's Six Box Model are frequently cited (see Sikdar & Payyazhi, 2014, and Al-Haddad & Kotnour, 2015).

While the distinction between these two types of models is clear, and models are specifically differentiated for each type, some Scholars argue that this isolated approach will fail. Successful OT requires coordinated efforts to integrate and thoroughly investigate three divergent views of OT into a model: the process for sustaining this intention, the specific dimensions of change, and, equally important, its integration with the business context (Self et al., 2007).

However, as evidenced in 2007 by Self et al. (2007) and, in 2017, by Bigdeli et al. (2017), this integrative and global view of the transformation reflected in a model has received little attention. It can, notwithstanding, be seen in recent works, such as Bigdeli et al. (2017), Maes & Van Hootegem (2019), and Arazmjoo & Rahmanseresht (2020).

This is understood as the first lesson of our investigation. The current study is mainly concerned with the dimensions of change. The other two views of OT will be developed in subsequent research[5].

4.1.3. Methodology

Two research phases were developed. The first phase attempts to identify the set of dimensions that can be consistently integrated to support a transformational model proposal, while the second phase, fueled by the first, lists the lessons learned that must be brought into the CI field of research.

The literature review was conducted using Scopus and Web of Science (WoS), which are two of the largest databases for abstracts and citations of research papers. The search query concentrated on organizational change and transformation models.

To ensure that only relevant papers are analyzed, some inclusion/exclusion criteria were established: (i) the exclusion of conference and book chapters, and (ii) the consideration of only peer-reviewed journals written in English and published until May 2022, and in the Business and Management subject areas. This resulted in 283 Scopus papers and 175 WoS papers.

Following that, two more inclusion criteria were added: (a) the article contributes to the literature by presenting a transformation model; and (b) the article presents transformation holistically and systemically. We also looked into grey literature because a large number of models developed by large consulting firms are reported in various scientific papers.

These consulting firms employ well-known professionals who present their valuable perspectives on transformation based on their experience and expertise with businesses of all sizes and industries. This choice boosts the review's relevance and impact. This is also consistent with a growing understanding that grey literature contributes to knowledge in a specific field (Adams et al., 2017).

In this case, five more models were added to the initial twelve papers filter using a snowball approach (Thomé et al., 2016) and analyzing the grey literature through the first five pages of Google search results for the *"organizational change transformation process model framework"* in

[5] Explored in the next Subsection

accordance with Adams et al. (2017); resulting in a total of seventeen relevant models to analyze, answering the Research Question 1.

It's worth noting that the majority of Google's results refer to well-known models that were previously identified using the snowball strategy. This, nevertheless, demonstrates their practical importance; however, it may divert the Scholars' attention. Table 4.1 presents the models identified from their sources, which include both literature and grey literature.

Table 4.1: List of fifteen papers included in the review

Authors	Model's name	Source
Burke & Litwin (1992)	A Causal Model of Organizational Performance and Change	Journal of Management
Robertson et al. (1993)	A Theoretical Model of the Dynamics of Planned Organizational Change	Academy of Management Journal
Cao et al. (2003)	A Systemic Management of Change Framework for Action	Systems Research and Behavioral Science
Alas (2004)	A Process model for organizational change	Journal of Business Economics and Management
Lukas et al. (2007)	An organizational transformation model to deliver high-quality patient care	Health Care Management Review
Oakland & Tanner (2007)	The Organizational Change Framework	Total Quality Management and Business Excellence
Bigdeli et al. (2017)	Organizational change towards servitization: A theoretical framework	Competitiveness Review
Maes & Van Hootegem (2019)	A systems model of organizational change	Journal of Organizational Change Management
Imran et al. (2021)	Digital Transformation of Industrial Organizations: Toward an Integrated Framework	Journal of Change Management
McKinsey Company	McKinsey's 7-S Framework	https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/enduring-ideas-the-7-s-framework
Jay Galbraith	The Star Model	https://www.jaygalbraith.com/images/pdfs/StarModel.pdf
David Nadler and Michael Tushman	Nadler-Tushman Congruence Model	https://www.mindtools.com/adofd5j/the-nadler-tushman-congruence-model

Table 4.1: List of fifteen papers included in the review *(continue)*

Authors	Model's name	Source
The Center for Organizational Design	Organizational design framework – the transformation model	https://centerod.com/framework/
Deloitte	Deloitte Capability Hexagon TM	https://www2.deloitte.com/us/en/pages/operations/articles/operating-models-that-navigate-business-volatility.html
Management Studied Guided	Systems Model of Change Management and Continuous Change Process Model	https://www.managementstudyguide.com/systems-model-of-change-management.htm

4.1.4. Lessons Learned for the Development of a Transformation Model Toward Construction Industrialization

This section is divided into two parts. The first focuses on models, specifically the dimensions that should be included and their interrelationships, while the second focuses on the more general guidelines and recommendations discovered in the reviewed papers, which will provide substantial insights into the CI literature. Throughout the discussion, the fit of OT with the CI context will be examined.

4.1.4.1. Findings from previously published OT models

As previously stated, the integration of three interconnected views of a transformational attempt – Process, Content, and Context - constitutes the first lesson of OT literature. Ignoring one of these core aspects, in a transformational aspiration, can lead to failure.

Further, before identifying the primary dimensions that support transformational change, a second lesson about how these dimensions are currently organized must be introduced. The importance of balancing the hard (management) and soft (sociocultural) sides of change is widely acknowledged in the OT literature (Gallego & Calderón Hernández, 2021) and among consultancies (e.g., in the McKinsey 7S Framework). Furthermore, some Scholars (Al-Haddad & Kotnour, 2015; Montano, 2019; Gallego & Calderón Hernández, 2021) believe that an OT will fail if one of these factors, or their interaction, is overlooked.

As a result of the importance and notoriety of this second lesson, the following discussion will attempt to define the organizational dimensions that can be consistently integrated to support a

proposed transformational model, as well as explore its key ideas and demonstrate how having an integrated and comprehensive view of transformation can help its success. The dimensions are meticulously split into hard and soft sides of change, as shown in Table 4.2.

Table 4.2: Transformation management dimensions found in the reviewed models (dimensions transcribed as they appear on models)

Model	Hard Side of Change Dimensions	Soft Side of Change Dimensions
Burke & Litwin (1992)	Mission And Strategy; Management Practices; Structure; Systems (Policies and Procedures)	Leadership; Task and Individual Skills; Organizational Culture; Work Unit Climate; Individual Needs and Values; Motivation
Robertson et al. (1993)	Technology; Physical Setting; Technology; Organizing Arrangements	Social Factors
Cao et al. (2003)	Political; Processual; Structural	Cultural
Alas (2004)	Management Practices	Leadership; Organizational Culture Values
Lukas et al. (2007)	Mission, Vision, Strategy and Priorities; Organizational Functions and Processes; Infrastructure	Leadership; Culture and Values
Oakland & Tanner (2007)	Organization And Resources; Systems and Controls; Planning	Leadership and Direction; Behaviors
Bigdeli et al. (2017)	Structure; Power; Policial Characteristics; Strategic Directions;	Culture; Level of Trust; Stage of Board Development
Maes & Van Hootegem (2019)	Strategy; Structure	People; Culture
Imran et al. (2021)	Structure; Joint Optimization	Culture; Leadership
McKinsey Company	Strategy; Systems; Structure	Shared Values; Skills; Style; Staff

Table 4.2: Transformation management dimensions found in the reviewed models (dimensions transcribed as they appear on models) *(continue)*

Model	Hard Side of Change Dimensions	Soft Side of Change Dimensions
Jay Galbraith	Strategy; Processes; Structure	People; Reward (Motivation)
David Nadler and Michael Tushman	Structure; Work	People; Culture
The Center for Organizational Design	Strategy; Systems; Structure; Core Processes;	Leadership; Culture
Deloitte	Strategy; System: Process; Technology	People
Management Studied Guided	Strategy; Design; Task; Technology	People; Culture

Hard Side of Change

Table 4.2 reveals a common perspective in bringing together Strategy and key elements of organizational functioning – namely, Structure, Processes, and Systems – that are controllable by management and can influence employee behavior. With less emphasis, but also mentioned in some models, the term *"Resources"* is also debated.

Strategy. OT capability can only be fully developed when a strategy is in place (Burke & Litwin, 1992; Kotter, 2007; Maes & Van Hootegem, 2019) (third lesson). Strategy is about reflection, choices, and planning: reflection on what it is, selection of what it wants to be for, and planning to establish direction and priorities (Sikdar & Payyazhi, 2014; Bigdeli et al., 2017). Leaders must align transformation priorities with the overall mission, vision, and goals of the organization (Burke & Litwin, 1992; Lukas et al., 2007). Communication is essential (Alas, 2004; Kotter, 2007). Furthermore, business model innovation enhances the value of OC (Burke & Litwin, 1992; Cao et al., 2003; Jacobs et al., 2013; Sikdar & Payyazhi, 2014; Al-Edenat, 2021). Similarly, CI appears as a new way of operating and managing the business, with significant changes primarily at the level of production and a highly refined strategic direction of the business model. As a result, there is a fit between this dimension and a new understanding of CI.

Structure. No transformation process is complete unless functions and people are organized in such a way that the mission and strategy of the organization are effectively implemented (McKinsey

7S framework; Burke & Litwin, 1992; Oakland & Tanner, 2007) (fourth lesson). Different designations associated with an understanding of a new way of working are used in the reviewed models, such as structure, design, planning, organizational functions, management practices, and politics. On the other hand, Maes & Van Hootegem (2019) define Structure in a broad sense as *"including both the actual organizational structure for processes and systems"*. Also, Lukas et al (2007) share the same definition. In light of the Industrialization paradigm, which alters the way buildings are manufactured and has repercussions for their business model, the organization required to respond to this change must be considered and discussed.

Processes. OT is concerned with transforming a company's business processes in order to establish a competitive business structure that is effective and efficient (fifth lesson). All models investigate this as a prerequisite, either explicitly (by naming them *"Processes"*) or implicitly (by naming them *"Dimensions"*). In particular, process analysis is embedded in the system prerequisite associated with an operational change in some cases (how work is to be done). Company systems, according to the McKinsey 7S Model, are the daily procedures, workflow, and decisions that comprise the organization's standard operations. Parallel to the paradigm under consideration, industrialization implies a new way of producing, which results in the emergence of new processes and systems to efficiently concretize the new value proposition and operational model. In parallel with the paradigm under consideration, industrialization implies a new way of producing, and, as a result, new processes and systems emerge to efficiently manage the flow of materials and information.

Resources. As part of an organizational change driven by external pressures for innovation and/or better organizational efficiency, a new operational model (Gallego & Calderón Hernández, 2021) centered on digitalization, process improvement, or even new facility investments (automation), for example, necessitates a thorough examination of its resources (sixth lesson). Lukas et al (2007) (health care system transformation), Nordin et al (2012) (lean implementation), and more recently, Imran et al (2021) (digital transformation) are the only academic models that include the dimension *"Resources"*. Because of its interdependence, it is occasionally found as a component of the *"Structure"* or *"Processes"* elements to maximize their benefits (Robertson et al., 1993). Models gathered from grey literature, on the other hand, have sparked increased interest in this topic. Modernization of information technology and new facility investments are two of the most important practices closely related to our paradigm, and as a result, special attention must be paid to changes

for greater organizational efficiency and technological changes in productive processes that increase product quality, decrease time spent and waste, and increase profitability.

Soft Side of Change

Table 4.2 is triggered by two key influential elements: People and Culture are the dimensions considered in this paper. However, there is some overlap between the models. Some examples include the McKinsey 7S Framework and Maes & Van Hootegem (2019).

People. All models agree that effective OT adoption and implementation are subject to and dependent on the *"right people"* whether it is to restructure and orchestrate the change, support and implement it, or even their willingness to receive and institute it (as shown in Table 4.2) (seventh lesson). People's behaviors, skills, experience, and knowledge (often referred to simply as *"People"*), as well as management style and leadership, are critical contributors to successful change. Employee availability and skills, according to Robertson et al. (1993), limit the change initiative. Management style and leadership are critical in ensuring that change is implemented, in addition to setting direction and inspiring change throughout the organization. Understanding how these elements interact and influence each other, as well as the previously mentioned hard factors and the external context, increases the chances of implementing changes, planning, and creating new conditions within the organization; and this is the challenge for the Construction Industry.

Culture. Transforming and managing organizational culture and mindset is a critical component of nearly all enterprise-wide transformation efforts (Gallego & Calderón Hernández, 2021) (eighth lesson). This component can be found in a variety of places. Culture is viewed as an influencing factor by Bigdeli et al. (2017), a moderator for OT by Hussain et al. (2018), and an enabler by Imran et al. (2021). Furthermore, Shared Values are the central dimension in McKinsey's 7-S. Whatever their stance, this is a topic that applies to all models. Culture reflects the organization's true *"mind"* and *"personality"* in the people's collective new way of being, shaping, working, and relating (Cao et al., 2003). It reflects the social relationships, leadership style, worker attitudes, and habits defined by shared values, beliefs, and human behaviors (Lukas et al., 2007). It examines and assesses how well an organization's philosophy has been implemented. The construction industry, on the other hand, has high resistance to change with a conservative mindset, and must address this dimension urgently. Indeed, the cultural issue is highlighted in some contributions that investigate the main critical success factors (Wuni et al., 2021).

4.1.4.2. Additional recommendations discussed in the reviewed articles

In this section, four additional lessons are discussed, whether because of their transversality or similarity to the Industrialization paradigm, allowing the exercise of gathering knowledge from the OT literature to be completed.

The present study's ninth lesson is based on research developed by Burke & Litwin (1992) and Robertson et al. (1993), two of the most significant early publications on planned organizational transformation, and has been adopted over the years. Both studies explain how planned change impacts both individual growth and organizational performance. Successful organizational transformation cannot be achieved without the two broad sides of change - hard and soft - as mentioned earlier, and these two objectives are in line with this evidence. Determining the desired organizational results for the Construction Industry, both organizational and human growth, is therefore a critical step toward Construction Industrialization; something that is currently lacking in this field of study.

The tenth lesson is about understanding OT as a process. The literature defines OT as a complete, long-term, and ongoing strategic business process, applicable to a wide range of organizational contexts with distinct purposes. Each model employed a distinct perspective to cope with the complexity of OT and its environment when addressing the broad goals and priorities of a transformation effort. As a result, a more in-depth examination of this issue is required to be used in the CI development process[6].

Several concerns are addressed in the papers studied in the question of *"how to effectively implement a planned OT"*. Analyzing likely reasons for failure first allows the industry to ensure that they do not occur again, putting it in a stronger position for CI adoption (eleventh lesson). Poor planning, a lack of commitment to change, inefficient management of organizational resistance to change, and an inappropriate leadership style are among the explanations identified (Cao et al., 2003; Alas, 2004; Higgins, 2005; Jacobs et al., 2013; Silva et al., 2020). It should also be noted that people's behavior and psychological reactions are acknowledged as significant aspects of the process of transformation, with a major focus in every OT. Another source of concern for the Scholars was misunderstanding the notion and purpose of the concept, as noted by Nordin et al (2012), in the context of an organizational transformation anticipating the adoption of a lean

[6] Developed in the next Subsection.

strategy. Despite being a separate context, it is part of the Industrialization paradigm and should be included in the creation of the Industrialization conceptual model. This is because, despite excellent studies in the context of CI, the concept's clarity requires additional attention.

Finally, still in the discussion of *"how to best implement a planned OT"*, Scholars have placed a heavy emphasis on the integration of different disciplines, which is our twelfth lesson. For instance, Al-Haddad & Kotnour (2015) argue that successful organizational transformation necessitates fundamental changes in management and leadership; industrial engineering and management; and sociology and psychology domains. Furthermore, Maes & Van Hootegem (2019) suggest that change cannot be described by a single theory. This reflects the complexities of change, but it also provides an opportunity for Industrialization to pursue study in this sector as a new discipline.

Table 4.3 provides a complete summary of the twelve lessons learned in the vast and solid field of Organizational Change, translated into Construction Industrialization. These, in turn, can be understood as important theoretical advances to be achieved in a comprehensive approach to CI transformation.

Table 4.3: List of lessons learned for a successful CI transformation

Lesson Number	Lesson Description
1st	CI will require coordinated efforts to integrate three divergent views: the process, the dimensions, and the context.
2nd	CI must present two sides of change: simultaneously manage and align the hard and the soft factors.
3rd	CI can only be fully developed if the strategy is in place.
4th	CI will require a refined organizational design that effectively implements the organization's strategy.
5th	CI will necessitate a restructuring of the company's business processes.
6th	CI will require a thorough examination of the company's resources.
7th	CI will be subject to, and dependent on, the people's behaviors, skills, experience, and knowledge.

Table 4.3: List of lessons learned for a successful CI transformation (*continue)*

Lesson Number	Lesson Description
8th	CI will reshape organizational culture and mindset.
9th	CI will improve not only organizational but also individual performance.
10th	CI must be viewed as an ongoing and long-term process.
11th	CI must investigate the root causes of failure in the OT.
12th	CI will require fundamental changes in management and leadership, industrial engineering and management, and sociology and psychology domains.

4.1.5. Conclusion

This paper seeks to advance theory development in the field of CI by identifying a set of lessons learned from the OT literature that may be helpful for the development of a transformation model for Construction Industrialization.

This paper is the first attempt to provide Managers, Consultants, and Scholars with effective and comprehensive guidance on how to truly plan the action required to achieve the desired results, while always keeping in mind the widely accepted principle that each organization is unique, both at the strategic, human, structure, and values levels, making each transformation unique and, as a result, more uncertain and complex.

Because the CI research field, as well as the uncertainties associated with this transformation, are still in their infancy, it was decided to structure the transformation in accordance with organizational change theory. Working across multidisciplinary domains is an extension provided by OT, allowing the construction industry to learn from previously discussed and improved knowledge within this framework.

Two research questions emerge. The first led to the identification of 15 transformational models as critical to advancing the debate over what an OT can represent. A second one focuses on the

transformation's content, specifically, which dimensions are suggested as critical for a transformation implementation.

Based on our research in this field and the comparison of the models discovered, six dimensions were found that must occur to carry out effective planned change. In other words, a transformative model toward construction industrialization must include at least these six dimensions. They are strategy, structure, processes, and resources from the hard factors, and people and culture from the soft factors.

Furthermore, in addition to the six lessons learned for each of the dimensions, six more lessons learned were identified (a total of twelve lessons were identified). These include an explanation of how CI literature might anticipate potential implementation problems, as well as how it approaches the transformation process and its multidisciplinary nature.

It is important to recognize that this article is part of a comprehensive study on how to industrialize construction and so represents the first effort to understand CI as an organizational change. Later on, the goal is to develop a transformational model for industrialization, enriching OT literature with CI insights and experience, which will serve as a foundation for future validation and implementation.

4.2. Analyzing Construction Industrialization: A Theoretical Model Including the Perspective of Organizational Change Theory

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Out for Review in the Engineering Management Journal

ABSTRACT

This paper aims to expand the theoretical understanding of the Construction Industrialization (CI) phenomenon by applying the lens of Organizational Change and Change Management theories - an approach rarely explored in construction management literature. Intended for construction engineers, project managers, and construction leaders, this paper conceptualizes CI implementation as an organizational transformation rather than merely a technical advancement of CI innovations such as prefabrication, modularization, and digital integration. Through two systematic literature reviews—one focused on CI and the other on change management theories—the study synthesizes key insights using an established framework of change Context, Process, and Content[7]. This synthesis results in a novel, transformation-oriented model[8] that integrates both domains. The model provides construction managers with a comprehensive understanding of CI's complex nature and offers practical guidance for implementing CI initiatives within their respective companies. Findings highlight the complementarity between CI and change theories, introduce new dimensions of change relevant to Industrialized Construction, and emphasize the critical, yet underexplored, social and organizational dimensions of CI. This paper is the first to frame CI explicitly through the lens of organizational change, offering engineers a condensed and actionable model to navigate the complexities of CI adoption. Moreover, by bridging the gap between technological innovation and organizational readiness, this research supports more effective implementation strategies and lays the foundation for future empirical studies on the socio-technical dynamics of CI transformation.

Keywords: Construction Industrialization; Process; Change Management; Organizational Transformation; Model.

[7] Derived from the previous Subsection 4.1.

[8] Appendix A provides an overview of how the content and form of the CI definition and CI model evolve throughout Chapters 3 and 4.

4.2.1. Introduction

Construction Industrialization (CI) is increasingly recognized as a promising phenomenon for boosting productivity and competitiveness in an industry historically characterized by underperformance (Wuni et al., 2022). According to Ågren et al. (2014), CI is indispensable for driving modern growth and prosperity, emphasizing the urgent need for companies to transition toward this transformative phenomenon.

However, Managers on a global scale have expressed some reservations regarding such a transition. Recent studies (Liu et al., 2019; Wuni & Shen, 2020) have noted several barriers and indicated low adoption rates worldwide. High implementation costs, perceived operational risks, and uncertainties associated with the transition have impeded widespread managerial uptake.

While CI literature has grown substantially in recent years, particularly around technological innovations such as prefabrication, off-site construction, modular systems, and automation, the focus remains predominantly on technical issues. Furthermore, traditional frameworks often focus narrowly on project-specific concerns (Hosseini et al., 2018) and have been criticized for their limited and ambiguous perspectives (Ayinla et al., 2019; Nabi & El-adaway, 2020).

Recent works critique current approaches for inadequately addressing the organizational implications of CI (Hu et al., 2019; Luo et al., 2020). Current literature does not adequately bridge the gap between CI's technical innovations and the organizational transformations necessary to leverage them fully (Hosseini et al., 2018; Liu et al., 2019). Practitioners are thus left without practical, actionable guidance that integrates both aspects into a cohesive implementation strategy.

The lack of a clearly defined, comprehensive framework to assist such transition has left the implementation process fragmented and inconsistent (Liu et al., 2019; Ayinla et al., 2019; Sabet & Chong, 2019; Luo et al., 2020). Without a well-defined and structured understanding of CI development, its full potential remains constrained, limiting the effectiveness of its adoption.

Porras & Silvers (1991) noted that companies become more responsive to environmental shifts if they are guided by generally accepted and unified theories of organizational management and change management. Over the years, extensive research has led to the development of specific models tailored to different contexts and purposes, assisting Managers in understanding and planning change (Al-Haddad & Kotnour, 2015). Embracing these theories in this paper signifies a shift towards more comprehensive discussions of the CI development process (Bigdeli et al., 2017)

and carefully assessing the dynamics that such a phenomenon implies for a company (Armenakis & Harris, 2009).

This paper explores how Organizational Change and Change Management theories can inform and enrich the CI development process. Despite their relevance, the application of such theories in the CI context remains underexplored. Liu et al. (2019) explicitly call for further research into how these can support CI—a call yet to be adequately answered.

Accordingly, a dual systematic literature review is conducted in this paper. The first review examines the maturity of CI research with respect to Organizational Change and Change Management theories. The second explores established change models that could inform CI development. Insights from both reviews are synthesized using the Process, Content, and Context framework. An organizational transformation-oriented model for the CI development process is proposed based on this synthesis.

The developed model offers a structured, practical guide for understanding and managing CI implementation as an organizational transformation rather than a purely technical enhancement. Ultimately, it aims to capture the complexity of CI and serve as a practical tool for guiding its implementation comprehensively.

This study offers a three-fold contribution. First, it bridges CI literature with organizational change theory, establishing a comprehensive understanding of how change management principles can support CI development. Second, it introduces a transformation model grounded in the dimensions of context, process, and content, offering a holistic framework for managing CI as a socio-technical system. Third, it highlights the critical importance of the social dimension, often overlooked in CI research, thereby introducing new perspectives on change that are essential for practice.

The paper is structured as follows. An overview of change theories is presented in Section 4.2.2. Section 4.2.3 outlines the research method. Section 4.2.4 discusses the review findings, and Section 4.2.5 presents an organizational transformation-oriented model for the Construction Industrialization development process based on such discussion. Implications for research and practice are outlined in Section 4.2.6. Section 4.2.7 ends the paper with the main conclusions and directions for future work.

4.2.2. An Overview of Organizational Change and Change Management Theories

Unlike the CI literature, in the domain of organizational theory, how to plan a change is a well-established debate (Karasvirta & Teerikangas, 2022). Change is part of business, and there is a vast and solid field of research.

Three types of change have stood as references: changes can be developmental, transitional, or transformational (Gallego & Calderón Hernández, 2021). Developmental and transitional types refer to the study of a specific, isolated aspect of an organization. Profound organizational change emerges in the form of transformations and goes beyond fostering growth (Brandt et al., 2019).

> "*A transformation creates a sustainable metamorphosis from a vision that produces radical changes in an organization's products/services, consumers/clients, market channels, skills, sources of margin, competitive advantage, and persona, integrating these changes with core competencies*."

This is how Organizational Transformation (OT) is described in Nutt and Backoff's (1997) study. Years have passed, but the depth, scope, and perceived change extended over time are still similar: an OT can be understood as radical, fundamental, and large-scale system-wide change with transformational depth that impacts how business is seen and conducted to adapt to a new and more challenging market condition (Kotter, 2007; Brandt et al., 2019). For Tosey & Robinson (2002), an OT results in wholly new paradigms for organizing and carrying out work. Gallego & Calderón Hernández (2021) point out OT as *"a radical change that affects everything from values to routines to how business occurs"*.

In this study, the phenomenon of Construction Industrialization will be referred to as a transformational change. In the context of transformational models of change, different approaches have been deployed in Organizational Change and Change Management theories (Al-Haddad & Kotnour, 2015), dictating how each transformation is conceptualized and forming the foundation for developing the transformation model.

Three identifiable, interrelated elements are predominantly considered the core aspects of such conceptualization: Process, Content, and Context. This identification follows the studies developed by Self et al. (2007), Al-Haddad & Kotnour (2015), and Arazmjoo & Rahmanseresht (2020). Figure

4.1 depicts a schematic diagram illustrating how the planning of a transformational change should be described using the theoretical lens of the studied theories. It outlines the three core aspects.

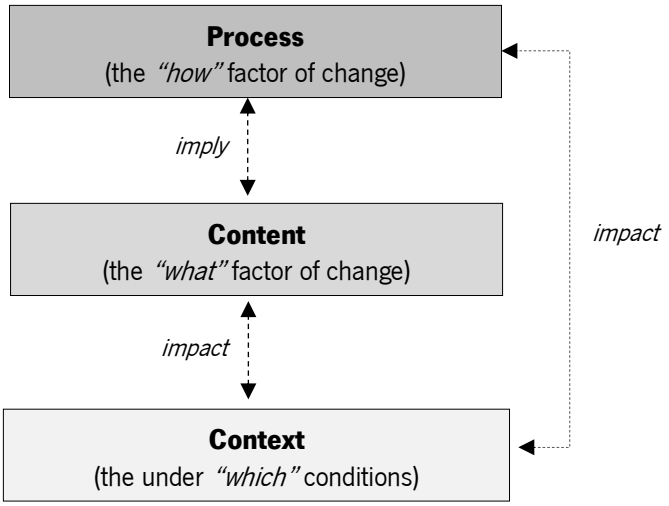


Figure 4.1: Schematic diagram of change using the lens of Organizational Change and Change Management theories (own elaboration)

4.2.3. Methodology

As previously referred to, this study is grounded in two Systematic Literature Reviews. According to scholarly consensus, systematic literature reviews provide a rigorous methodological review of research findings and are a critical part of any scientific research (Seuring & Müller, 2008; Hussein & Zayed, 2021).

The dual SLR approach serves as the foundation for developing an integrated model to guide the transformation process of Construction Industrialization. The main research question is: *"How can Organizational Change and Change Management theories assist the CI development process?*[9]*"*. A further refinement of the objectives and the research approach of this paper can be stated as follows (Figure 4.2):

Objective 1: Linking CI and Organizational Change and Change Management theories. SLR 1 aims to examine the unique and complex nature of CI, with particular focus on how CI literature has been approaching organizational change and change

[9] The main research question of this paper corresponds to the research question formulated as RQ2 in Chapter 1.

management theories. This review aims to assess the extent to which CI research incorporates these theoretical lenses, thereby identifying conceptual limitations and uncovering areas where deeper theoretical integration is needed.

Objective 2: Exploring the current transformation models. SLR 2 aims to examine how current models have approached planning for transformative change. Its purpose is to extract actionable insights that could inform the CI domain, offering a structured understanding of how transformational processes can be conceptualized and operationalized in other disciplines.

Objective 3: Confronting the two review findings. Building upon the findings of Objectives 1 and 2, this objective undertakes a comparative synthesis to identify areas of convergence and divergence between the two bodies of knowledge. This integrative analysis is organized around the three foundational dimensions of change—Process, Content, and Context—as a means to better capture the complex socio-technical nature of CI. The result is a conceptual transformation model designed to improve the understanding of CI and support its sustainable implementation in practice.

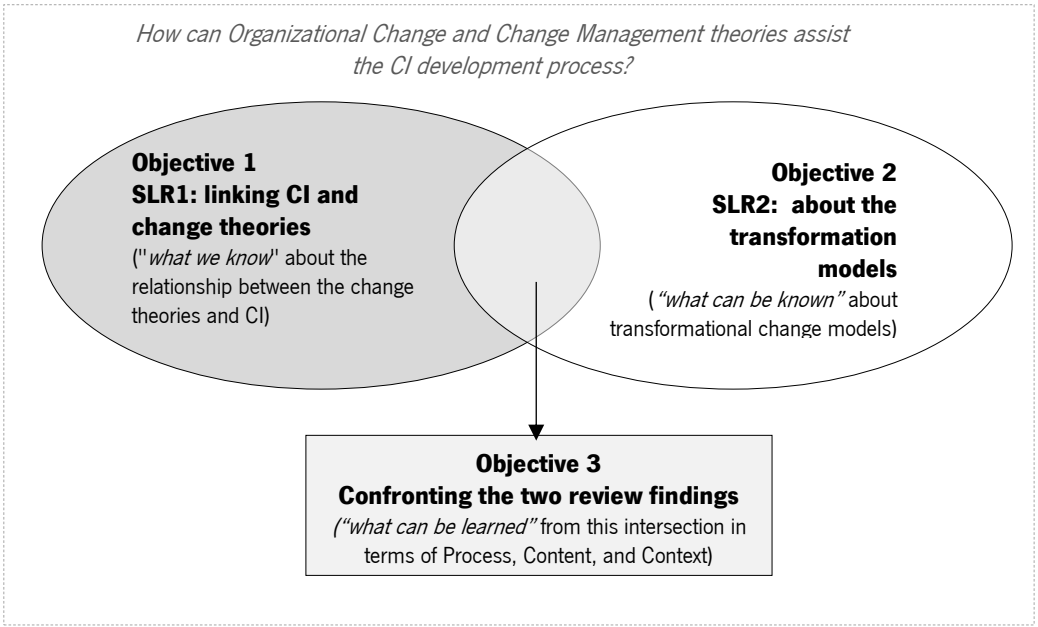


Figure 4.2: Methodological approach

The study's search process followed a structured approach using the Preferred Reporting Items for the Systematic Review and Meta-Analysis (PRISMA) (Hussein & Zayed, 2021), complemented by studies by Tranfield et al. (2003), Seuring & Müller (2008), and Thomé et al. (2016). It involved four phases: data identification, screening, eligibility, and data analysis and synthesis.

Objective 1: SLR linking CI and change theories

Data identification

This phase identifies bibliographic databases, keywords, and the search strategy (Thomé et al., 2016). A search was conducted using the Scopus and Web of Science (WoS) databases, which are two of the largest databases for abstracts and citations of research papers.

To ensure a rigorous search process for each review, while obtaining the broadest sample of papers for analysis, three levels of keywords were formulated in the first SLR (Table 4.4). The first two strings are CI-related terms based on a previous Author's contribution (Costa et al., 2023). The third string is organizational change-related terms chosen based on previous literature reviews on similar topics (Brandt et al., 2019).

Table 4.4: Level and list of keywords used in this study

Level	Keywords
1 - Construction Industrialization set of keywords[10]	"*Manufactured Construction*"; *"Off-Site Construction*"; "*Offsite Construction*"; "*Prefabricated Construction*"; "*Construction Industrialization*"; "*Construction Industrialization*"; "*Industrialized Construction*"; "*Industrialised Construction*"; "*Modular Construction*"; "*Industrialized Building System*"; "*Industrialised Building System*"; "*Industrialization*"; "*Industrialisation*"

[10] By comparing the keywords used in Chapter 3, the Author has notably enhanced the research vocabulary, making the main terms used to study the CI phenomenon clearer. This approach effectively narrows down the research while ensuring the integrity and objectivity of the search terms. Additionally, the terms *"industrialization"* and "*industrialisation"* have been included as redundant concepts. This set of keywords (Table 4.4) aims to be as comprehensive as possible to capture the evolution and advancements in construction practices, particularly in the area of change management, where research is still limited. Moreover, it is relevant to highlight that keywords associated with Industry 4.0 were intentionally excluded to maintain the integrity of the study. The vast body of knowledge in this area has the potential to divert the literature from the CI field which contradicts the primary purpose of this research. This thoughtful exclusion ensures that the findings remain focused and relevant to the intended scope.

Table 4.4: Level and list of keywords used in this study *(continue)*

Level	Keywords
2 - Construction industry set of keywords	"*Construction Industry*"; "*Building Industry*"; "*House-Buidling*"
3 - Organizational Change keywords[11]	"*Organizational Change*"; "*Organisational Change*"; "*Organizational Transformation*"; "*Organisational Transformation*"; "*Change Management*"; "*Transformational Change*"; "*Business Change*";" *Business Transformation*"; "*Organizational Development*"; "*Organisational Development*",

For the two databases, a string with the three levels of keywords was applied to the *"title, abstract, and keywords"*, with an open starting time to include as many publications as possible by December 2023. A total of six papers were found on the Scopus database, and two on the WoS search. After eliminating duplications, seven papers were available for analysis.

Upon reviewing the findings, it is evident that a sample size of just seven papers is too restrictive. Given the recent calls for more in-depth exploration, the existing literature highlights a significant gap in the comprehensive examination of theories of change within the field of Construction Industrialization. To address this issue, it is advisable, as recommended by Thomé et al. (2016), to expand the search parameters to compile a broader collection of papers.

To achieve this, while continuing to seek the first two levels of keywords in *"title, abstract, and keywords"*, the search for the third level was extended to *"all fields"*. This refined search approach will potentially enable the comprehensive identification of papers discussing the studied theories within the context of CI research.

A total of 45 relevant papers were found in the Scopus database, and the same two in WoS. Therefore, 46 papers advance to the next phase. No papers were found when a filter was exclusively applied for *"title"* searches with Level 3. This paper is the first to introduce such theories in the title of a CI paper.

[11] New keywords have been introduced in relation to those used in the conference paper (Section 4.1). This set of keywords is based on existing reviews of Organizational Change and Change Management. The goal is to gather a larger number of papers compared to those in Subsection 4.1.

Screening

The screening stage requires clarity concerning boundaries to frame the research (Hussein & Zayed, 2021). So, filtering was implemented to include (1) articles or reviews, (2) written in English, (3) published in journals, and (4) from areas of engineering and management, economics, and related sciences. As recommended by Tranfield et al. (2003), only peer-reviewed publications in academic journals were used to ensure the quality of the papers in the sample. Applying such filter criteria and eliminating the duplicates, a total of 33 papers proceeded to the next phase.

Eligibility

The eligibility phase rigorously assesses the validity of selected studies and determines whether this review strategy can be applied to one's research (Tranfield et al., 2003; Seuring & Müller, 2008; Hussein & Zayed, 2021). For this study, only papers that introduce and/or analyze the intersection of studied theories with the field of Construction Industrialization were included for review. Papers that only refer to the theories studied without analyzing them or only mention them as an opportunity for future research were excluded from the analysis. This decision was made to ensure a thorough review of scientifically profound papers on this topic.

In the full-text analysis, keywords related to the theories studied were predominantly found in references. Wong et al.'s (2017) paper was highly cited, and several Scholars called for further research to support CI development. According to Xiahou et al. (2018) and other Scholars, organizational change strategies within the CI field are still inadequately developed, despite being essential for understanding the phenomenon's development.

The seven selected papers (Davidson, 2009; Alazzaz & Whyte, 2015; Loudoun & Townsend, 2017; Wong et al., 2017; Gao et al., 2021; Ezcan & Goulding, 2022; Costa et al., 2023) fulfill the inclusion criteria for review analysis. Despite a small sample size, the research process offers a comprehensive understanding of the examined theories.

Analysis and Synthesis

The descriptive and thematic analyses enabled the development of a transformation model. The descriptive analysis was based on the publication year and the core aspects addressed in each

paper (Process, Content, and Context). In the same line, the thematic analysis was also conducted to examine the contributions to each core aspect: Process, Content, and Context.

All seven papers focused on the Content aspect of change. Interestingly, the Context aspect was addressed only by two papers, and none of the papers introduced CI as a change process.

Three additional conclusions can be drawn:

- All the reviewed papers used *"organizational change"* as an umbrella term to study change in the construction industry. Organizational Transformation is only referred to by Costa et al. (2023) as a synonym for OC, and by Ezcan & Goulding (2022), where the latter replaced it with *"organizational capability theory"*.
- Each paper introduces a distinct theoretical approach to CI development, indicating a lack of consensus. Divergent interpretations of the concept and its implementation persist, even within papers claiming comprehensive knowledge. This aligns with recent literature reviews that underscore the absence of a unified theoretical foundation (Ayinla et al., 2019).
- No study has culminated in a framework for addressing the planning or management of change in the CI process. According to Edmondson & Mcmanus (2007), conceptual models are essential links between the initial descriptions of the phenomenon and the theories capable of explaining and predicting this phenomenon. If they are lacking, this means that CI as a change process still needs to be better explored, and research that aims to describe, explain, test, or refine it is still nonexistent.

Objective 2: SLR about the transformation models

Data identification

The same databases (Scopus and WoS) were consulted to ensure that the research was consistent. Due to the vast body of knowledge in the change management fields, two search tests with the third level of keywords (Table 4.4) with the words *"Model"*, *"Framework"* and *"Process"* were developed: a first test on the Scopus database for the *"title, abstract, and keywords"* (26781 papers), and a second test for the *"article title"* only (1119 papers) (until December 2023). This last test serves as the starting point of this research. Jedynak et al. (2021) also developed a title-based filtering method to handle the extensive literature on the topic of change management.

Screening

As a filter criterion, only (1) articles or reviews, (2) written in English, and (3) published in journals were included. The (minimum) time filter was not used because the organizational change topic was not an emerging phenomenon. Its study dates back some decades, and consolidated models have been proposed since then. A filter for Management areas was also established. After applying the filter criterion, 249 papers were found in the Scopus database and 96 papers in WoS. After eliminating duplicates, a total of 342 papers proceeded for analysis.

Eligibility

Title/abstract analysis derived that papers that did not focus on providing a model (or framework) that supports a planned transformational change were excluded. A total of thirty-four models were reviewed. A background snowballing was applied, following the recommendations provided by Thomé et al. (2016), which resulted in nine more papers being included in the final sample. Grey literature research was also considered, as suggested by Adams et al. (2017). Therefore, a search string *"organizational change transformation process model framework"* (in September 2022) was developed. The first five pages of Google search results were evaluated, as Adams *et al.* (2017) performed. A total of six models were identified. So, forty models compose the review sample of this second SLR (Appendix E lists the transformation models reviewed).

Analysis and Synthesis

The papers were analyzed similarly to SLR1, based on their contributions to the core aspects of Process, Content, and Context. This aligns with transformational model literature, aiding in fully understanding the developmental process of the phenomenon. It also allows for a comprehensive comparison between the review findings.

One observation must be drawn as well. Although literature is moving toward understanding change as composed of Process, Content, and Context, not all reviewed models address these three aspects simultaneously.

4.2.4. Findings

The analysis of the selected papers is structured around three fundamental aspects - Process, Content, and Context – integrating the findings from two systematic literature reviews conducted in this paper.

4.2.4.1. Process of Change

The Process of change is about understanding how OT has been thought of (the "*how*" factor of change). Since CI literature does not refer to the CI phenomenon as a process, valuable insights can be drawn from the Organizational Change and Change Management literature to assist the CI field on this topic.

In the second SLR, Scholars state that a transformational change is not an end state or a final product, but rather a transformation journey, the *"odyssey or voyage of discovery"* (Tosey & Robinson, 2002). It is a revolutionary, not incremental, process of change, providing insight into its lasting impact on organizational dynamics (Dunphy & Stace, 1988).

Two main streams have been identified in the literature: the classical sequential model (e.g., Alas, 2004; Hussain et al., 2018) and the dynamic, open approach (e.g., Burke & Litwin, 1992; Maes & Van Hootegem, 2019). Traditional linear models have been widely criticized for not capturing the complexity and dynamism inherent in transformative change. Additionally, they do not guarantee success, as change processes are often unpredictable and nonlinear according to Pollack & Pollack (2015) and Maes & Van Hootegem (2019).

For dynamic, open-system models, academic and grey literature present various frameworks, usually including 3 to 6 phases. Table 4.5 shows how different transformation models interpret and structure open system phases. The most commonly identified phases include Input, Throughput (or Transformation), Output, and Feedback.

Table 4.5: Results of content analysis of key process phases in the OT literature in open systems models

Reference	Phases	Input	Throughput	Output	Feedback
Burke and Litwin (1992)	6	1-External Environment	2- Transformational elements 3- Transitional elements 4- Motivation	5-Organizational and individual outcomes	6-Feedback
Jacobs et al. (2013)	4	1-Input (internal context and the external environment)	2-Throughput (organizational identity, leadership, change content, and change process)	3- Organizational performance and organizational legitimacy	4- Feedback
Maes & Van Hootegem (2019)	4	1-Rationale for change (affected by the external environment)	2-Object of change (Strategy, Structure, People, Culture)	3- Organizational, individual/group, social/industry effects	4– Dynamism and Connectivity
Nadler-Tushman Congruence Model	5	1-Input (environment, resources, and history)	2-Strategy 3-Transformation process (Culture, People, Work, and Structure)	4- Organizational Performance	5-Feedback
Organizational design framework – the transformation model	4	1-Environment	2-Throughput (Strategy, Core Processes, Structure, Systems, Culture, Leadership)	3-Results	4-Feedback

All these models emphasize how inputs (environmental factors and internal context) are transformed internally (through internal processes and organizational elements), and result in outputs (performance, outcomes, and changes), with feedback loops helping adjust future actions.

In this schematization, the first phase corresponds to the input—the rationale for change. As highlighted by Jacobs et al. (2013), OT is often prompted by a perceived misalignment between an organization (as a living system) and its external environment.

The transformation (throughput) phase is where models diverge most significantly. Some models (such as Burke & Litwin) go deeper into transformational/transitional dynamics, while others take a broader view (such as Maes & Van Hootegem, 2019). The models presented in Table 2 represent various organizational dimensions, each aligned with the specific purpose of each model.

Additional variation exists in emphasis: for example, the Nadler-Tushman Congruence Model isolates strategy as a distinct phase, underlining its role in aligning inputs with transformation processes. Other models highlight organizational identity, legitimacy, and congruence, recognizing that values and perceptions are critical in guiding change.

Across models, environmental factors and feedback mechanisms are consistently integrated, underlining their foundational importance in enabling dynamic adaptation. Feedback is understood not only as a learning tool but as a vital component of system dynamism and continuous evolution.

Table 4.6 intersects the findings from both reviews in terms of driving factors in each context. It can be noted that a promising convergence between CI research (focused on process and performance metrics) and organizational theory (focused on systemic, behavioral, and strategic aspects).

Table 4.6: Driving factors (Rationale) intersected in the two SLRs

Rationale	Some references SLR1 (CI field)	Some references SLR2 (OT Models)
Industry Productivity	Alazzaz & Whyte (2015); Wong et al. (2017); Costa et al. (2023)	Robertson et al. (1993)
Company Competitiveness	Wong et al. (2017); Costa et al. (2023)	Burke and Litwin (1992)
Human Development		Burke and Litwin (1992)
Quality of Life and Well-Being of Society		Maes & Van Hootegem (2019)
Environmental Scenario	Wong et al. (2017)	Montano (2019)
Project Performance	Davidson (2009); Wong et al. (2017)	

Themes such as human development and societal well-being remain largely absent from CI literature. This gap represents an opportunity to incorporate human-centric and socio-technical perspectives into construction industrialization, potentially enhancing workforce capability and engagement. Conversely, project performance—measured in terms of time, cost, and quality—is well covered in CI literature (e.g., Davidson, 2009; Wong et al., 2017), but lacks contributions from OT models. Incorporating organizational behavior, team dynamics, and learning theories from OT could deepen the understanding of factors influencing successful project delivery.

From this analysis, six key aspects were identified for further exploration in the context of CI development:

1. Improvement in industry **Productivity**, stressing that such a goal requires more than just technical innovation (as typically found in the CI literature); it also demands an understanding of organizational behavior and structural alignment;
2. Enhancement of company **Competitiveness** (organizational performance), balancing technological and managerial innovation with adaptive organizational strategies;
3. Promote individual **Human Development**, addressing group and individual impacts;
4. Improvement of the quality of life and well-being of **Society**;

5. Improvement of the **Environmental** scenario;
6. Improvement of **Project Performance**, in terms of time, cost, and quality.

Taken together, these factors form a fundamental basis for studying the key drivers of CI by integrating insights from both the CI domain and OT models. However, it is important to note that the reviewed literature does not clearly differentiate between the rationale for implementing CI processes and the outcomes achieved—they are often treated as a single entity.

4.2.4.2. Content of Change

The Content of Change refers to the key dimensions that support and drive the successful implementation of transformational change within an organization (the *"what"* factor of change).

In total, eleven dimensions of change have been identified through this research, offering a comprehensive framework for understanding change from a CI perspective. These dimensions emerge from the intersection of findings in both the CI field and OT models. Table 4.7 presents a comparative analysis of these perspectives, synthesizing the critical dimensions necessary for ensuring that CI change initiatives are both effective and sustainable. The eleven dimensions are as follows:

1. Companies must establish a **Strategic decision-making process** based on a reflection on what they are as a company, a vision of what they want to be, and decisions to determine the future direction and priorities around their business model;
2. Companies must do a thorough examination of how they conduct business in order to **Restructure Organizationally** in order to embrace the CI phenomenon;
3. Companies need to implement major adjustments in the way they construct and operate their **Operations** to achieve high efficiency in the manufacturing of off-site modular products.
4. Companies must create an appropriate decision flow and connected control processes across intra- and inter-company boundaries (**Management Systems**);
5. Companies must rethink, upgrade, and invest in **Technology**;

6. Companies must recognize that people are change agents and that the success of a CI development is dependent on the appropriate people, in the right positions, with the **Skills/Capabilities** needed **and knowledge**;
7. Companies should be concerned with the social environment as well **as People's Behavior**, needs, attitudes, sentiments, and reactions to change to foster a culture of sharing, enthusiasm, engagement, and proactivity inside the organization.
8. Companies must create a **Culture** of shared values that supports the goal and plan for change while also empowering, motivating, and inspiring everyone participating in or being affected by the CI phenomenon;
9. Companies must recognize the critical role that effective **Leadership** plays in motivating and inspiring employees to accomplish what is necessary to achieve the company's vision in an atmosphere of dedication, creativity, and engagement.
10. Companies must manage their **Supply Chain** to increase the performance of their operations, provide new solutions, and ensure efficient building projects.
11. Companies must implement **Innovation** in their operations, including product design, process decisions, and Supply Chain connectivity.

Table 4.7: Organizational dimensions intersected in the two SLRs (●=dimension identified)

References	Strategy	Structure	Operations	Systems	Technology	Capabilities	Social	Culture	Leadership	Supply Chain	Innovation
SRL 1 (CI field)											
Davidson (2009)		●	●							●	●
Alazzaz & Whyte (2015)						●	●	●	●		
Loudoun & Townsend (2017)									●		
Wong et al. (2017)				●		●					
Gao et al. (2021)							●				
Ezcan & Goulding (2022)	●		●			●					
Costa et al. (2023)	●	●	●		●	●		●	●	●	
SLR 2[12] (OT Models)											
Dunphy & Stace (1988)	●	●		●							
Walsham (1992)				●				●			
Burke and Litwin (1992)	●	●		●		●	●	●	●		
Robertson et al. (1993)	●	●	●	●			●				
Burn (1993)	●	●		●			●	●			
Hill & Collins (2000)	●	●			●	●		●	●		
Cao et al. (2003)	●	●	●					●			
Alas (2004)			●					●	●		
Chen et al. (2006)	●			●	●	●	●	●	●		
Alas (2007)	●	●	●	●		●	●	●			
Lukas et al (2007)	●	●	●	●				●	●		
Oakland and Tanner (2007)	●	●	●	●			●		●		

[12] The following OT models were not included in the previous Table 4.5, which focuses solely on content-related models: Leifer (1989); Matheny (1998); Mossholder et al. (2000); Liu & Perrewé (2005); Meyer et al. (2007); Latta (2009); Jacobs et al. (2013); Parry et al. (2014); Sikdar & Payyazhi (2014); Pollack & Pollack (2015); Al-Haddad & Kotnour (2015); Cha et al. (2015); Montano (2019); Maes & Van Hootegem (2019); Arazmjoo & Rahmanseresht (2020); Silva et al. (2020); and Gallego & Calderón Hernández (2021).

Table 4.7: Organizational dimensions intersected in the two SLRs (●=dimension identified) *(continue)*

References	Strategy	Structure	Operation	Systems	Technolog	Capabilitie	Social	Culture	Leadershi	Supply	Innovation
Nordin et al. (2012)	●		●	●		●	●	●	●		
Bigdeli et al. (2017)	●	●	●					●	●		
Hussain et al. (2018)	●	●	●		●		●	●	●		
Maes & Van Hootegem (2019)	●	●	●	●		●	●	●			
Imran et al. (2021)		●	●					●	●		
McKinsey Company	●	●		●		●		●	●		
Jay Galbraith	●	●	●			●	●				
David Nadler & Michael Tushman		●	●			●		●			
The Center for Organizational Design	●	●	●	●				●	●		
Deloitte Model	●		●	●	●	●					
Management Studied Guided	●	●	●		●	●		●			

The comparative analysis presented in Table 4.7 reveals critical insights into the CI literature:

First, it shows that CI literature tends to adopt a more narrowly defined scope, often emphasizing a specific subset of organizational dimensions that are directly aligned with performance improvement and operational efficiency. Costa et al. (2023) stand out for their holistic approach, identifying eight of the eleven possible dimensions and thereby bridging the gap between operational and strategic levels. In contrast, the OT-focused literature, as expected, shows a broader and more systemic perspective, particularly by including cultural and social dimensions that are often underexplored in the CI field.

Second, it highlights several dimensions—Strategy, Structure, Operations, Systems, Technology, Worker Skills, Social, Culture, and Leadership —that align with the findings of both reviews. A critical observation, however, is that while the CI literature addresses these dimensions, it does so in isolation, without providing a holistic and integrated perspective. This fragmented approach stands

in contrast to the more comprehensive viewpoint advocated by established organizational change and management theories, which emphasize the interconnections among these elements.

Third, CI literature makes valuable contributions to the field of organizational change by introducing two essential dimensions: Innovation Management and Supply Chain Management. Innovation Management, as discussed by Davidson (2009), plays a pivotal role in driving continuous improvement initiatives, fostering adaptability, and ensuring long-term competitiveness. Additionally, Supply Chain Management, as highlighted by Costa et al. (2023), is crucial in shaping CI strategies. It influences efficiency, responsiveness, and overall organizational and building project performances, thereby extending the scope of traditional change management theories and demonstrating how CI intersects with broader organizational decisions and supply chain priorities.

A fourth critical insight emphasized by OT models is the interdependence between the soft and hard sides of change. The Socio-Technical Systems (STS) approach highlights the need to address both sides simultaneously to ensure a successful transformation. Neglecting either side or failing to recognize their interconnection can result in a flawed development process (Gallego & Calderón Hernández, 2021). However, CI literature has largely overlooked this relationship. As shown in Table 4.7, some CI studies do not support the interdependence of these dimensions, while most focus on only one side, limiting the overall understanding of their interaction in the CI context. Moreover, no CI studies explicitly cite the STS approach by name, revealing a gap in the literature.

Fifth, on the hard side of transformation, it should be noted that the often-seen "*Processes*" dimension throughout the models has been replaced with the *"Operations"* dimension. This replacement provides a better grasp of what changes are necessary for an organizational transformation in the CI effort. *"Operations"* refers to a change in how work is done through the design, operation, and improvement of productive systems that create and deliver value to the customer, in line with the definition given by Jacobs & Chase (2018) for Operations and Supply Chain Management.

Furthermore, the traditional overlap between Processes, Management Systems, and Technology in the literature has diminished. Management Systems are defined as the formal rules and structures established by organizations to ensure the coordination and control necessary for change (Cao et al., 2003). Technology, on the other hand, is often included in a limited number of models, typically focusing on automation or digitalization. From this distinction between the

dimensions, and taking a broader, author-centric perspective, no paper addresses all five hard-side dimensions simultaneously or explicitly within an OT model, as highlighted in Table 4.7.

On the soft side of transformation, the concept of *"People"* in the OT field is vast, with various definitions put forth by Scholars. However, these definitions often diverge and, at times, fail to capture the full impact of the human element in transformation processes. This study refines the definition of *"People"* proposed by Maes & Van Hootegem (2019)— "*refers to the actors in organizations, their abilities and weaknesses, and the behaviors they exhibit in interaction with each other"*—by breaking it down into two distinct dimensions: Work Skills and Behavioral.

This distinction is made to provide a clearer and more comprehensive understanding of their role in organizational transformation within the CI phenomenon. Particularly, there is a noticeable gap in research regarding the relational, behavioral, and psychological aspects of the CI field, as highlighted in Table 4.7. The OT field emphasizes the worker as a whole, thinking, feeling, and acting, as a crucial element in any transformation. Their predispositions, attitudes, engagement, and personality significantly shape the process (Ipinazar et al., 2021). Therefore, studying these dimensions in isolation is essential (Armenakis & Harris, 2009; Apostolopoulos et al., 2016).

Moreover, this distinction also enhances recent literature, which underscores the importance of the human side of transformation and its interconnections with Leadership and Culture—two dimensions that are central to the OT models reviewed. From an author-centric perspective, no existing paper fully integrates all four of these *"soft side"* dimensions into a cohesive OT model, nor has this been achieved in the CI field.

A last critical insight: Scholars (Teng et al., 1996; Jacobs et al., 2013; Gallego & Calderón Hernández, 2021) argue that there is no universal solution in the Content discussion. They emphasize the importance of understanding the specific context and purpose of implementation to effectively tailor the model. Consequently, attention shifts to the nature of CI. At the core of this discussion, the Author's earlier work (Costa et al., 2023) provides a foundation for reflecting on the ten principles of a CI strategy that must be fully and effectively met. The fundamental premise is that achieving CI is impossible without strict adherence to these principles.

However, a nuanced change is proposed in the list of Design Principles. A systematic literature review on organizational change and change management theories underscores the critical role of technology in today's landscape. In line with this, Costa et al. (2023) argue that automation should integrate both automation and digitalization as a design principle. Based on organizational change

theories, Scholars have drawn a distinction that is also reflected in this study. As a result, the design principle of automation is divided into two principles: industrial (automated) production and digitalization.

Industrial, automated production focuses on building systems for repetition, utilizing operational technologies to automate factory production processes. The objective is to transform traditional handicraft industries into highly efficient, automated systems. Digitalization refers to the digital advancements applied in building projects and processes within CI development. This design principle aims to enhance quality, efficiency, and traceability in both construction projects and production processes. This distinction also aligns with existing reviews that highlight CI's transformative potential for revolutionizing both production and digital processes in the industry.

4.2.4.3. Context of Change

The Context of change means that each organizational transformation is impacted by its context (under "*which*" conditions). Transformational changes, contrary to developmental and transitional types, are predominantly driven by environmental factors, as noted by Leifer (1989). These factors are closely linked to both the internal and external aspects of organizations, requiring an interdisciplinary and multi-level approach for effective study and practice (Jacobs et al., 2013).

According to OT models, two contextual levels must be considered: external environmental conditions and internal circumstances. In our literature review, five key external and internal environmental conditions were identified, as well as eight internal circumstances, highlighting their importance in understanding these changes.

The five external and internal environmental conditions are identified below and in Table 4.8:

1. Companies must be aware of their **General environment** (market forces, legislation, ethical positioning, uncertainty, client demand, and societal pressure);
2. Companies must be aware of their **Industry context**;
3. Companies must be aware of their **Company environment** (organizational innovativeness, company context, organizational readiness, and resilience);
4. Companies must be aware of their **Building Project context** (stakeholders, trends, pressures, and needs);

5. Companies must be aware of their **Workers' capability** to change.

Table 4.8: Environmental influencing conditions intersected in the two SLRs

Environmental conditions	Scope	Some references SLR1 (CI field)	Some references SLR2 (OT Models)
General Environment	Political, economic, social, technological, environmental, industry.	Ezcan & Goulding (2022)	Oakland & Tanner (2007); Bigdeli et al. (2017)
Industry	Regulation, ownership structure, overall risk, business environment competition, and customer requirements.	Ezcan & Goulding (2022); Costa et al. (2023)	Oakland & Tanner (2007); Bigdeli et al. (2017)
Company	Organization's life cycle, firm's size, organization's chart, internal tension for change, type of ownership, type of activity, human resource maturity, organization governance.	Ezcan & Goulding (2022); Costa et al. (2023)	Arazmjoo & Rahmanseresht (2020)
Building Project	Impact of the building project context and its entities on the adoption of the CI phenomenon.	Davidson (2006); Costa et al. (2023)	.
Individual	Internal resistance to change, experience with change, and level of trust.	Ezcan & Goulding (2022); Costa et al. (2023)	Alas (2004); Sikdar & Payyazhi (2014)

As shown in Table 4.8, both review findings highlight that the CI field and OT models emphasize the importance of the general environment, industry context, company environment, and worker as key factors influencing CI development as a transformational change. Each of these environmental factors plays a crucial role in determining how CI initiatives are adopted, developed, and sustained over time.

In the CI field, Ezcan & Goulding (2022) identify key external conditions influencing businesses, including the general environment, market forces, legislation, ethical positioning, uncertainty, client demand, and societal pressure. Within the company environment, factors such as organizational

innovativeness, company context, organizational readiness, professionalism, and resilience are highlighted by both Ezcan & Goulding (2022) and Costa et al. (2023) as crucial determinants of success.

Drawing attention to the social aspects of change, the individual/worker's role—viewed holistically—emerges from the studied OT models. Although both review findings reveal common themes, such as resistance to change, the influence of experience, and the level of trust in a phenomenon still relatively new to the construction industry, OT models offer a broader perspective on social factors. In the OT field, rather than being seen in isolation, the individual's role is embedded within a broader organizational and societal system that shapes change processes and, in turn, influences the development of the CI phenomenon.

Meanwhile, the focus on the building project and its impact on decisions regarding the adoption and development of a CI mindset and practices originates from the CI field. The impact of such projects extends beyond the immediate results, influencing long-term decisions about CI adoption and development across various industry sectors. Davidson (2006), for example, emphasizes the plurality of entities that the construction industry involves; entities that work and collaborate with each other at the temporary level of a building project.

Based on this discussion, while both fields address the importance of environmental conditions, OT models focus on the broader social dynamics and the role of workers in enabling or hindering change, the CI field places a greater emphasis on project-specific practices and its decision-making processes and pressures.

In addition, eight internal circumstances could be identified (Table 4.9):

1. Companies must ensure clear and objective **Communication** along the entire transformation effort, as well as along the whole supply chain, to effectively implement CI;
2. Companies must understand that CI implementation depends on effective, high-energy group efforts (**Teamwork**);
3. Companies must guarantee information sharing and continuous learning (**Knowledge Management**) in order to achieve a competitive advantage through more effective use of organizational knowledge;
4. Companies must ensure that their workers feel **motivated** in their jobs and tasks;
5. Companies must ensure **Employee Involvement** throughout the process;

6. Companies must ensure a unified, shared **Organizational Commitment**;
7. Companies must **connect their supply chain** throughout the CI process in order to create value in operations and customer service, as well as develop innovative solutions for more efficient industrial projects;
8. Organizations must strengthen **Collaboration and Coordination** among stakeholders across the supply chain to effectively implement CI.

Table 4.9: Internal influencing circumstances intersected in the two SLRs

Internal circumstances	**Some references SLR1 (CI field)**	**Some references SLR2 (OT Models)**
Communication	Ezcan & Goulding (2022); Costa et al. (2023)	Bigdeli et al. (2017); Gallego & Calderón Hernández (2021)
Teamwork	Davidson (2009); Costa et al. (2023)	Alas (2004, 2007); Sikdar & Payyazhi (2014)
Knowledge Management	Ezcan & Goulding (2022);	Latta (2009); Jacobs et al., 2013; Hussain et al. (2018)
Motivation	Ezcan & Goulding (2022)	Robertson et al. (1993); Burke & Litwin (1992); Alas (2004);
Employee involvement	Alazzaz & Whyte (2015)	Arazmjoo & Rahmanseresht (2020) Hussain et al. (2018)
Organizational Commitment	Ezcan & Goulding (2022)	Alas (2004); Gallego & Calderón Hernández (2021)
Supply Chain Integration	Davidson (2006); Ezcan & Goulding (2022); Costa et al. (2023)	
Collaboration and Cooperation	Costa et al. (2023)	

The findings from the reviews (Table 4.9) show that internal circumstances overlap in both organizational transformation and CI practices. These include Communication, Teamwork, Knowledge Management, Employee Involvement, and Organizational Commitment.

Among these, Communication, Teamwork, and Knowledge Management are particularly vital in facilitating the transformation process, ensuring employees collaborate effectively, share information, and align with organizational goals. In the OT field, Silva et al. (2020) identify a "*lack of clarity in communication"* as a major barrier to the OT process. Likewise, Lukas et al. (2007) argue that without strong partnerships and teamwork, improvement efforts fail to address root causes and sustain long-term change.

Employee Involvement and Organizational Commitment are equally essential in fostering engagement and ensuring that individuals actively support and contribute to the change process. According to OT models, Employee Involvement is one of the most effective strategies for overcoming resistance to change (Alas, 2004; Gallego & Calderón Hernández, 2021; Hussain et al., 2018). Resistance to change, lack of involvement, and weak commitment are fundamental challenges to the legitimacy of transformation efforts (Jacobs et al., 2013).

Motivation, while primarily emphasized in OT models, must be recognized as a critical influencer of change and CI development. These models stress the importance of cultivating an environment where employees feel motivated to adopt new practices and actively participate in CI initiatives. Kotter (2007) asserts that *"without motivation, people won't help, and the effort goes nowhere"*.

In the context of the CI field, the review findings emphasize that Supply Chain Integration, Collaboration, and Coordination across stakeholders play a crucial role in driving and influencing CI implementation. This perspective is often underexplored in the reviewed OT models, which tend to focus more on internal organizational dynamics rather than external factors like the supply chain.

CI research underscores that the active involvement of stakeholders, including suppliers, contractors, and customers, significantly impacts the success of improvement initiatives. Poor collaboration among project participants and the absence of collaborative work processes are key challenges related to project stakeholders' concerns (Davidson, 2006).

Moreover, the high fragmentation within the construction industry needs extensive external collaboration, involving diverse physical, intellectual, and cultural structures. This insight highlights a critical gap in traditional organizational theories, which often fail to account for the influence of modern industrial contexts, particularly in industries dependent on complex supply chains, on CI implementation.

An analysis of Tables 4.8 and 4.9 reveals that no existing OT model or CI studies effectively address all internal and external factors simultaneously. In addition, the literature on CI remains

fragmented, with most studies focusing on either internal or external factors in isolation rather than integrating them.

The convergence of these review findings underscores the need for a comprehensive approach to CI and organizational transformation—one that aligns both internal and external factors. According to Jacobs et al. (2013) and Sikdar & Payyazhi (2014), when these elements are effectively managed and harmonized, they can drive meaningful and sustainable improvements.

Additionally, OT models stress the interconnected nature of internal factors, emphasizing that a deep understanding of these elements is essential for effective organizational transformation. Sustainable change requires the active engagement of the people who will maintain it, fostering the right attitudes, behaviors, routines, habits, and emotional commitment to achieve desired goals. The increasing focus on the human aspect of change is a key consideration in this study.

4.2.5. The Organizational Transformation-oriented Model for the Construction Industrialization Development Process

Figure 4.3 depicts a conceptual model that describes how construction Managers should implement the Construction Industrialization phenomenon comprehensively according to Organizational Change and Change Management theories. It is derived from the findings discussion developed in the previous section.

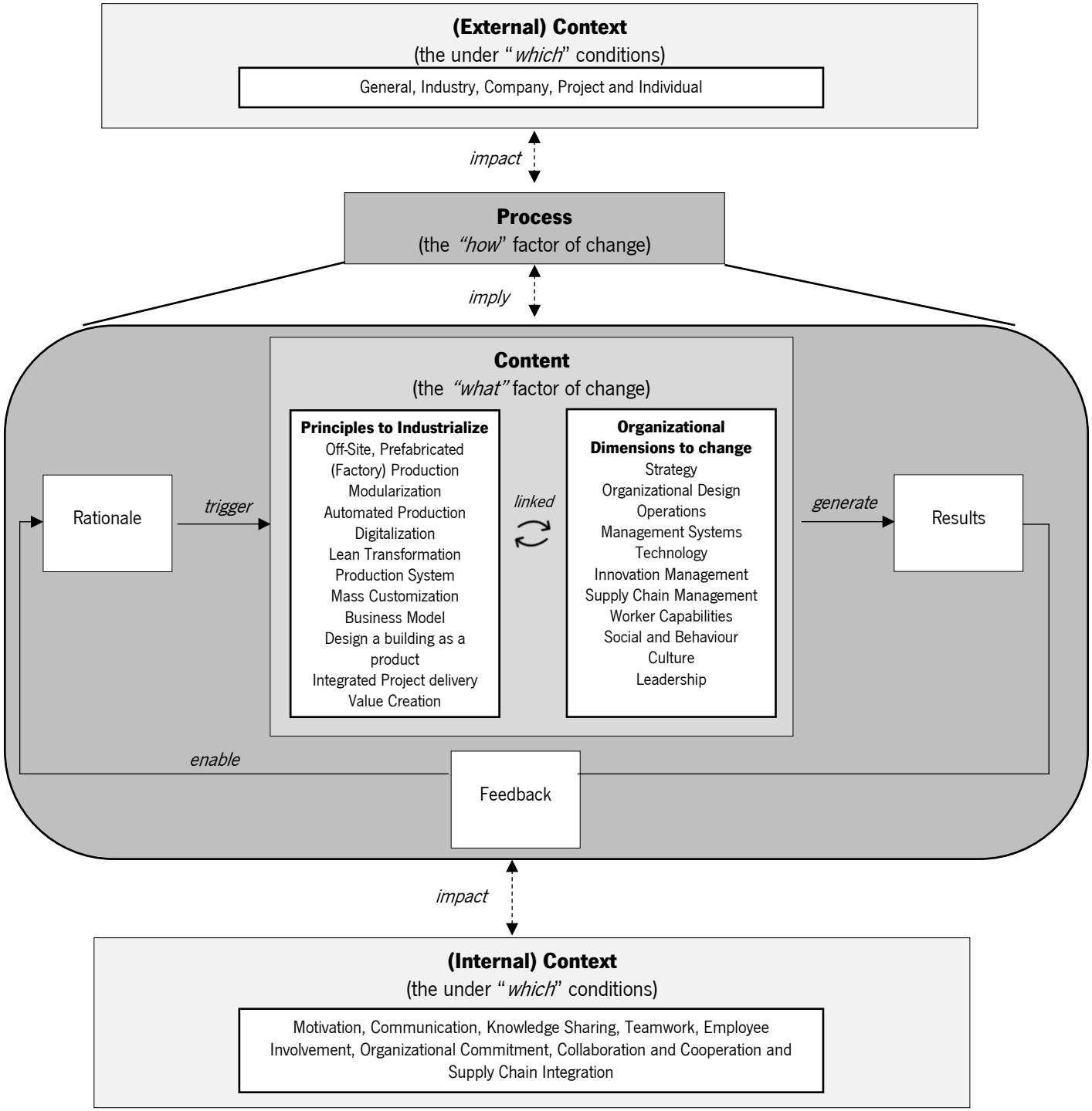


Figure 4.3: Organizational transformation-oriented model for the Construction Industrialization development

The transformation model suggests that a CI process relies on an integrated approach, addressing three core aspects: Process, Content, and Context. Seven building blocks are represented by *"boxes"* connected by *"arrows"* as suggested by Whetten (1989), with relationships labeled by various words such as *"impact"*, *"imply"*, *"trigger"*, *"linked"*, *"generate"*, *"affect"*, and *"enable"*.

The CI process development should start with a clear rationale. It is influenced by its context (Jacobs et al., 2013). Companies must anticipate trends and respond to internal pressures to sustain competitiveness. In the CI literature, Davidson (2009) emphasizes the need for manufactured construction to find a fit in the marketplace. Construction Managers must consider the broader impact of change, beyond individual projects.

The Content of Change outlines a clear strategy and essential changing practices for implementing change. Figure 4.3 depicts that Organizational Change and Change Management theories are not the sole solution for implementing CI. Instead, they provide support for the transformation journey, which is akin to an *"odyssey or voyage of discovery"* (Tosey & Robinson, 2002).

In Figure 4.3, the fields of CI and studied theories are actively intertwined ("*linked*") in a two-way relationship. All dimensions impact all principles, and vice versa, in a CI effort. At the same time, they are discriminating against each other. This relationship can represent a logical prediction: *a link between CI principles and change dimensions is positively associated with CI implementation*. Prediction is based upon the logical development of a theory and is usually the focal point of a theory's validity, according to Wacker (2004). The theoretical extension approach was essential to the concept's consolidation and growth.

In short, CI requires a new approach to management and production. Leaders must align transformation priorities with the overall vision and plan for future actions (Burke & Litwin, 1992; Lukas et al., 2007). The CI strategy should be based on *"what is expected"* (Burke & Litwin, 1992; Kotter, 2007; Maes & Van Hootegem, 2019; Imran et al., 2021), involving operational changes, innovative management systems, technology improvements, innovation, and prioritizing supply chain management. Ten design principles underlie all the efforts to industrialize the Construction Industry, as suggested by Costa et al. (2023). Without them, Industrialization as a broad and complete concept cannot be undertaken.

This paper emphasizes the importance of construction Managers considering both the soft and hard sides of change for successful transformation. It highlights the importance of Practitioners' skills, behaviors, and attitudes in developing comprehensive CI strategies. It is widely acknowledged

that the whole worker, who thinks and feels, plays a crucial role in any transformation (Ipinazar et al., 2021). Workers' predispositions, attitudes, and engagement are important factors. Therefore, improving skills, changing mindsets, and altering established ways of working, often seen as unchangeable, pose significant challenges. Moreover, having leaders capable of envisioning this transformation and making it happen in an industry dubbed as resistant to change is a decisive factor.

The Context surrounds all change efforts (Figure 4.3) and comprises two levels: external conditions and internal circumstances, as discussed in the previous section. Jacobs et al. (2013) also proposed in their model that context *"explicitly relates to both the inside and the outside world of organizations, which makes the case for an interdisciplinary and multi-level approach to the study (and practice)"*.

Organizations can anticipate trends and opportunities and be proactive by developing an analysis of the external context (Alas, 2007). However, in some cases, they may need to respond reactively to market pressures in order to maintain their competitiveness, as highlighted by the Center for Organizational Design. Internal organizational strengths and weaknesses can also drive change, as noted by Jacobs et al. (2013). Additionally, research suggests that industrialization depends on the alignment of stakeholders and their supply chains (Davidson, 2009). This can be achieved through strategies such as securing and promoting modular projects, optimizing production processes, and driving new solutions to address the challenges of change.

To get ahead of the competition, companies must foster collaboration. In balancing proactivity, reactivity, and collaboration, companies must strategically position themselves. As Davidson (2009) suggests within the CI literature, "*manufactured construction has to "beat", or at least to find a fit with the marketplace*".

This study emphasizes that for success, companies must integrate their supply chains, enhance collaboration and coordination among stakeholders, ensure clear communication, foster teamwork, encourage information sharing, motivate workers, involve them in the process, and cultivate a shared commitment to transformation across the organization (Alas, 2004; Lukas et al., 2007; Imran et al., 2021; Costa et al., 2023).

By integrating OT models and drawing insights from CI literature, the study highlights the critical role of both external and internal factors in supporting the implementation of the CI phenomenon.

These factors serve as cornerstones for the transformation process, influencing and shaping all change efforts.

The CI Process *"generates"* results, which can be tangible and intangible. Borrowing from the OT theory, CI must be well-established as a radical, fundamental, and large-scale system-wide change that affects everything from values to routines to the way in which business occurs. The CI phenomenon offers a new mindset and approach to construction, resulting in outcomes that are more comprehensive and varied, often having a far-reaching impact compared to the typical focus on operational issues.

The driving forces behind CI usually include objectives such as improving productivity, enhancing sustainability, and optimizing construction project performance. In contrast, OT emphasizes organizational performance, human development, and social impact. Consequently, the adoption of CI leads to positive effects across these six results, though, in line with OT theory, these outcomes are also influenced by the broader context in which CI is implemented.

The final phase is Feedback, which follows the transformation effort and ensures the dynamism and iterative nature inherent in a transformation model. This, in turn, *"enables"* a new rationale for change, and the cycle repeats.

4.2.6. Implications for Theory and Practice

The present study offers interesting implications for theory and practice.

Implications in terms of phenomenon clarity. This study emphasizes the importance of recognizing it as a broad, multi-level, and multidisciplinary concept (definition); and where its implementation should be perceived as a complex and intense journey, rather than a finished product (development process). Findings reveal that none of the CI papers distinctly define the type of change, be it development, transition, or transformational. The CI literature needs a more comprehensive exploration of the depth, scope, and perceived change over time to truly develop.

Implications in terms of CI process significance. This study emphasizes the importance of developing comprehensive models to assist construction Managers in the CI development process. Since 2019, Scholars (Luo et al., 2020) have acknowledged the unclear and poorly structured CI transition process. While this study frames the CI transition as a process, further theoretical developments and empirical validation are required.

Implications in terms of the CI process. The analysis of Process, Content, and Context is crucial for guiding CI efforts. CI literature has been limited in addressing these core aspects. Scholars and Practitioners should plan and develop a comprehensive and large-scale change that impacts everything from values to routines, and how business occurs and creates value (Maes & Van Hootegem, 2019; Gallego & Calderón Hernández, 2021). This understanding is essential for developing a conceptual model and further empirical study.

Implications in terms of the soft and hard sides of change. This paper emphasizes the importance of considering the soft side of change alongside the hard side in the CI process. As noted above, studies linking change theories and CI topics diverged between soft and hard sides, and there are few the ones that considered both sides. To the best of the Authors' knowledge, there is no similar study in the literature that brings such a topic to discussion. So, CI is much more than its hard changes.

Implications in terms of theory elaboration. This study identifies a set of dimensions perceived as robust categories to effectively capture the phenomenon's essence. This represents the first attempt in the literature to present such a model, offering a comprehensive theoretical view and laying the foundation for further enriching knowledge in future studies.

Implications in terms of practical clarity. This paper emphasizes that Managers should be aware that CI transforms the construction industry, its companies, supply chains, and the workforce. Expanding the scope provides Managers with a deeper understanding of the global scale of the changes that CI entails, encompassing deeply rooted practices, decisions, and routines within businesses and society that need transformation. This expanded understanding also presents new research opportunities.

4.2.7. Conclusion

CI has garnered attention from theory and practice. This paper introduces a transformation model to conceptualize CI from the perspective of Organizational Change and Change Management theories. Two systematic literature reviews were conducted. An intersection between the two fields was developed.

The focus on operational and technological elements in CI literature has led to the neglect of the soft side of change, crucial for transformative processes. This paper provides valuable

contributions. It provides a greater understanding of CI and offers a comprehensive review of the academic literature on planning and managing a transitional process. It stands as a pioneering paper that systematically introduces a comprehensive change planning approach rooted in robust organizational change and change management theories. Lastly, this paper also presents a conceptual model with the potential for theoretical and empirical advancements.

Further research is needed to maximize the use of the transformation model in strategic planning and decision-making. Further research is also needed to incorporate real-world context and expert knowledge for practical application and validation. Additionally, exploring the social dimension and examining outcomes at the human and social levels is essential. Understanding the impact of the CI phenomenon and its potential to address societal problems could drive growth in this topic.

As with any research, there are some limitations. The first SLR uncovered a limited number of papers, indicating an underdeveloped connection between change management theory and Construction Industrialization. In most of these papers, the application of such theories is suggested as a direction for future research rather than being substantively integrated. While we recognize the academic interest in exploring this intersection, we found that these studies require further development to establish a stronger theoretical foundation. Consequently, they were excluded from the final sample analyzed in this paper. Another constraint was the decision to filter the research on SLR 2, focusing solely on papers addressing large-scale transformational change. However, the foundations have been laid out in this paper, and new avenues of research are expected to follow.

Chapter 5

Multiple Case Study

This fifth Chapter reports the multi-case study findings. It was designed to explore the intersection between academic and practical perspectives on the CI phenomenon. Based on such an intersection, the theory developed in Chapter 4 is elaborated, and a greater understanding of the CI concept and its development process is provided. Two sections are developed. The first section addresses the conceptualization of CI, presenting essential guidelines for understanding this complex phenomenon. The second section explores the CI development process, thereby enhancing the understanding established in the previous subsection. The findings of both sections are closely interconnected, reinforcing their importance. A detailed list of unique findings from the empirical study, along with a thorough definition of CI and an exploration of the CI process, effectively links theory to practice. Each section provides further details on the methodology used in collecting and analyzing the data. Furthermore, each section ends with the main implications for both theory and practice.

5.1. Conceptualizing the Phenomenon of Construction Industrialization: Linking Theory and Practice Through a Cross-Sector Case Study

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ABSTRACT

This study examines the intersection between Practitioner and Academic perspectives on the Construction Industrialization (CI) phenomenon. The goal was to understand the prevailing perspectives of how CI is perceived, how it is performed, and what benefits it is expected to offer. The study begins with a literature review, followed by an exploratory multiple case study encompassing the Architecture, Engineering, Traditional Construction, and Manufactured Construction sectors. Within-case and cross-case analyses were performed, leading to ten new insights that elaborate on the theoretical understanding of the phenomenon. An important conclusion is the criticism of the interchangeable terms of Off-site Production, Modular Construction, or Prefabricated Construction as being insufficient to conceptualize CI across the four sectors. This paper proposes a more comprehensive conceptualization that challenges current definitions. It distinguishes between the Constructive System and the Productive System; it redirects the CI theory toward a constant process of technical and sociocultural change; and it emphasizes the importance of societal sustainable development beyond productivity. This paper represents the first attempt to conceptualize the CI phenomenon, bridging the theory-practice gap. It seeks to stimulate further research and create new debates about the phenomenon.

Keywords: Construction Industrialization; Conceptualization; Case Study; Construction Industry; Modular Construction; Cross-case Analysis; Definition.

5.1.1. Introduction

Construction Industrialization (CI) has become the most significant paradigm in the construction sector since it *"leverages significant gains such as improved productivity, speed, cost, and quality"* (Wuni & Shen, 2020).

Undoubtedly, the increasing importance of the CI phenomenon is shared by practice and theory. An evolution has been observed, both via real-world experimentation with the phenomenon and through academic research and theory building (Hu et al., 2019; Wuni & Shen, 2019b; Brissi et al., 2021).

Despite such evolution, academic research has long warned of the bias caused by vague and fragmented descriptions of CI, leading to both the advancement of the theory and its practical adoption being consistently hampered (Liu et al., 2019).

A previous contribution by Costa et al. (2023) was one of the first attempts to provide a comprehensive definition for the phenomenon of Construction Industrialization. Such a contribution was developed based on a systematic literature review that returned 112 journal papers from 2010 to 2021. In that article, CI is defined as:

> *"a new form of production and management, driven by the adoption of several individual (but interrelated) construction, industrial engineering, and management innovations whose objective is to improve the productivity and the sustainable development in the construction industry"*.

To date, this is the most comprehensive conceptualization found in the literature on CI, albeit primarily conceptual. To the best of the Scholars' knowledge, no study has followed up on this contribution. In this regard, the lack of a comprehensive and encompassing conceptualization that intersects theory and practice is noted.

The study conducted by Lessing et al. (2015) appears to be the sole endeavor to conduct a case study aimed at gaining a better understanding of the phenomenon. Its specific focus is on construction companies in Sweden and the use of the term *"Industrialized Housing System"* in the Swedish context. Nonetheless, there seems to be a dearth of studies that approach the CI phenomenon from a cross-sectoral standpoint and encompass a geographical spectrum.

This lack results in Scholars interpreting the phenomenon according to their perspectives and shaping their research accordingly. As a result, Hu et al. (2019) acknowledged the theoretical

ambiguity surrounding the phenomenon, while Nabi & El-adaway (2020) stated that despite the evolution in the research on CI, it is still a messy and ambiguous issue with incomplete meanings and under-researched complexities. In 2020, Luo et al. (2020) emphasized the lack of consensus on the definition of CI.

According to Whetten (1989), empirical evidence is a fundamental input for theorizing. In practice, Practitioners have earnestly considered this phenomenon, putting their theories and research into practice, thus gaining valuable insights and experiences. According to Ketokivi & Choi (2014), the academic community must capitalize on the existing endeavors to further develop and refine the understanding of a phenomenon, thereby informing and inspiring future research. Stock & Boyer (2009) argued that only when Practitioners' experiences and perspectives are integrated into the body of research can a discipline consider what a specific phenomenon is and what it is not.

In this sense, this research tackles one of the gaps in existing research into the phenomenon of CI: the lack of a unifying conceptualization that intersects Practitioner and Academic perspectives about the CI phenomenon. The goal is to integrate various perspectives on CI and assess how well the proposed definitions in the existing literature translate theory into practice.

From the foregoing, two research questions[13] were raised as follows:

RQ1: How has the Construction Industrialization phenomenon been perceived in practice?

RQ2: How can the phenomenon of Construction Industrialization be conceptualized in order to fill the current gaps in the literature and advance its understanding by linking theory and practice?

This paper contributes to the theory and practice with a much more comprehensive understanding of the phenomenon of CI. A comprehensive conceptualization that bridges theory and practice aims to convey the fundamental character of the CI phenomenon, delineate its boundaries and critical issues, and apply it in practice. The goal is to eliminate any perceived ambiguity or misunderstanding within the academic discourse. Moreover, by integrating practical experience, the paper seeks to assist academics in gaining a deeper understanding of real-world implications, thus yielding enhanced conclusions for their studies. Anticipated changes in the literature's focus

[13] RQ1 in this paper corresponds to RQ3 formulated in Chapter 1 and RQ2 in this paper aligns with RQ4 in Chapter 1.

and scope are expected to yield novel perspectives that will enrich both theory and practice. Ultimately, the paper aims to align Scholars and Practitioners, thereby facilitating ongoing discussions and the advancement of CI theory.

To carry out the study, this research begins with a review of previous research aimed at conceptualizing CI. This review serves as a foundation for presenting preceding conceptualizations and provides a platform for empirical research, enabling a comparison between prevailing academic discourse and practical perspectives.

CI conceptualization is centered on three major questions: how CI is perceived (interpretation), how it is performed (key constituents), and what gains (benefits) it is expected to offer. These questions are consistent with the definition established by Costa et al. (2023). To the best of the Scholars' knowledge, no study has been carried out to date that includes these three questions. Three questions, however, according to Wacker (2004), are to be asked related to theoretical maturity. The ultimate goal is to enhance the clarity of the concept by establishing an integrated conceptualization that addresses these important questions for theory elaboration.

In order to cross Practitioners and Academic perspectives, an international, cross-sector multiple case study is conducted. This case study aims to empirically explore the perspectives of Practitioners from the Architecture, Engineering, Traditional Construction, and Manufactured Construction sectors on the phenomenon of Construction Industrialization. The selected sample is drawn from a major Governmental Funding Agenda in Portugal that endeavors to promote the adoption of CI.

The paper is organized as follows. Section 5.1.2 presents a review of existing research as a theoretical foundation for the present research. Section 5.1.3 describes the research methodology. Subsequently, Section 5.1.4 discusses empirical findings. Section 5.1.5 intersects Practitioner and Academic perspectives on the phenomenon of Construction Industrialization. Section 5.1.6 ends the paper, and a conclusion is drawn.

5.1.2. Background

A literature search was conducted for papers focused on studying the conceptualization of the Construction Industrialization phenomenon. Three levels of keywords were defined (Table 5.1), and

a search was conducted on the Scopus database using *"title, keywords, and abstract"* as search parameters, yielding a total of 66 journal papers.

Table 5.1: Keywords used in the literature search

Level	Keywords
CI-related keywords[14]	"*Manufactured Construction*"; *"Off-Site Construction*"; "*Offsite Construction*"; "*Prefabricated Construction*"; "*Construction Industrialization*"; "*Construction Industrialization*"; "*Industrialized Construction*"; "*Industrialised Construction*"; "*Modular Construction*"; "*Industrialized Building System*"; "*Industrialised Building System*"; "*Industrialization*"; "*Industrialisation*"
Conceptualization related keywords	"*Conceptual **"; "*Definition*"
Industry-related keywords	"*Construction Industry*"; "*Building Industry*"; "*House-Buidling*"

Note: An asterisk at the end of the search keyword was used as indicated to cover a broader range of results.

A preliminary screening process, involving a thorough review of the title and abstract of each paper, was employed to assess their focus on reviewing the CI conceptualization. Only four papers met the criteria of conceptualizing CI, resulting in a drastic reduction. Table 5.2 presents the varying definitions of CI in an effort to synthesize them. The remaining papers delved into specific aspects of the phenomenon, such as total cost of ownership, design for manufacturing and assembly, drivers, challenges, key risks, stakeholder perspectives, uncertainties, collaborative work, and digitalization. Papers addressing these specific aspects were not included in the present review.

[14]The set of CI-related keywords and industry-related keywords are the same as those used in Chapter 4, Section 4.2.

Table 5.2: List of previous definitions gathered from previous works that focused on providing a conceptualization of the CI

Paper Reference	Paper Contribution	Definition provided	Research Design presented
Taylor (2010)	Develop a historical development and growth of the Off-site Construction (OSC) sector in the UK	*"the various constituent technologies and manufacturing processes"*	Academic journals and specialist industry publications, financial reports, and supplier and manufacturer databases
Lessing et al. (2015)	Describe the development of Industrialized House-Building (IHB) to increase the understanding of the field	*"a strategically different process- and product-oriented alternative to traditional project-oriented house-building methods and principles"*	Extensive literature study, followed by a case study with three Swedish companies
Ayinla et al. (2019)	Develop a more inclusive working definition and a formalized classification system for Off-Site Construction to enable a common basis of evaluation and communication	*"OSC is defined as based on three high-level concepts: the product, the process, and the on-site/off-site workforce organization."*	Extensive literature study
Costa et al. (2023)	Develop a conceptual definition of the phenomenon of Construction Industrialization based on the review findings	*" (...) new form of production and management, driven by the adoption of several individual (but interrelated) construction, industrial engineering, management innovations whose objective is to improve the productivity and the sustainable development in the construction industry"*	Systematic Literature Review

Different boundaries are presented in each definition presented in Table 5.2: Taylor (2010) and Ayinla et al. (2019) offer an operational perspective; Lessing et al. (2015) introduce a strategic element to CI development; and lastly, Costa et al. (2023) define the CI phenomenon broadly from an industry perspective.

Moreover, the CI concept is also built from different changes: while Taylor's (2010) definition is limited to a process change, Lessing et al. (2015) and Ayinla et al. (2019) include both product and process changes. In line with the definitions presented in Table 5.2, CI has traditionally been perceived as an alternative to conventional construction, wherein modular components (product change) are prefabricated in a factory setting (process change) and then transported to the construction site for assembly.

Scholars (see e.g. Hosseini et al., 2018) have suggested that the segmentation of CI into these *"thematic silos"* (product and process changes) has been blamed for fragmentation in the CI literature, and this compounds the problems associated with defining and conceptualizing it. Costa et al. (2023) emphasize that Construction Industrialization encompasses more than just changes in construction industry products and processes, and stress the importance of clarification. Other academics (see e.g., Nabi & El-adaway, 2020, and Hussein et al., 2021) have also claimed this clarification.

Scholars have also acknowledged that the limited perspective provided by certain conceptualizations is insufficient to fully understand the complex and multi-faceted nature of today's academic and practical experiences (see e.g., Peltokorpi et al., 2018, and Liu et al., 2019). Consequently, the conceptualizations proposed by Taylor (2010), Lessing et al. (2015), and Ayinla et al. (2019) are deemed incomplete.

In addition, the Authors of this paper believe that the phenomenon of CI has been frequently neglected due to the use of other terms, which makes it difficult to have an objective and clear conceptualization of what this phenomenon is, how it is performed, and for what gains - the three questions on which the Practitioners' perspectives will be collected.

As previously stated, Costa et al. (2023) was the first paper to define the phenomenon of CI, rather than its terms, and it was concerned with providing a definition that was holistic and comprehensive, in order to understand. However, Costa et al.'s (2023) study has failed to include the perspective of those actively engaged in the field. The only study to have undertaken a case study is the one developed by Lessing et al. (2015), which specifically observed manufactured

construction companies located in the Swedish geographical context. Other sectors, such as Architecture, Engineering, and Traditional Construction, for instance, were not included.

It is also missing from the literature an international and cross-case study. Lessing et al. (2015) were exclusively in the Swedish context. This paper aims to explore the perspectives of Practitioners from Spain, England, and Portugal. Previous conceptualizations (Table 5.2) are therefore incomplete in considering both intersectoral diversity and geographical heterogeneity. This paper brings these two points to the literature in the sense of a unifying conceptualization of the CI phenomenon.

5.1.3. Methodology

This section initially describes the empirical basis for exploring the phenomenon of Construction Industrialization from Practitioners' perspectives. Then, details of the research design, case selection, and methods of data collection, as well as data analysis, are presented.

5.1.3.1. Empirical basis

Defining refers to the act of establishing the exact meaning of a specific phenomenon. The absence of maturity leads to misunderstanding and divergence in the interpretation of the concept as stated by Stock & Boyer (2009), and as being acknowledged in the CI field.

In the empirical study, many conceptualizations may emerge. These conceptualizations may be subject to many perspectives and understandings, which may either coincide or diverge from one another. The absence of a globally recognized definition of Construction Industrialization also contributes to this potential plurality.

Therefore, as stated in the Introduction, Section 5.1.1, the conceptualization of the CI phenomenon will be traced concerning three questions, namely: how CI is perceived (interpretation), how it is performed (key constituents), and what gains (benefits) it is expected to offer, in line with the study developed by Costa et al. (2023).

These are the empirical bases that serve as the foundation for the empirical study. The empirical findings will be organized using these three questions. The purpose of such an organization is to accurately capture the depth and comprehensiveness of each of them, in a way that effectively

conceptualizes the phenomenon under study from a practical point of view and then intersects them with academic discourse. These three questions strive to provide answers to the fundamental theoretical questions of what, how, and why.

5.1.3.2. Research Design

Given the exploratory nature of the first research question ("*How has the Industrialization of Construction phenomenon been perceived in practice?*[15]"), the present study applies a case study approach.

Following Yin (2012), a holistic multiple case study research design was selected. The study encompassed four sectors (cases) - Architecture, Engineering, Traditional Construction, and Manufactured Construction - to explore the perspectives of Practitioners on the CI phenomenon (unit of analysis). A cross-sectoral multiple case study with geographic diversity was thus developed.

The selection of the holistic research design over an embedded research design was based on its potential to offer a comprehensive understanding of the various elements that contribute to the phenomenon, given its complexity.

The use of multiple cases, rather than a single case, was also chosen because it offers rich interpretative information, allowing for comparisons across cases that a single case cannot achieve. Different sectors in the construction industry are affected by the phenomenon and account for their influence on its implementation. Given that each sector may harbor its distinct interpretation of the phenomenon, a thorough conceptualization necessitates a consolidated perspective from each sector to yield an all-encompassing portrayal of the industry with its diverse interpretations.

Replications and differences across cases will appear in this regard. Understanding which are the differences across cases and how these differences can be merged into a single understanding represents another major goal of this study. These comparisons allow a more accurate reflection of empirical realities and their intersection with literature.

The four cases and the sample of Practitioners that compose the cases were purposefully selected (McCutcheon & Meredith, 1993; Eisenhardt & Graebner, 2007). These are the reasons. The

[15] Related to the RQ3 of this thesis (Chapter 1)

sample used in this study comprises four sectors engaged in a Governmental Funding Agenda to transform the construction industry in Portugal toward Construction Industrialization.

This context is well-suited for researching such a complex phenomenon in its real-life context, with real work teams, aligning with the perspectives of Edmondson & Mcmanus (2007) and Yin (2012). In addition, the sample companies present a geographical diversity; the Practitioners selected had prior experience in modular construction and belonged to the board responsible for defining and leading the CI development in Portugal.

Table 5.3 presents a description of the Practitioner's profile. Seventeen Practitioners with different backgrounds, hierarchical levels (in their companies), and levels of decision-making (on CI strategy) compose the sample of the empirical study. Overall, the traditional construction experience of the selected Practitioners ranged from less than 2 years to more than 20 years. Engineering case Practitioners are those with more experience in manufactured construction.

Table 5.3: Sample Characterization

Sector (Case)	Company		Practitioners Description					Code
	Nº	Country	Background	Hierarchical Level (in their company)	Years of experience in traditional construction	Years of experience in modular construction	Degree of responsibility in the Funding Agenda	
Architecture	1	Spain	A	Medium level	11-15	3-5	Member of Team	A1
			A	Medium level	6-10	3-5	Member of Team	A2
Engineering	2	United Kingdom	CE	Executive	>20	6-10	Decision-maker	E1
	3	Portugal	CE	CEO	11-15	6-10	Member of Team	E2
Traditional Construction	4	Portugal	CE	Executive	16-19	3-5	Decision-maker	TC1
			CE	Medium level	11-15	<2	Member of Team	TC2
			CE	Executive	11-15	<2	Support	TC3
Manufactured Construction	5	Portugal	CE	Medium level	16-19	3-5	Member of Team	MC1
			PE	Medium level	6-10	3-5	Member of Team	MC2
			IEM	Medium level	<2	<2	Member of Team	MC3
			CE	Medium level	6-10	3-5	Responsible	MC4
			A	Medium level	16-19	3-5	Responsible	MC5
			A	Executive	>20	3-5	Decision-maker	MC6
			CV	Executive	>20	3-5	Decision-maker	MC7
			U	Medium level	>20	<2	Responsible	MC8
			ME	Executive	16-19	3-5	Decision-maker	MC9
			IEM	Medium level	6-10	<2	Support	MC10

5.1.3.3. Data Collection

Data collection was carried out over two years. Four data sources (interviews, meetings, reports, and site visits) were used. Following the guidelines of Voss et al. (2002), semi-structured online or face-to-face interviews were conducted with the seventeen Practitioners (Table 5.3).

Three Practitioners were independently interviewed as part of a pilot study to validate an interview protocol and test the understandability and duration of the interviews (Saunders et al., 2008). These Practitioners were selected based on their role in their company's industrialization process, and their backgrounds included Civil Engineering, Mechanical Engineering, and Industrial Engineering and Management.

The interview protocol was sent via email to all Practitioners, both in the pilot test and in the final interviews. The protocol encompassed questions related to (i) general information about the company and the interviewee, and (ii) details about their perspectives on the CI definition when they approach the topic. All interviews were transcribed verbatim.

To enhance the validity of the research, the Scholars relied on secondary sources of data. In total, the Scholars served as observers in thirty meetings, had access to ten reports, and conducted five site visits to a manufacturing facility that produces prefabricated bathrooms using Manufactured Construction. For two years, the Scholars closely followed the Funding Agenda's progress.

The use of secondary sources of data was extremely important as it enabled the Scholars to access, assist, and observe discussions, debates, and reports that enriched the conceptualization of the CI phenomenon.

5.1.3.4. Data Analysis

The data collected was coded and grouped by each major theme, in line with the previous discussion. This was performed via an iterative process with both the interview transcripts and secondary data independently. Subsequently, a within-case analysis and a cross-case analysis were conducted sequentially. The analytical generalization is achieved using the subset of published definitions presented in Table 5.2, through their comparison with the findings of the empirical study. According to Eisenhardt (1989), Scholars must constantly compare theory and data. In this exercise, Scholars can take advantage of the new insights possible from the data and yield an empirically validated theory.

5.1.4. Findings

This Section discusses the similarities and differences across the sectors and their intersection with the previous definitions (Table 5.2). This Section is organized around three major questions: how CI is perceived (interpretation), how it is performed (key constituents), and what gains (benefits) it is expected to offer.

5.1.4.1. Interpretation

Practitioners' interpretation of CI is the initial analysis. Two specific aspects were created to explore this understanding. Firstly, throughout the interviews, an open question was developed on the aspect of *"what CI is".* Secondly, the interviews delved into a more detailed exploration of the synonyms used by Practitioners to interpret the phenomenon.

Findings reveal that the four sectors hold comparable terminology and similar patterns of thinking about *"what CI is"*. Practitioners at the first instance describe CI as encompassing a shift in production, *"typically on-site, to (or part of) off-site and in which, part, or a whole building, is produced in a controlled environment, and with repetitive and automated processes"*.

This depiction of CI has been a longstanding emphasis in both theoretical discourse and, as expected by this study, in practical application. *"These [product and process changes] are the most visible changes in the way we work and build",* according to the Practitioners. As such, literature and practice are indisputably aligned in this interpretation. Distinctly, Practitioners also argue that CI goes beyond this initial interpretation, as evidenced by the discussion surrounding synonyms.

The interpretation of the phenomenon is enhanced when the exercise requires the ability to synthesize. This is because the terms Off-Site Construction, Modular Construction, and Prefabricated Construction were expected to be shared interchangeably as synonyms to interpret the phenomenon; however, this assumption was proved inaccurate. It was observed that Practitioners refrain from explicitly employing any of these terms to encapsulate the CI phenomenon[16].

Practitioners critique this limited perspective, asserting that using certain terminologies is inadequate, given the intricacy and complexity that Construction Industrialization introduces to the

[16] A summary table of the synonyms provided by each practitioner is presented in Appendix I.

field of building. This conclusion was drawn from a comprehensive analysis of the interviews, secondary data, observed meetings, and site visits. Consequently, Practitioners in all the sectors covered in the sample consider these terms as a component of a phenomenon. As one Practitioner stressed:

> *"Prefabricated construction is rarely sufficient to define or explain the transformation that this paradigm implies."* (Extracted from the interview with Practitioner TC3)

Another Practitioner also said:

> *"Moving to a controlled environment, per se, does not define Industrialization"* (Extracted from the interview with Practitioner MC7)

The empirical finding supports the findings provided by Hosseini et al. (2018), which suggests that defining CI considering only the lens of product- and process-changes is insufficient.

Analyzing the forthcoming discussion about the CI interpretation and juxtaposing the established theory with empirical findings yields four contributions to CI theory.

First, the interviews and secondary sources across all four sectors discuss the notion of a *"system"* and delineate the *"constructive system" from* the *"productive system"*. The *"constructive system"* denotes the design scheme, whereas the *"productive system"* pertains to the productive aspect. For the Practitioner MC7, this distinction *"makes perfect sense"* as it elucidates the subject of discussion, be it design or production related. Moreover, in the Funding Agenda, there are teams for the design and teams for the production schemes. This understanding, in turn, differs from the literature. The literature frequently conflates these two systems by not establishing a differentiation between them. For instance, there is a tendency to use the terms *"Industrialized Building System"* (design-related) and "*Off-site construction*" interchangeably (Table 5.2). The interchangeable use of similar terms has posed challenges to the development of theory on this topic. Furthermore, the absence of practical input in academia has precluded the establishment of such a distinction. Although these two systems are interconnected in the CI adoption, they encounter distinct challenges and are overseen by Practitioners with varying backgrounds and experiences.

Second, intersecting the previous definitions (Table 5.2) with the most comprehensive interpretation from Practitioner MC7, the word "*knowledge"* also stands out. The acquisition of diverse and new knowledge is a recurring focal topic discussed at meetings observed. Moreover, integrating knowledge about Practitioners involved in design, thinking, production, and

management is acknowledged to be a challenging task. Practitioner A2 underscored the notion that *"the design of an industrialized building differs from that of a conventional building. Until the construction industry realizes this, the success of Industrialization will remain compromised"*. In a related vein, Practitioner TC2 articulated that *"Industrialization is only achieved if the projects have already been conceived to be designed and built industrially"*. Hence, CI means a shift in how buildings are conceived and produced, which in turn requires the development and acquisition of novel knowledge. Moreover, such new knowledge of design and production is intricately linked to the decisions made regarding constructive and productive systems.

Third, synonyms that also stand out are *"product systematization"*, which is related to the aim of repetition of the process and the product, to be replicated in future projects. The word *"systematization"* did not emerge in the literature review conducted by Costa et al. (2023). In a business environment, it is commonly used. It is the vocabulary of the Practitioners involved in the Construction Industrialization development process.

Fourth, the debate about *"integration"* also arises from Practitioners' perspectives, who shared that Industrialization requires a close integration between thought and activity, where an architect thinks about modular design, the project then works on it, and the building materializes.

> *"Designers (architects and engineers) have to think about projects from the moment "0" based on assumptions of systems integration, spatial metrics, and sizing adapted to the transportation of construction solutions."* (Extracted from an interview with Practitioner MC5)

In this regard, empirical findings reveal a notable emphasis on the integration of the various teams in industrial project development, leading to discussions at both the design and production levels. *"Contrary to traditional construction, the design strives to be simultaneously repeatable, modular, adaptable, and flexible – the industrial mindset"* (Practitioner E2). At the same time, to achieve such a design scheme, *"the stakeholders must manage their operational choices, coupled with the refinement of interconnected structural, spatial, architectural, and installation considerations"* (Practitioner MC5). However, the existing literature has largely overlooked the supply chain perspective in the conceptualization of CI. Costa et al. (2023) show its significance, emphasizing the necessity for a more comprehensive understanding that CI transcends individual company boundaries and encompasses the entire chain.

5.1.4.2. Key Constituents

This section presents the analysis regarding CI development (how it is performed). To address this analysis, Practitioners were asked to *"indicate what requirements they consider necessary to say that there is a process of Industrialization of Construction in place."*.

Practitioner perspectives aligned with constructive, industrial engineering, and management dimensions in line with Costa et al. (2023). The transition of production to an industrial environment is widely regarded as a prominent component of CI development. All sectors emphasize the necessity for a fundamental revamp of the operational framework when shifting towards off-site production and adopting CI.

Empirical findings stress the importance of this reconfiguration to ensure that resources are used to achieve the best outcomes possible through the use of new equipment, production lines, automated tools, processes, and industrial paradigms and philosophies. It is noteworthy that all sectors characterize CI as an off-site, automated, repetitive, and modular construction, which means a process of technical, engineering, and constructive innovations. While the literature has been unclear and shallow about what CI means for productive transformation, many Practitioners refer to this shift as CI.

The empirical findings further shed light on two additional significant contributions to CI theory.

First, the practical perspective stresses that CI is regarded as a new process that extends into the production mindset, and Supply Chain Management plays a crucial role in coordinating and overseeing the entire project execution, logistics operations of the entire supply chain, and inter-firm relationships in the implementation and the process of CI transition. These findings align with the existing literature (Lessing et al., 2015; Hu et al., 2019; Wuni & Shen, 2020; Hussein et al., 2021). The integration of knowledge and collaborative teamwork under industrial principles seems essential for the successful implementation of CI. Practitioners suggest that Construction Industrialization should be industry-wide rather than project- or company-specific, contrary to the traditional theoretical understanding of CI (Table 5.2). This interpretation aims to provide a clear notion of the boundaries of the CI phenomenon.

Second, this empirical study introduces the socio-cultural aspect of the Construction Industrialization process as a new way of understanding the phenomenon. What has led to this concern, according to Practitioners, is that construction companies are facing multiple complex

changes simultaneously in this recent topic in the business world, particularly with respect to both the supply and demand sides.

From the supply side, CI is bringing about a revolution in the industry, necessitating a new approach to work. For the industry to progress, *"the traditional construction methods must be updated to industrial knowledge, and construction workers must accept, adapt, study, and execute modern industrial design ideas and technology"*. This was shared by a Practitioner with over twenty years of experience in traditional construction. According to him, *"This is the major challenge in the CI development"*. A new way of working is expected, which requires completely changing long-established stigmas and routines. There is a need for a shift in mentality, a transformation in knowledge and behaviors, attitudes, beliefs, and fear of the change that exists. Social changes, together with the changes in construction technology and adjustments in political and regulatory structures, are the *"changes that are all believed to add to CI complexity"*, as observed in the meetings.

In this line, on the demand side, there is an acknowledgment of the social barriers that continue to affect the market. CI is a decade-old concept that has now become dominant. And, if previously the social aspects for acceptance and implementation of change for those who work and for those who buy/use were one of the factors for the failure of some attempts, Practitioners say that they still must be faced today. High (market) resistance to change is identified. The Funding Agenda is attuned to these sides (supply and demand sides), with dedicated teams committed to acknowledging the significance of both elements within the broader Industrialization phenomenon. Therefore, the traditional concern of managing production, typically referred to in the CI literature, becomes incomplete due to the social conceptualization achieved with the empirical study.

5.1.4.3. Benefits

The third analysis focuses on the expected CI benefits. Practitioners were asked to remark on the reasons for implementing this process and on the expected gains. Based primarily on the interview answers, supplemented by the secondary sources of information, all the sample sectors acknowledged that the implications of the CI phenomenon affected the productivity of the industry. Sustainable development, mainly from an environmental perspective, is also a top priority. Both benefits are aligned with the previous definition developed by Costa et al. (2023). These two perspectives are also consistent with the vast CI literature.

Analyzing the upcoming discussion and comparing the established theory with empirical findings reveals three intriguing contributions to CI theory.

First, the improvement of the production system and productivity from a practical point of view involves schedule, efficiency, quality, and competitiveness aspects. The purpose is to increase productivity as an indicator of the process efficiency of the new production system. *"Reducing man-hours to the construction process"* is a major goal, as defended by an Executive from the Traditional Construction sector. Only Yu et al. (2013), Gbadamosi et al. (2019), Hou et al. (2020), and Qi et al. (2021), in a vast body of literature about CI, used this crucial indicator (man-hour) for decision-making.

Second, environmental concerns are also ubiquitous throughout all four sectors. This is also supported by CI research that predicts Industrialization would improve built environment sustainability and mitigate climate change (Wuni & Shen, 2020). In this regard, environmental optimization should be integrated into the CI process to emphasize its benefits more effectively (according to Practitioner A1). According to the Practitioners, CI intends to be part of a "*better and cleaner future*". As another Practitioner stressed:

> *"We are in a difficult moment, and resources need to be carefully addressed and utilized. The incorporation of industrialization processes in construction and design can help optimize their use."*

Third, an important conclusion of this study when it comes to the benefits is that they are much more than the economic ones, being also sustainable development of the sector, and particularly the sustainable development of society. Practitioner perspectives suggest that CI is expected to have an unprecedented impact on society by significantly improving industrialized buildings' speed, quality, and cost.

While the literature has largely focused on defining CI as a project or even an industry level, this empirical study highlights a broader scope and impact on society and the world. Hence, social processes were not previously complemented in the definitions of CI (Table 5.2) and have been hardly researched in the CI field.

Practitioners often explain the societal benefits of CI by highlighting how it contributes to the common good and well-being of individuals. They believe that CI profoundly transforms the construction context, improving the working conditions of construction workers and the quality and dignity of life of those who live in the buildings and cities. CI also being a vehicle for "*better working*

conditions" for the construction workers is also acknowledged, and in the literature (Loudoun & Townsend, 2017). The answer to providing housing for all at controlled costs, that Construction *"has and must respond to"*, as one Practitioner interviewed put it, is one of the benefits widely referenced across all sectors and at all decision-making levels.

Moreover, during an interview, one of the Practitioners (A1) emphasized that *"construction accompanies the development of a society, both aesthetically and historically, as well as intellectually and culturally"*. Another Practitioner (A2) expressed concern about the potential consequences of bad decisions in construction, *as "buildings often remain in our cities for over 100 years, and rectifying mistakes could be extremely difficult"*. Construction Industrialization appears to reevaluate construction science and practice.

5.1.5. Discussion

Drawing on the empirical findings, this study offers a fresh perspective by challenging the previous definitions provided in Table 5.2, while also shedding light on the complexity of the CI phenomenon as portrayed in the literature.

Table 5.4 reflects the answer to RQ1 of this paper ("*How has the Construction Industrialization phenomenon been perceived in practice?*") very clearly, highlighting the main findings aligned with the existing literature, and revealing what is new. Table 5.4 also provides a pathway to address RQ2 of this paper ("*How can the phenomenon of Construction Industrialization be conceptualized in order to fill the current gaps in the literature and advance its understanding by linking theory and practice?*").

Table 5.4: Empirical findings regarding the intersection between Practitioner and Academic perspectives on the CI phenomenon

Themes	**Practitioners' perspectives that align with the existing literature**	**New perspectives derived from the empirical study that enrich the existing literature**
Interpretation	1. CI as encompassing a shift in production, "*typically on-site, to (or part of) off-site and in which, part, or a whole building, is produced in a controlled environment, and with repetitive and automated processes*", in line with Table 5.2.	1. CI-related terms are not sufficient to conceptualize the phenomenon; 2. The notion of a "*system*" and the distinction between "*constructive system*" and "*productive system*"; 3. The acquisition of diverse and new knowledge about an industrial mindset; 4. The concern about achieving "*product systematization*" to achieve repetition of the process and the product, to be replicated in future projects; 5. The notion of close integration between thought and activity along the supply chain;
Key Constituents	2. Operational perspective in line with Taylor (2010) and Ayinla et al. (2019); 3. The strategic element in line with Lessing et al. (2015); 4. The industry perspective regarding construction, industrial engineering, and management innovations is in line with Costa et al. (2023).	6. Construction Industrialization should be industry-wide rather than project- or company-specific; 7. Construction Industrialization is also composed of a socio-cultural process, alongside the expected and intensely referred to, technical process;
Benefits	5. Productivity and sustainable development in the construction industry in line with Costa et al. (2023).	8. Productivity must be evaluated by the man-hours indicator and depends on schedule, efficiency, quality, and competitiveness aspects; 9. Environmental optimization should be integrated into the CI process to emphasize its benefits more effectively. 10. CI has an unprecedented impact on society (societal benefits).

The practical voice presented in this study underscores that CI encompasses the involvement of people, companies, and industry, rather than being confined to the prefabricated, off-site construction components traditionally synonymous with CI (Table 5.2). While these components are unquestionably necessary conditions for the phenomenon, Practitioners argue that they are insufficient for a comprehensive conceptualization of the phenomenon.

Conceptualizing CI using such terms is the object of practical criticism in all four sectors researched, due to their failure to capture the full complexity of the phenomenon, as stated in the recent literature, and confirmed in practice. This presents a new finding for theory, as previous studies had only theoretically acknowledged this issue, while this work substantiates it with a practical perspective. This suggests that both theory and practice need to evolve in their understanding of CI.

Another contribution of this study is that CI requires, represents, and develops sociocultural changes in workers, firms, residents, and society. This introduces a fresh perspective to the current literature on CI's conceptualizations. By incorporating the experiences and perspectives of Practitioners, the study enables a more comprehensive understanding of what CI encompasses and what it does not (aligned with Stock & Boyer, 2009). The notion that CI is also a sociocultural process suggests the need for further research and for Practitioners to consider this dimension when planning the CI adoption process. This social concern could be the missing piece to a comprehensive understanding of the phenomenon.

All Practitioners perceived the phenomenon of CI as also a social process. Such perception represents an interesting novel insight obtained from the practice that literature has neglected. Technical topics and decisions occupy the major body of literature so far. Therefore, this study provides a turning point for literature and practice, with the ambition of inspiring future research to pursue new lines of investigation about the social side of the CI process, and with that, the nature of the researched problems, seeking to expand the field of CI and practice implementation. Practitioners are very aware of the need to change the habits and practices of teams, stakeholders, the entire industry, and society, which remains resistant to the change to modular construction, while also being aware of the need for change. A trigger will have to happen, and it needs to be hit.

A third major contribution is that effective integration and cultural alignment must be attended to by the projects and the channel members. CI knowledge has been fragmented in the literature, hindering the true complexity of CI adoption. A restricted vision to project vision remains in the CI

literature. This study adds to the literature by suggesting that such integration of systems (constructive and productive), from a building perspective, and knowledge, and a collaborative perspective, leads to the possibility of knowledge transfer and learning economies within groups of companies. Following the discussion about the novel and interesting insights obtained from the practice, one new insight added to the CI literature is the distinction between design (*"constructive system"*) and production (*"productive system"*), ensuring that both topics are addressed when interpreting CI. Practitioners have perceived the need to differentiate between these two aspects for a clear interpretation.

A last major contribution stems from Practitioners extending the boundaries of the perceived CI benefits. This empirical study's findings appear to redirect the existing theory to a new dimension of benefits that transcends the industry and positions it in a world sphere. It aims to redirect the CI theory towards a societal impact. Practitioner perspectives defend that when it comes to the benefits, CI is much more than economic benefits. This study, by bringing the voice of the practice, shows that CI aims to achieve a better level of productivity and embrace sustainable development in the sector, in line with the literature; but at the same time, aims to produce a highly favorable impact in the construction workers, as well as in the cities, in the citizens, and the society, in general. Further, Practitioners from the four sectors emphasize the significance of the design process, not just due to the need to think in an industrialized manner from the very beginning, but also because of the crucial role design plays in urban environments and cities. This is a significant empirical finding from the research, one that contributes to the body of knowledge by highlighting the voices of individuals with real-world experience who are driving industrialization in Portugal and other countries.

In this regard, this paper proposes a more comprehensive conceptualization that challenges current definitions and allows for the possibility of elaborating the most comprehensive conceptualization found in the literature on CI, albeit primarily conceptual (Costa et al., 2023). Thus, the main contributions are as follows and are shown in bold.

> *"new form of production and management (in line with product and process changes and as proposed in Costa et. al, 2023), driven by the adoption of several individual* ***and integrated*** *(in line with* Table 5.*4) construction, industrial engineering, and management innovations (in line with Costa et al., 2023),* ***in a process of technical and***

sociocultural change *(in line with* Table 5.*4), whose objective is to improve the productivity in the construction industry and* ***societal sustainable development****".*

5.1.6. Conclusion

In this paper, theory and practice intersect toward a unifying conceptualization of the CI phenomenon. Two research questions were established to properly guide the present research. The answer to RQ1 (*"How has the Construction Industrialization phenomenon been perceived in practice?"*) was developed through the analysis of case study findings and resulted in the identification of new perceptions about CI interpretations, regarding its key constituents and perceived benefits. In practice, CI is perceived as a complex phenomenon that goes beyond the operational perspectives. To address RQ2 (*"How can the phenomenon of Construction Industrialization be conceptualized in order to fill the current gaps in the literature and advance its understanding by linking theory and practice?"*), The intersection between Practitioner and Academic perspectives on the Construction Industrialization phenomenon is performed. A summary of such a comparison is provided. Ten new perspectives are derived from the empirical study that enriches existing literature. This has resulted in the derivation of novel and interesting insights from practice, contributing to the enrichment and unification of theory and practice.

As with any research, some limitations need to be acknowledged. Primarily, the empirical study sample was confined to the specific domain of the Funding Agenda, encompassing the Architecture, Engineering, Traditional Construction, and Manufactured Construction sectors. Subsequent research endeavors should attempt to encompass insights from developers, suppliers, clients, consumers, and regulatory bodies to provide practical perspectives and refine the definition. A second limitation is related to the span of the analysis. The analysis should remain attuned to forthcoming advancements and assimilate the lessons garnered along the agenda to afford a more precise reflection on the evolution of CI. A third limitation is related to the number of Practitioners included in the sample, while customary in theoretical studies, as acknowledged by Song et al. (2020), is a notable constraint. This study serves as a pilot in the effort to refine and expand the CI theory, hence opening up various avenues for informing and inspiring future research. As such, this paper ends by highlighting the unique character of this investigation and suggesting potential areas for further research and reflection in both practical and academic debates around the

phenomenon of Construction Industrialization, which has great relevance to the building industry today.

Overall, this study gives a new meaning to Practitioners and decision-makers. It provides a better grasp of what CI is and what it is not. Without a clear definition, the nature, the boundaries, and the essence of the phenomenon are not understood. Scholars and Practitioners must speak the same language, with the same vocabulary and scope. Such meaning alignment provided in this paper would allow a way to bring together future industry working groups, research initiatives, and supporting policies.

5.2. The Construction Industrialization Process: Results of an International Cross-Sector Case Study

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ABSTRACT

This paper focuses on the transition process from conventional construction to the contemporary Construction Industrialization (CI) phenomenon. Despite the significant challenges faced by construction companies, the nature of this shift is often not well understood and is inadequately systematized in the existing literature. This study aimed to explore the perspective of Practitioners from different sectors involved in construction in terms of CI Drivers, Changing Practices, and Elements of Influence. This paper argues that Scholars and Practitioners can fully systematize such a transition process by the close integration of these three aspects. An exploratory multiple case study was conducted from an international and cross-sector perspective. The empirical findings are compared with the existing theory. This study highlights the importance of societal concerns that impact all three aspects. In addition, novel practices and the social and contextual factors affecting CI are identified. This research confirms that technical issues are a significant part of the CI process, but sociocultural and contextual issues are considered the biggest challenges that have been hindering its progress. This study is one of the first to empirically explore CI as a process, and it is also the first to provide a comprehensive industry-wide perspective on its implementation. The paper concludes by suggesting avenues for future research.

Keywords: Construction Industrialization; Process; Agenda; Cross-Industry; Multiple Case Study; Conceptualization; Drivers.

5.2.1. Introduction

The phenomenon of Construction Industrialization (CI) has been at the center of a promise of prosperity in an industry typically labeled for its resistance to change, low productivity, and low appetite for innovation (Goh & Loosemore, 2017).

Construction companies - including builders, suppliers, and all entities involved in building projects - are under intense pressure to move from labor-intensive methods, characteristic of traditional construction, to more efficient, industrialized approaches. These modern methods emphasize off-site fabrication, automation, modular construction, and prefabrication, significantly enhancing productivity and reducing costs. Wuni & Shen (2020) stated that its benefits are *"no longer esoteric but overt",* highlighting its growing significance for construction companies.

Whilst the CI phenomenon is not new for the construction industry, and much has been written by academics around the world, its global adoption rates are low (Ayinla et al., 2019), significant barriers to its implementation remain (Mao et al., 2015), and there is a general lack of understanding regarding the transformation process required for its successful integration into existing industry practices (Luo et al., 2020).

Recent literature highlights significant gaps in support for this endeavor. Academic discussions consistently portray CI as a complex and ambiguous topic with fragmented interpretations and a lack of comprehensive research on the challenges surrounding its adoption (Hu et al., 2019; Ayinla et al., 2019; Luo et al., 2020).

Additionally, tools for a systematic and detailed description of the transition process are lacking in the CI field. Vague characterizations and an underdeveloped field have raised concerns about the feasibility and success of CI efforts despite global interest. Luo et al. (2020) support that much of the misunderstanding about CI development arises from a lack of a systematic framework detailing its broader knowledge agenda. As a result, there is an urgent need for robust, practice-oriented knowledge to support construction managers in making informed decisions throughout the CI development process.

This paper contributes to theory and practice by answering the identified need through an in-depth study of the CI development process, driven by the need to improve CI practices.

A two-year multiple case study that brings an international and cross-sector perspective is reported in this study. The Practitioners' perspectives on the transition from traditional construction to

industrialized construction are explored. A robust, empirically grounded tool tailored for Practitioners has been developed to facilitate this transition, offering a more cohesive, comprehensive, and practical understanding of CI.

In contrast to previous research that emphasized isolated aspects of CI, this empirical study focuses on the three key aspects directly responsible for its implementation: the Drivers that initiate the efforts, the Changing Practices that (or should) constitute it, and the Elements of Influence that have an impact on it. The definition of these three key aspects was grounded in prior CI literature and further refined through insights from a working paper by Costa et al. (2024), as discussed in Section 5.2.3.

In doing so, this study explores the CI phenomenon from the Practitioners' point of view by answering the following research questions[17]:

RQ1: What Drivers prompt the establishment of a transformation process for construction industrialization?

RQ2: What Changing Practices do Practitioners identify as necessary for the development of a transformative process toward construction industrialization?

RQ3: What internal and external Elements of Influence shape or inhibit the establishment of a transformation process for construction industrialization?

The present research positions itself as positivist in orientation and abductive in research approach, drawing on and extending an initial theoretical conceptualization rooted in a working paper (Costa et al., 2024[18]). The nature of this research suggests an explicit aim of exploring the CI development process focused on revising such conceptualization.

Abductive studies seek theorizing involving an ongoing reflection of data and its positioning against prior theory so that a new theory can be elaborated, and novel and unanticipated insights may emerge empirically that can refine, adapt, and enhance the initial theoretical conceptualization (Dubois & Gadde, 2002; Borgström, 2012; Towers et al., 2020).

Therefore, following a path of theory elaboration (Ketokivi & Choi, 2014), attention has turned to empirically elaborating on the three CI key aspects: the Drivers (through the dimensions of

[17] In this paper, RQ1 combines RQ3.1 and RQ3.5 from the thesis, RQ2 combines RQ3.2 and RQ3.3, while RQ3 corresponds to RQ4 of the thesis.

[18] Costa et al. (2024) refers to the working paper "*Analyzing Construction Industrialization: A Theoretical Framework Developed from the Perspective of Organizational Change Theory"*, which is featured in Chapter 5.

Rationale and Results), the Changing Practices (through the central dimension of transforming the construction industry that comprises the two dimensions: Principles and Dimensions), and the Elements of Influence (through dimensions of Environment Conditions and Internal Circumstances).

A preliminary list was developed in Costa et al. (2024) (Section 5.2.3), primarily grounded in theoretical foundations. Building on this, the present study aims to refine and elaborate the list using empirical insights that reflect the experiences and convictions of construction 0ractitioners. The goal is to ensure that the resulting tool captures actionable insights rooted in practical implementations of CI, thereby supporting industry 0ractitioners in navigating the complexities of CI adoption and aligning their strategic initiatives effectively.

Each aspect is elaborated by tracing similarities and differences within and across cases, merging the different perspectives about the CI process in a structured opportunity for a theory to be advanced. A more accurate image of the realities and perceptions that emerge empirically is especially established. Novel and unique insights for both Scholars and Practitioners interested in CI are provided, to which the literature has not yet paid attention. Furthermore, a strong foundation for further theorizing and research in the CI process is offered in this paper. This should be used to systematize, inform, and inspire future research.

The integration of theoretical depth, empirical richness, and practical relevance positions this work as a foundational contribution to both the theory and practice of the CI process. It provides a structured basis for systematizing existing knowledge, informing ongoing debates, and inspiring future research. Ultimately, the findings aim to foster strategic alignment among scholars, policymakers, and construction managers, thereby supporting the industry's transition toward more sustainable, industrialized, and efficient practices across diverse contexts.

The paper is structured into six sections. Section 5.2.2 summarizes the significant literature on the CI topic, and Section 5.2.3 elaborates on a research framework. The research methodology is then described in Section 5.2.4. Intra and cross-case analyses follow Section 5.2.5. Discussions and Implications for Research and Practice are specified in Section 5.2.6. Finally, Section 5.2.7 displays the conclusion, the limitations, and some future work suggestions.

5.2.2. Literature Review

A literature review was conducted to justify the need for the present research and position its contributions within existing literature. Table 5.5 summarizes the prior contributions to the field of CI development, analyzing these works based on CI interpretation, the contributions of each study, and the research design employed. Building on this review, four major limitations have been identified, which this study aims to address. They can be broadly categorized as conceptual, systematic, empirical, and practical.

Conceptual limitation. Prior studies often adopt vague and fragmented interpretations, leading to conceptual misunderstandings and limiting the generalizability of findings. As shown in Table 5.5, a wide range of terms—such as *off-site production, industrialized housebuilding, prefabricated construction, and modular construction*—are frequently used interchangeably, despite referring to different aspects of the broader CI spectrum. Moreover, CI interpretations vary across levels of analysis, ranging from project-specific to organizational and industry-wide perspectives, contributing to a fragmented theoretical base. Table 5.5 further highlights the frequent lack of alignment between the specific CI concept adopted and the corresponding level of analysis employed, with scholars often using the same concept while referring to different scopes (for instance, Lessing et al., 2015, and Zakaria et al., 2018).

Therefore, this paper adopts the term Construction Industrialization as a unifying concept that integrates the diverse interpretations within a comprehensive, holistic framework. Building on Costa et al. (2023) - a previous author's contribution (however, conceptual in nature) – CI is defined in this paper as:

> *"a new form of production and management, driven by the adoption of several individual (but interrelated) construction, industrial engineering, and management innovations whose objective is to improve productivity and sustainable development in the construction industry".*

To the best of the authors' knowledge, this is the most comprehensive definition currently published in the academic field. It is therefore adopted as the conceptual foundation for this study due to its broad, integrative, and multidimensional scope.

Unlike previous research, which often provides narrow or fragmented characterizations, this study seeks to advance a more holistic understanding of the CI transition. By grounding the analysis in

this comprehensive conceptual foundation, this study supports more robust and generalizable empirical research. This approach facilitates the exploration of the phenomenon's complexity and multidimensional nature as perceived by Practitioners. As shown in Table 5.5, prior works have failed to capture this depth, leading to the next limitation.

Systematic limitation. Table 5.5 highlights a lack of systematic coherence in the existing literature. Existing contributions are marked by fragmented interpretations, divergent research designs, and substantial variation in the dimensions and practices associated with CI, resulting in a poorly structured and inconsistent understanding of CI transition. Many studies adopt narrow, fragmented frameworks, focusing on specific CI aspects—such as modularity or off-site production—while overlooking their broader systemic dimensions. As Ayinla et al. (2019) and Hussein et al. (2021) note, this conceptual ambiguity hampers both academic understanding and practical application.

Furthermore, existing research often examines Drivers, Changing Practices, and Elements of Influence in isolation or in limited combinations, which restricts the development of comprehensive theoretical models capable of capturing the multifaceted and systemic nature of CI. Yet, these three key aspects represent the core dimensions through which CI development is typically explored. Building on this foundation and supported by recent contributions such as Costa et al. (2024), which introduces change management into the CI field, this study focuses on these three key aspects to explore the dynamics of CI transition.

In response, this study adopts an integrative approach, simultaneously analyzing all three key aspects within a unified, multi-level perspective—an approach still uncommon in the field. This design seeks to foster a more systematic and holistic understanding of CI and to provide a stronger theoretical basis for explaining its transition. Although Razkenari et al. (2020) similarly adopt a holistic perspective by considering all three key aspects, their exclusive emphasis on business models limits the generalizability of their findings across broader contexts.

Empirical limitation. Empirical research on CI has been largely constrained by a narrow geographic and sectoral focus. Moreover, as shown in Table 5.5, prior studies rely extensively on literature reviews (e.g, Costa et al., 2024) or questionnaires with complementary interviews; however, in a single country perspective (e.g, Li et al., 2018; Razkenari et al., 2020; Wang et al., 2020; Dang et al., 2020; Zhang et al., 2022) and often based on small sample sizes.

Even multiple case studies tend to focus on specific building project scopes or national perspectives (e.g., Wuni et al., 2022; Lessing et al., 2015), offering limited insights into how CI is adopted across different regions and sectors. This narrow empirical scope has been limiting the generalizability and applicability of findings, particularly in light of CI's global and interdisciplinary relevance.

This paper argues that a transition as significant as CI demands cross-sectoral and international perspectives to fully capture its complexity, contextual variability, and potential for widespread scalability. Therefore, the current research makes a new contribution by employing a multiple case study design that spans different countries and sectors, including Architecture, Engineering, Traditional Construction, and Manufactured Construction. By doing so, it offers a richer, more nuanced empirical foundation for understanding CI and enhances the relevance of findings to a broader range of stakeholders.

Practical Limitation. Despite growing interest in CI, few studies provide practical, comprehensive frameworks to guide construction managers and industry stakeholders. Most existing models are either overly abstract or too fragmented to inform real-world decision-making effectively. Moreover, as highlighted in Table 5.5, the dimensions of change associated with CI stress the need for a more cohesive and practice-informed conceptualization of the phenomenon. As Liu et al. (2019) emphasize, this lack of practical orientation often leads to confusion and delays in CI adoption, particularly among construction managers.

Table 5.5: Existing literature about Construction Industrialization implementation (D-Drivers, CP-Changing Practices, and EF-Elements of Influence)

Paper Reference	CI interpretation		Paper Contribution			Research Methodology			
	Concept	Level of Analysis	Object of study	Tool	Dimensions	Research Strategy	Countries	Sectors/ Backgrounds	Sample
Goulding et al. (2015)	Off-site Production	Construction industry	CP	Roadmap	People; Technology; Process.	Workshop	United Kingdom, Netherlands, Australia	Design, construction, and off-site construction	9 (Practitioners and Scholars)
Lessing et al. (2015)	Industrialized Housebuilding	Manufactured construction company	CP	Framework	Planning; Technical Systems; Collaboration; Logistics; Customer Focus; Technology; Performance Assessment; Continuous Improvement; Production Strategy; Business Strategy; Organization	Multiple Case Study (interviews, observations, and documents)	Sweden	Contractors and timber companies	15 (12 Practitioners in 2005 and 3 experts in 2013)
Li et al. (2018)	Prefabricated Construction	Building Project	CP	List	Technology and Method; Information, Communication, and Collaboration; External Environment; Experience and Knowledge; Competence of the Project Manager.	Literature Review, questionnaire, and interviews	China	Manufactured Construction companies and Consultancies	5 (Practitioners)
Zakaria et al. (2018)	Industrialized Housebuilding	Building Project	EF	Framework	Contextual; Structural; Behavioral.	Literature Review	-	-	-

Table 5.5: Existing literature about Construction Industrialization implementation (D-Drivers, CP-Changing Practices, and EF-Elements of Influence) *(continue)*

Paper Reference	CI interpretation		Paper Contribution			Research Methodology			
	Concept	**Level of Analysis**	**Object of study**	**Tool**	**Dimensions**	**Research Strategy**	**Countries**	**Sectors/ Backgrounds**	**Sample**
Wuni & Shen (2019)	Off-site Production	Construction industry	D	Framework	Quality; Market; Policy; Time; Productivity; Cost; Innovative Competitiveness; Sustainability.	Literature Review	-	-	-
Luo et al. (2020)	Prefabricated Construction	Construction industry	CP	Framework	Performance Assessment; Prefabricated Product; Prefabricated Process; Prefabricated Material; Technology.	Literature Review	-	-	-
Razkenari et al. (2020)	Off-site Construction	Manufactured construction business model	EF	Framework	Internal and External Drivers; Challenges	Interviews and Questionnaire	United States	Contractors; Architecture; Engineering.	30 questionnaire answers No information about the number of interviews
Bendi et al. (2020)	Off-site Production	Manufactured Construction Sector	CP	Readiness Maturity Model	Operational Challenges; Broad Execution Strategy; Planning Uncertainty; Operational Efficiency.	Interviews	India	Architecture; Suppliers; Engineering.	5 (Practitioners)

Table 5.5: Existing literature about Construction Industrialization implementation (D-Drivers, CP-Changing Practices, and EF-Elements of Influence) *(continue)*

Paper Reference	CI interpretation		Paper Contribution			Research Methodology			
	Concept	**Level of Analysis**	**Object of study**	**Tool**	**Dimensions**	**Research Strategy**	**Countries**	**Sectors/ Backgrounds**	**Sample**
Wang et al. (2020)	Industrialized Construction	Building Project	D; CP	Maturity Model	(CP) Leadership; Participants' capabilities and collaboration; Planning and Control; Technology and Schema (D) Product, Society, Organization; Management and Control.	Questionnaire and Interviews	China	Real State; Engineering; Manufactured Construction; University.	15 (Practitioners and Scholars) in questionnaire 10 (Practitioners in interviews)
Dang et al. (2020)	Prefabricated Construction	Building Project	D; CP	Maturity Model	(D) Sustainable Construction capability; Economic capability (CP) Technology capability; Operational Management Equipment.	Literature Review and Interviews	China	Government; Engineers; Contractors; Consultants.	10 (Practitioners and government offices)
Ribeiro et al. (2022)	Modular Construction	Construction industry	EF	List	Design; Market Demand And Competition; Quality and Performance; Experience; Lack of Awareness of CI Benefits; Lack of Innovation; Lack Of Organizations to Certify Quality.	Questionnaire	Portugal	Consultant; Contractors; Clientes.	90 questionnaire asnwers

Table 5.5: Existing literature about Construction Industrialization implementation (D-Drivers, CP-Changing Practices, and EF-Elements of Influence) *(continue)*

Paper Reference	CI interpretation		Paper Contribution			Research Methodology			
	Concept	**Level of Analysis**	**Object of study**	**Tool**	**Dimensions**	**Research Strategy**	**Countries**	**Sectors/ Backgrounds**	**Sample**
Zhang et al. (2022)	Prefabricated Construction	Building Project	CP	List	Information communication; Trust and cooperation; Technical and managerial ability; Organizational integration; Standardization; Technical environment; Contract management.	Literature Review, questionnaire, and interview	China	Engineers; Consultant; Scholars; Contractor; Manufactured Construction.	66 questionnaire answers, and 5 interviews with Practitioners
Wuni et al. (2022)	Industrialized Construction	Building Project	CP	List	Best practices along the conceptualization, planning, design, and production phases.	Multiple case study	Australia, China, Singapore	Manufactured Construction.	9 building projects
Costa et al. (2023)	Construction Industrialization	Construction industry	CP; EF	Framework	(CP) Ten Design Principles and Five Organizational Dimensions (Strategy, Organization, Supply Chain, Business Process, and Resources) EF (Culture & Leadership, Collaboration & Cooperation, Technological infrastructure, Worker's expertise, and Company Context).	Literature Review	-	-	-

Table 5.5: Existing literature about Construction Industrialization implementation (D-Drivers, CP-Changing Practices, and EF-Elements of Influence) *(continue)*

Paper Reference	CI interpretation		Paper Contribution			Research Methodology			
	Concept	**Level of Analysis**	**Object of study**	**Tool**	**Dimensions**	**Research Strategy**	**Countries**	**Sectors/ Backgrounds**	**Sample**
Current Research	Construction Industrialization	Construction industry	D; CP; EF	List	Developed in this paper	Multiple case study (interviews, documents, site visits, and meeting observations)	Portugal, England, and Spain	Architecture; Engineering; Traditional Construction; Manufactured Construction.	17 (Practitioners)

5.2.3. Research Framework and Constructs

As an approach to research, the abductive research approach has gained prominence in qualitative research due to its ability to unify theory development and empirical observations (Kovács & Spens, 2005; Fisher & Aguinis, 2017). When applied within a positivism paradigm, abductive reasoning enables the elaboration of theories that remain grounded in the intersection of the empirical world, the prior framework, the theory, and the case (Dubois & Gadde, 2002).

A prior specification of constructs must be developed as the basis for this type of research (Borgström, 2012). Particularly, within the positivism paradigm, following an abductive research approach, well-defined constructs prove to be fundamental elements as the study progresses to empirical exploration, ensuring the internal validity of abductively derived explanations (Eisenhardt, 1989; McCutcheon & Meredith, 1993).

According to Suddaby (2010), constructs are robust categories that are considered the precise language to capture, as effectively as possible, the essence of a phenomenon. For Fisher & Aguinis (2017), *"theory is therefore advanced when constructs are refined such that they sufficiently but parsimoniously capture and reflect the phenomenon in question"*.

The specification of constructs within this study is grounded in the previous literature review (Section 5.2.2), which identifies three key aspects through which CI development has been examined: Drivers, Changing Practices, and Elements of Influence. Such studies were already addressed in the systematic review developed by the Authors in the paper by Costa et al. (2023).

Furthermore, construct specification is shaped by Costa et al. (2024). This working paper uses the theoretical lens of Organizational Change and Change Management theories to deepen the understanding of CI's true nature and its development process. In Costa et al. (2024), a preliminary link between such theories and CI development as a system-wide transformation is established.

It must be noted that the three key aspects identified in the CI literature align closely with the primary components essential for understanding planned organizational change. A convergence further reinforces the conceptual robustness of the research framework and highlights the dynamic interplay between CI development and Organizational Change and Change Management theories.

Therefore, a transformation model, conceptualized by Costa et al. (2024) as an evolution of the CI study, provides the foundational theoretical framework of this paper. Abductive reasoning brings

the notion that CI development has to be, firstly, built theoretically and further elaborated through empirical insights.

Table 5.6 presents the list of constructs related to each key aspect (Drivers, Changing Practices, and Elements of Influence) that combines CI literature and the transformation model developed by Costa et al. (2024). Modifications of these constructs are expected to be developed as empirical evidence is collected and analyzed (Barrat et al., 2011). The iterative process between theory and practice accommodates unanticipated empirical findings and acknowledges the potential necessity for substantial theoretical reformulation based on new empirical insights (Awuzie & McDermott, 2017). An enriched list of constructs aims to be developed, in which prior constructs will likely stay unchanged, or they may undergo further revision, or new constructs may arise. The purpose of this outcome is to provide a systematic and detailed description of the transition process (Barratt et al., 2011).

Table 5.6: Initial list of constructs corresponding to the three key CI aspects and research significance

Aspect and respective RQ	Correspondence in Figure 5.1	Significance of the data collection and analysis phases	Initial Constructs
Drivers (D)	Rationale	Reasons (triggers) behind the decision to implement a CI process.	D1: Productivity of the Industry D2: Competitiveness of the company D3: Individual human development D4: Quality of life and well-being of society D5: Environmental concerns D6: Performance of each project, in terms of time, cost, and quality
	Results	Expected consequences that are generated (or expected to be generated) by the CI process.	
Changing Practices (CP)	Principles to Industrialize (P)	General (and unique) principles of a CI transformation that can be applied in any context (or country).	CP.P1: Off-Site, Prefabricated (Factory) Production CP.P2: Modularization CP.P3: Automated Production CP.P4: Digitalization CP.P5: Lean Transformation CP.P6: Production System CP.P7: Mass Customization CP.P8: Business Model CP.P9: Design a Building as a Product CP.P10: Integrated Project Management CP.P11: Value Creation
	Dimensions to transform (D)	Hard and soft dimensions of change need to be embraced to assist in the transformation toward CI.	CP.D1: Strategy CP.D2: Organizational Design CP.D3: Operations CP.D4: Innovation CP.D5: Management Systems CP.D6: Technology CP.D7: Supply Chain Management CP.D8: Worker Capabilities CP.D9: Social & Behaviors CP.D10: Culture CP.D11: Leadership
Elements of Influence (EF)	External and Internal Environmental Conditions (E)	Influencing factors (internal and external) with positive/negative impact on the Construction Industrialization process.	EF.E1: General Environment EF.E2: Industry EF.E3: Company EF.E4: Project EF.E5: Individual
	Internal Circumstances (I)	Aspects of human and social behavior and relations with a crucial role in the Construction Industrialization process.	EF.I1: Supply Chain Integration EF.I2: Collaboration and Cooperation EF.I3: Communication EF.I4: Teamwork EF.I5: Knowledge Management EF.I6: Motivation EF.I7: Employee involvement EF.I8: Organizational Commitment

5.2.4. Methodology

Throughout this section, details about the empirical basis, research design, and case selection, methods of data collection, as well as data analysis, are presented.

5.2.4.1. Empirical Basis

Proponents of Case Research in qualitative research have been justifying the importance of using such a research strategy as a deemed strategy when the phenomenon is not at all understood, Scholars do not know what issues may emerge from the data, and when little or no prior work related to a research question exists (Voss et al., 2002; Edmondson & Mcmanus, 2007). Case Research is particularly well-suited for exploring in-depth data on a contemporary phenomenon, such as CI, in its practical context and with actors who experience the phenomenon being studied (Näslund, 2002).

In the context of abductive reasoning, Case Research enables the development and refinement of theoretical constructs through the iterative process of observation, interpretation, and theoretical elaboration. One of the major advantages put forward in the literature, in such a context, relies on its role in identifying unanticipated empirical findings, fostering the emergence of novel constructs and conceptual refinements.

Moreover, the development of contextual knowledge also appears as an advantage. Unlike deductive and inductive approaches, abductive studies lead to new and plausible insights about existing phenomena by also examining them from a new perspective to determine which constructs of a situation are generalizable and which only pertain to the specific situation itself (Towers et al., 2020). This contextual knowledge is particularly valuable for CI research, as it enhances the comprehensive understanding of the CI phenomenon from a broad industry perspective.

5.2.4.2. Research Design

A holistic multiple case study research design was selected (Yin, 2012). The unit of analysis was the transition to the CI implementation process. As for the number of cases, a multiple case study was chosen to overcome the shortcomings of much of the previous research reported in Section 5.2.2, which has concentrated on a single sector.

The chosen cases are four sectors: Architecture, Engineering, Traditional Construction (general contractor companies), and Manufactured Construction. These four cases were purposefully selected using replication logic to ensure a theoretical replication approach of their apparently contrasting perspectives and priorities in the construction industry (Voss et al., 2002).

A generalizable exploration of the overall CI process in an international and cross-case perspective will allow each case to complement the others in a common understanding of the phenomenon under study (Barratt et al., 2011), which seems appropriate to a comprehensive research on the challenges surrounding its adoption. Additionally, Yin (2012) suggests that the multiple case study provides greater confidence in a study's findings than single cases by its cross-case comparisons that enable more generic and replicated conclusions to be reached about the phenomenon, which strengthens the external validity of the findings.

After defining the cases, the next decision was to choose the empirical context to apply the Case Research. In this paper, the empirical context is mainly based on the unique opportunity of being part of a Government Funding Agenda in Portugal to promote the adoption of CI. This agenda is made up of international teams, involving the four sectors selected for the case study, and under a comprehensive work plan that culminates in the construction of modular buildings. Researchers were integrated into this working group, participating in meetings, observing experiments, and accessing reports.

This context presents a unique opportunity to truly observe and embrace the phenomenon in its natural setting (Voss et al., 2002; Noor, 2008), thereby deepening the understanding of CI Drives, Changing Practices, and Elements of influence from the perspective of those who experience them firsthand.

In line with the theory-elaboration purpose, this context also offers valuable theoretical insights that would illuminate the underexplored CI transition process. Specifically, it would facilitate the stimulation of new theoretical ideas while figuring out if the existing theory holds up in practice (Do et al., 2022). Moreover, the study's abductive approach is reinforced through the nuanced application of research phronesis (Conaty, 2021). The direct, in-depth engagement with actors within the situational domain of the phenomenon further strengthens the study's methodological rigor. This level of direct involvement is, therefore, achieved through the Author's proximity to the CI phenomenon, maintained with ongoing self-awareness and vigilance to mitigate potential biases.

5.2.4.3. Data Collection

A key feature of Case Research widely cited by scholars is that such research strategy relies on multiple sources of evidence, with data needing to converge in a triangulation fashion while investigating contemporary issues within a real-life context (Voss et al., 2002; Yin, 2018). So, multiple sources of data were collected to enable a more nuanced understanding of the phenomenon. The data collection phase took place from January 2022 to January 2024.

Firstly, following the guidelines provided by Voss et al. (2002), semi-structured (online or face-to-face) interviews were conducted with the seventeen Practitioners. The interviewees were Practitioners who participated in decision-making regarding the CI development process and/or are responsible for the operational implementation of the phenomenon. The selection of interviewees also ensured that data was collected from Practitioners with different perspectives with respect to the CI phenomenon. Therefore, different backgrounds, geographic locations, hierarchical levels, and levels of decision-making on CI strategy were interviewed (Table 5.7). This diversity aligns with the recommendations of Conaty (2021) for abductive studies, as it facilitates the elaboration of a broad and multifaceted perspective on the phenomenon. The names of the companies are disguised to preserve anonymity.

Three pilot interviews were conducted to ensure the understandability and duration of the interviews, as suggested by Saunders et al. (2008). The interviewees, who were Professionals in the fields of Civil Engineering, Mechanical Engineering, and Industrial Engineering and Management, played a crucial role in making the necessary corrections to improve the effectiveness of the pilot test.

An email describing the research objectives and providing the interview protocol was sent to the interviewees before each interview. An interview protocol was developed that included both open-ended questions and Likert scale questions derived from the previously defined list of constructs. These two types of questions aimed to ensure flexibility in exploring the different issues and adding richness and alternative viewpoints about the predeterminate aspects (Drivers, Changing Practices, and Elements of Influence) (Eisenhardt & Graebner, 2007).

Concerning Drivers and Changing Practices, a 5-point Likert scale (with total disagreement to full agreement at points 1-5, respectively) was used to measure the level of agreement with each construct. Then, an open question was formulated to add fresh outcomes to the basic conception

(*"Do you consider this list complete? If not, what additional Driver/Changing Practice (Principle or Organizational Dimension) do you think is missing?"*).

Unlike the other two aspects (Drivers and Changing Practices), the Elements of Influence were not shown to the Practitioners. This decision was made to identify the most crucial factors that could greatly impact, delay, or even reverse the advancement of CI. In addition, it was drawn from an analysis of the pilot interviews, in which, in contrast to the Drivers and Changing Practices sections, the three Practitioners closely adhered to the original list without adding anything or changing it.

Table 5.7: Multiple case study characterization

Sector (Case)	Company		Practitioners Description					Code
	Nº	Country	Background	Hierarchical Level (in their company)	Years of experience in traditional construction	Years of experience in modular construction	Degree of responsibility in funding agenda	
Architecture	1	Spain	A	Medium level	11-15	3-5	Member of Team	A1
			A	Medium level	6-10	3-5	Member of Team	A2
Engineering	2	United Kingdom	CE	Executive	>20	6-10	Decision-maker	E1
	3	Portugal	CE	CEO	11-15	6-10	Member of Team	E2
Traditional Construction	4	Portugal	CE	Executive	16-19	3-5	Decision-maker	TC1
			CE	Medium level	11-15	<2	Member of Team	TC2
			CE	Executive	11-15	<2	Support	TC3
Manufactured Construction	5	Portugal	CE	Medium level	16-19	3-5	Member of Team	MC1
			PE	Medium level	6-10	3-5	Member of Team	MC2
			IEM	Medium level	<2	<2	Member of Team	MC3
			CE	Medium level	6-10	3-5	Responsible	MC4
			A	Medium level	16-19	3-5	Responsible	MC5
			A	Executive	>20	3-5	Decision-maker	MC6
			CV	Executive	>20	3-5	Decision-maker	MC7
			U	Medium level	>20	<2	Responsible	MC8
			ME	Executive	16-19	3-5	Decision-maker	MC9
			IEM	Medium level	6-10	<2	Support	MC10

Legend: A (Architecture); CE (Civil Engineering); PE (Polymer Engineering); IEM (Industrial Engineering and Management); U (Undergraduate); ME (Mechanical Engineering)

Therefore, three open questions were formulated:

1. *"Which external and internal influencing factors have a significant positive or negative impact on the process of Construction Industrialization?"*
2. *"Do you agree that the above-mentioned influencing factors are the most challenging barriers to overcome during the Industrialization process? If not, what do you consider to be the most serious challenges faced?"*
3. *"Why do you believe that implementing Construction Industrialization is still a difficult challenge?"*

In addition to the interviews, thirty meetings were attended as observers, five visits were made, and 10 reports were analyzed, which complemented the in-depth insights from the interviews. Field notes were also taken. It was the purpose of the meetings to discuss the subsequent phases of the Funding Agenda and the conceptualization of the modular buildings. To maintain impartiality and contribute to unbiased research, the Authors adopted a passive observational role instead of actively participating in the meetings. When the four data sources were combined, "*data triangulation*" was possible, which is essential for rigorous results in qualitative research (Benbasat et al., 1987).

From Table 5.7, it should be highlighted:

- The Engineering case featured two Practitioners from different companies. Such a definition ensures that at least two Practitioners' perspectives for each sector facilitate a comprehensive analysis of both similarities and differences in their perspectives.
- The geographical diversity shown in the cases allows for a highly effective method to collect global data. This not only broadens the existing theoretical boundaries but also introduces innovative ideas and adds strength to what is already known through previous theories, as recommended by Gammelgaard (2017). This approach directly addresses one of the research gaps identified in Section 5.2.2.
- The experience levels in Manufactured Construction varied from under 2 years to 10 years. This spectrum aligns with results from previous studies outlined in Table 5.5, demonstrating the reliability of the findings outlined in this paper.

Interviews with the seventeen Practitioners were conducted in Portuguese or English, lasted for 60-90 minutes roughly, and were recorded and later transcribed in English. At least two Researchers

participated in all the interviews. The interviewees were assured of anonymity and confidentiality of their business affiliations and personal identities throughout the interview process.

5.2.4.4. Data Analysis

Consistent with abductive reasoning, data analysis was performed to evaluate which (preexisting) constructs can be revised and/or introduced to more accurately reflect the realities and insights that emerge empirically (Maitlis, 2005; Barratt et al., 2011).

A two-step process was used: within-case analysis focused on each case (sector), followed by a search for cross-case patterns, as suggested by Miles and Huberman (1994), Eisenhardt (1989), and Barratt et al. (2011). This sequential process of data collection and emerging case interpretation further allows the patterns or explanations from each case to emerge and to be compared across cases, employing the replication mode for multiple cases (Yin, 1994).

In within-case analysis, all the data were organized separately for each case along the three key aspects (Drivers, Changing Practices, and Elements of Influence) as guidance for initial codes. A directed content analysis was built based on a three-order code method (Hsieh & Shannon, 2005). This method was also applied by Kreye & van Donk (2021), Do et al. (2022), and Gomes et al. (2023) in their theory-elaboration studies. According to Kreye & van Donk (2021), such a method enables a rigorous and consistent connection between theoretical and empirical, strengthening the external validity of the study findings.

The first-order codes rooted within the case evidence reflected raw data clustered based on the three key aspects, and the second-order reflected the theory-centric interpretations. Such interpretations are appropriately triangulated with the initial list of constructs to reach the empirical adequacy of the initial theory.

Meredith (1998) stresses that theory elaboration, using case research, can and often go beyond the initial theoretical framework, particularly if there is a need to explain exceptions and unexpected results. Therefore, second-order themes that were not interpreted or associated with any of the existing a priori constructs were clustered into newly potentially emerging aggregated themes (Zott & Huy, 2007). The third-order code reflected the final list of constructs within the three key aspects (Drivers, Changing Practices, and Elements of Influence).

Cross-case analysis was carried out after within-case analysis. A horizontal contrasting technique was developed to identify similarities and differences in terms of CI perspectives across different sectors, thus allowing the theory to emerge, as suggested by Fisher & Aguinis (2017). This approach aims to achieve a generalization of similar Drivers, Changing Practices, and Elements of Influence among the cases and a deeper understanding of how the constructs (revised and new) vary when applied in a different sector.

The data analysis process ends with Table 5.8 (presented in Section 5.2.5), which integrates theory and practice and offers a systematic and detailed description of the transition process.

5.2.5. Findings

This section discusses empirical findings. To begin, the empirical adequacy of the initial theory is discussed (Subsection 5.2.5.1). Then, each key aspect is elaborated (Subsection 5.2.5.2).

5.2.5.1. Empirical adequacy of the initial theory

The initial list of constructs is now linked to Appendix F, which presents the within and cross-case analysis concerning Drivers, Changing Practices, and Elements of Influence. Each Practitioner's measurements are clearly represented by their designated code in each table, making it easy to track and understand the data. This approach enhances clarity and encourages a more thorough examination of the findings.

The intersection of the initial theory with the empirical findings produced five major conclusions. First, the empirical findings support the initial theoretical conceptualization. The seventeen Practitioners who participated in the study provided positive evaluations of all constructs on the 5-point Likert scale, with no responses indicating *"total disagreement"*. Additionally, the study effectively identified all the Elements of Influence, as outlined in Appendix I, reinforcing the significance of these findings.

Second, this study shows a consensus within and across sectors on three constructs that determine the impact of a Construction industrialization process. Two Drivers (Productivity (D1) and Competitiveness (D2)) and one Principle (Value Creation (CP.P11)) have been given top priority status in all sectors. These elements are recognized as essential for success in all sectors. A study

developed by Razkenari et al. (2020) (listed in Table 5.5) found that increasing productivity ranks only fourth as the most important driver for using off-site construction. This underscores the need to focus not only on productivity but also on competitiveness and value creation across three levels of Sustainability (Economic, Social, and Environmental) to fully leverage industrialization's benefits.

Third, interesting cross-case similarities are highlighted in this study, where at least one sector Practitioner shows a high level of agreement on the following constructs:

- Drivers (all): Productivity (D1), Competitiveness (D2), Human (D3), Society (D4), Environment (D5) and Project (D6).
- Principles (eight out of eleven): Off-site Construction (CP.P1), Modularization (CP.P2), Automation (CP.P3), Digitalization (CP.P4), Production System (CP.P6), Design for Manufacturability and Assembly (CP.P9), Integrated Project Management (CP.P10), and Value Creation (CP.P11).
- Organizational Dimensions (seven out of eleven): Strategy (CP.D1), Organizational Design (CP.D2), Operations (CP.D3), Innovation (CP.D4), Supply Chain Management (CP.D7), and Skills (CP.D8).
- Elements of Influence (five of thirteen): Industry (EF.F2), Project (EF.F4), Supply Chain Integration (EF.I1), Collaboration and Cooperation (EF.I2), and Teamwork (EF.I4).

Conversely (and fourth conclusion), the empirical findings also indicate that there are sector-specific aspects that need to be addressed in a comprehensive cross-sector study. The Architecture sector demonstrates a clear resistance to production-related principles (CP.P3, CP.P5, CP.P6, and CP.P7), opting instead to focus on factors that influence project design (CP.P2, CP.P4, CP.P9, and CP.10). In contrast, the Engineering sector emphasizes the importance of digitalization while expressing caution regarding the impact of organizational dimensions on the Construction Industrialization development process. Conversely, other sectors show significant interest and agreement on the relevance of these factors for their enterprises, although the Engineering sector does not prioritize production-related issues. The Traditional Construction sector acknowledges the critical role of the external environment in the development of Construction Industrialization, largely due to its reliance on various stakeholders who are essential to construction activities. Meanwhile, the Manufactured Construction sector places substantial emphasis on production-related principles (consistent with Lessing et al., 2015). These empirical findings underscore the importance of

addressing sector-specific aspects within a comprehensive cross-sector study, an area where previous research has not been successful (see Table 5.5). Each sector highlights vital changes in routines and skills that are essential for advancing Construction Industrialization.

Five, there is a consensus across all sectors that the CI process should include both hard and soft aspects of organizational dimensions. Practitioners' perspectives provide a strong foundation for understanding the CI process as an organizational transformation. Practitioners believe that the Principles and Organizational Dimensions of the CI process are not only interrelated but also mutually reinforce each other. According to a Practitioner (E2) from the Engineering sector, as "*CI is a comprehensive change, it is necessary to relate the principles and organizational dimensions*". This view is supported by another Practitioner (MC5) from the Manufactured Construction sector, who believes that "*there is an absolute correlation and dependency between the principles and organizational dimensions".* An Architectural Practitioner (A2) also emphasizes the importance of integrating "*culture and training at the core of the business, allowing people to grow professionally and personally through continuous learning programs, which can have a positive impact on the construction industrialization process*".

5.2.5.2. Empirical insights to elaborate the CI theory

Table 5.8 provides a comprehensive view of the research findings, confronting theory and practice. It presents data on core aspects such as Drivers, Changing Practices, and Elements of Influence, which helps to synthesize the 36 constructs that remained, six that were revised, and 18 that emerged as a result of this research. The organization of these constructs follows the coding process outlined in Appendix I. Ultimately, Table 5.8 provides answers to the three research questions that guided this study.

Table 5.8: Summary of the initial list of each key aspect (Drivers, Changing Practices, and Elements of Influence) with the new contributions of the multiple case study in **bold**

Key CI Aspects and RQs	From the previous work, and its revision in this empirical study.	From this empirical research
	Rationale and Results	**Rationale**
DRIVERS	D1: Improve the productivity of the industry	**D7: Answer to market pressures**
(RQ1)	D2: Improve the competitiveness of the company	**D8: Desire to Innovate**
	D3: Individual human development	**D9: Client service pos construction**
	D4: Improve the quality of life and well-being of society* (**the worker, the social responsibility, the business environment, and the cities)**	**D10: Expand theoretical boundaries**
	D5: Promote **sustainable and efficient buildings and practices**	**D11: Transparency in the supply chain**
	D6: Performance of each project, in terms of **time-to-market**, cost, and quality	**D12: Excellent in cost and budget control**
		Results
		Main categories: economic, environmental, social, and design - Appendix I)

Table 5.8: Summary of the initial list of each key aspect (Drivers, Changing Practices, and Elements of Influence) with the new contributions of the multiple case study in **bold** *(continue)*

Key CI Aspects and RQs	From the previous work and its revision in this empirical study.	From this empirical research
CHANGING CONDITIONS (RQ2)	**Principles**	
	CP.P1: Off-Site, Prefabricated (Factory) Production	**CP.P12: Fulfill a New Constructive System ("*ready to use*")**
	CP.P2: Modularization	**CP.P13: Experimentation, Testing, and Collaborative Learning**
	CP.P3: Automated Production	**CP.P14: Environmental and Life Cycle Optimization and Certification**
	CP.P4: Digitalization, BIM and Industry 4.0	**CP.P15: Aesthetics and Creativity**
	CP.P5: Lean Transformation	
	CP.P6: Production System	
	CP.P7: Mass Customization	
	CP.P8: Business Model	
	CP.P9: Design for Manufacturing and Assembly (DFMA)	
	CP.P10: Integrated Project Management	
	CP.P11: Value Creation	
	Dimensions	
	CP.D1: Strategy	**CP.D12: Employment, Job Restructuration, and Health Management**
	CP.D2: Organizational Design	**CP.D13: Partnership, Cooperation, and Social Network Responsibility**
	CP.D3: Operations	**CP.D14: Budget and Cost Control**
	CP.D4: Innovation	**CP.D15: Risk Management**
	CP.D5: Management Systems	**CP.D16: Societal Barriers, Marketing, and Communication**
	CP.D6: Technology	
	CP.D7: Supply Chain Management	
	CP.D8: Worker Capabilities	
	CP.D9: Social & Behaviors	
	CP.D10: Culture	
	CP.D11: Leadership	

Table 5.8: Summary of the initial list of each key aspect (Drivers, Changing Practices, and Elements of Influence) with the new contributions of the multiple case study in **bold** *(continue)*

Key CI Aspects and RQs	From the previous work and its revision in this empirical study.	From this empirical research
ELEMENTS OF INFLUENCE (RQ3)	**External Factors**	
	EF.E1: General Environment	**EF.E6: Construction Community**
	EF.E2: Industry **(Externalities, Supply Market, Modular Construction Market, and Traditional Construction Market)**	**EF.E7: Universities and Schools**
	EF.E3: Company	
	EF.E4: Project	
	EF.E5: Worker	
	Internal Circumstances	
	EF.I1: Supply Chain Integration	**EF.I9: Ambition and Curiosity**
	EF.I2: Collaboration and Cooperation	**EF.I10: Training, Learning, and Research**
	EF.I3: Communication	**EF.I11: Culture Change and Mentalities**
	EF.I4: Teamwork	**EF.I12: Sense of Global Change**
	EF.I5: Knowledge Sharing	**EF.I13: Intellectual Humility**
	EF.I6: Motivation	
	EF.I7: Employee involvement	
	EF.I8: Organizational Commitment	

The following are the key findings of the study:

Regarding the **Drivers**, the CI theory (theoretical framework and constructs) is redirected since two dimensions are particularly emphasized. First, the societal dimension (D3, D4, and D5). This dimension was not given much attention in the prior contributions of the Drivers. The second dimension is the economic advantage (D6, D7, D8, D9, D10, D11, and D12) due to the new construction approach, which provides faster time and strategic opportunities. The study's empirical findings show that improved time-to-market (D6) is one of the main Drivers. The initial list has undergone a significant revision, placing a strong emphasis on three vital Drivers:

- **Improve the quality of life and well-being of society (the worker, the social responsibility, the business environment, and the cities) (D4).** The first (refined) Driver, known as the societal dimension, underscores the importance of considering the social implications and impacts of construction initiatives. This dimension highlights the necessity of aligning projects with community needs and values, fostering a positive relationship between development and the society it serves.
- **Promote sustainable and efficient buildings and practices (D5).** The second (refined) Driver focuses on sustainable advantages. This aspect emphasizes the critical need for long-term sustainability in construction practices, advocating for methods that not only minimize environmental impact but also promote economic viability and social equity. By prioritizing sustainable advantages, organizations can ensure that their projects deliver lasting benefits.
- **Performance of each project, in terms of time-to-market, cost, and quality (D6).** The third (refined) Driver concentrates on the execution of projects, which is rooted in a new, innovative construction approach. This approach is designed to streamline processes, thereby expediting project timelines while also creating strategic opportunities for growth and efficiency. By embracing advanced methodologies and technologies, the construction industry can enhance productivity and responsiveness to market demands.

The new constructs identified in this study include:

- **Answer to market pressures (D7).** A significant number of Practitioners from different sectors have pointed out the escalating pressure in the construction industry to embrace the CI phenomenon. Clients and Promoters are actively requesting enhancements, while

Governments are stepping in with incentives. Research on change indicates that a significant portion of transformations is driven by market pressure, and industrialization is no exception. Embracing CI is not merely an option — it's a necessary response to industry-wide pressure, according to the Practitioners.

- **Desire to Innovate (D8).** Many Practitioners have pointed out the long-standing stagnation in the construction industry. The prospect of contributing to a new and innovative future for construction is not just appealing; it serves as a powerful motivator for Practitioners eager to drive change. This enthusiasm for transforming the industry can be a compelling topic, inspiring more individuals to join the movement for progress.
- **The Improved post-construction warranty costs and processes via client service (D9)**: Goulding et al. (2015) introduced it, but they emphasized extending the warranty term, instead of considering how to make the warranty process more efficient and effective as part of the CI process. This study brings empirical evidence for the latter approach.
- **The Technological Boundaries topic (D10)** has not received much academic attention as a driver of CI in the construction industry. However, it was proposed by an Architecture Practitioner, highlighting its potential practical relevance.
- **The Stakeholder interactions and Communication (D11)**: while the literature often attributed it as a consequence of the CI process, this study views it as a Driver of sector-wide integration and collaboration, providing a novel perspective in the literature on CI.
- **The Excellence in Cost and Budget Control (D12)**: Wang et al. (2020) and Dang et al. (2020) suggest an expectation of cost reduction from a project perspective, and Wuni et al. (2022) warn of the initial investment barrier. Practitioners have defined CI in terms of economic profit from an organizational and industry perspective, which encompasses a wider scope than what has previously been presented in the literature.

In an analysis of the **Results**, this empirical study has identified four key categories: Economic, Environmental, Social, and Design. This broad societal perspective contrasts with previous literature, which primarily focuses on environmental issues (Section 5.2.2). While further exploration is necessary, these categories provide a vital foundation for CI development initiatives.

Regarding the **Changing Practices**, this study highlights four dimensions that have gained emphasis. The first dimension focuses on digitalization and achieving operational excellence (CP.P5, CP.P6). The second perspective is related to design (CP.P7, CP.P9, and CP.P12), and the third perspective pertains to assessment (CP.P13, CP.D14, and CP.D15). Finally, the fourth perspective is the societal perspective, which includes the Changing Practices previously discussed (CP.P14, CP.D12, CP.D13, and CP.D16). Changing practices are divided between Design Principles and Organizational Dimensions.

Concerning the Design Principles, the prior list of Design Principles was revised on two constructs.

- **Digitalization, BIM and Industry 4.0 (CP.P4).** The first (refined) construct prioritizes achieving complete digitalization across the entire life cycle of a building project, factory, and supply chain. It underscores the critical role of digital tools, particularly Building Information Modeling (BIM) software, as a key element in enhancing the efficiency and effectiveness of the CI phenomenon. This insight is supported by data from various sources and interviews across different sectors. In addition to digitalization and BIM, several Practitioners point to the relevance of the Industry 4.0 paradigm in the CI process, suggesting that the construct be further refined to incorporate this aspect as well.
- **Design for Manufacturing and Assembly (DFMA) (CP.C9).** This second (refined) construct aligns with Practitioner A2's warning about *"designing buildings as products"* due to the longevity of buildings, which typically last over 100 years, and the difficulty of quickly correcting bad decisions. In response, other Practitioners proposed shifting to DFMA (Design for Manufacturing and Assembly), aiming to optimize the design and construction process by focusing on efficiency and the unique requirements of the industry. This shift was further supported by meetings and reports centered on DFMA.

Additionally, four new Design Principles were added:

- **Fulfilling a New Constructive System (CP.P11).** Lessing et al. (2015) and Zakaria et al. (2018) may use "*Industrialized Systems*" and "*Off-site Construction*" as interchangeable terms (respectively), but Practitioners highlight an important distinction. Practitioners assert that there are two critical dimensions to CI adoption: the building itself and the processes employed to produce it. When a building deviates from traditional construction methods, it not only necessitates a different production approach but also introduces unique design challenges. Practitioners emphasize the importance of developing a new

constructive system specifically designed to offer a "*ready-to-use*" (Appendix I) modular systems that fit within the factory context. This tailored approach will address the evolving needs of the industry and pave the way for greater efficiency and effectiveness.

- **Experimentation, Testing, and Collaborative Learning (DP.P12).** The existing literature has placed considerable emphasis on computer-based experiments, focusing on both construction and operational aspects (Wu et al., 2019). However, it frequently overlooks the essential role of real-world experiments in the construction industry. Practitioners indicate that the development of full-scale prototypes within a Living Lab has successfully identified numerous issues and fostered significant improvements. Consequently, this practical dimension is crucial to advancing the process of Construction Industrialization.
- **Environmental and Life Cycle Optimization and Certification (CP.P13).** The literature highlights the significant impact of a project-based approach on building quality. Practitioners, including Practitioner E2, contend that product certification for modular systems is crucial for ensuring both quality and efficiency. One meeting observed highlighted crucial topics, as outlined in Appendix I, emphasizing the importance of Legislation and the Leadership in Energy and Environmental Design (LEED) certification. Furthermore, discussions centered on energy efficiency and energy poverty illuminated the pressing need for immediate action in these vital areas, urging a deeper commitment to sustainable practices. This commitment is not only essential but is also a driving force highlighted in this empirical study for Practitioners.
- **Ensure Aesthetics and Creativity (CP.P14).** Luo et al. (2020), Razkenari et al. (2020), and Wuni & Shen (2020) highlight that a lack of aesthetic appeal and monotonous design are significant barriers to CI development. While earlier literature has predominantly emphasized repetition and standardization, this study makes a compelling case for the critical role of creativity and complexity in the field. Practitioner MC8 clearly states that empowering architects with creative freedom is essential for driving meaningful industrialization and transforming the industry.

Regarding the **Organizational Dimensions**, none of the initial dimensions were revised. Consequently, only new ones were added:

- **Employment, Job restructuring, and Health Management (CP.D12).** The existing literature on CI practices inadequately addresses these three important topics. Each of these concerns holds significant implications for the industry and necessitates thorough examination and action from a practical standpoint. This study proposes that evolving CI practices should prioritize these three issues, as doing so will not only address existing challenges but also enhance the overall working conditions and efficiency for professionals in the construction sector. By focusing on these areas, the industry can foster a more conducive environment that promotes safety, productivity, and worker satisfaction.
- **Partnership, Cooperation, and Social Network Responsibility (CP.P13).** The issue of social concern has emerged once more, and the Authors of this paper contend that it has not been adequately addressed in the existing literature. This connects directly to the significant emphasis on collaboration, cooperation, and partnership highlighted in the empirical study (Appendix I). The introduction of the CI phenomenon represents a noteworthy shift towards a more integrated social behavior, rather than a fragmented industry. This transformation is crucial for nurturing a cohesive and collaborative future.
- **Budget and Cost Control (CP.P14).** Previous studies have emphasized the significance of conducting further research on this topic to better understand its implications and potential solutions. The phenomenon of CI, as outlined in the empirical study, plays a significant role in striving for excellence in cost control and management. By implementing rigorous calculations that consider both business perspectives and customer sales, companies can enhance their competitiveness, a primary rationale valued by industry Practitioners.
- **Risk Management (CP.P15).** The implementation of the phenomenon undoubtedly involves substantial risks. Wuni et al. (2022) identified major CI risk variables. As Practitioner E2 highlights, "*our understanding of its application remains limited*". Practitioners recommend categorizing and assessing the risks associated with implementing the phenomenon to ensure informed decision-making and enhance overall success.
- **Social Barriers, Marketing, and Communication (CP.D16).** The case study highlights a significant resistance to industrialized buildings from Clients, Developers, Inspectors, and the broader industry, as well as the general public. To effectively address

this challenge, Practitioners advocate for a targeted marketing and communication strategy designed to break down the social barriers that hinder the acceptance of this innovative approach. The construction industry suffers from a negative reputation, with many dismissing modular construction as "*low-quality building systems*," "*boring*", or "*unattractive*" (see Appendix I). By fostering understanding and awareness, "*we can pave the way for a more favorable perception and wider adoption of the CI phenomenon,*" as shared in a meeting observed.

Elements of influence are divided between External factors and Internal Circumstances.

Regarding the External Factors, one construct has been refined for a clearer understanding.

- **Industry (Externalities, Supply Market, Modular Construction Market, and Traditional Construction Market) (EF.E2).** An across-case analysis revealed the potential of externalities as a new influencing factor for companies. Additionally, according to the perspectives of Manufactured Construction Practitioners, the supply market—including materials, operational technologies, transportation, and handling solutions—also plays a significant role in both production and construction capacity, as well as in the logistical resources involved. Simultaneously, the entire industry is significantly influenced by the traditional and modular construction market, which fosters a growing demand for industrialized buildings.

Two new constructs are added, emphasizing the Practitioners' perspectives.

- **Construction Community (EF.E6).** Practitioners assert that it is crucial for regulators and industry-wide organizations to create or update certifications and standards to keep pace with emerging production methods. The findings from the empirical study indicate that CI plays a broader role, impacting not just companies relying on standardized processes.
- **Universities and Schools (EF.E7).** Practitioners argue that educational programs in the field of construction have yet to fully adapt to recent developments. The content being taught remains traditional, while companies are focusing on industrialization. Additionally, Practitioners note a lack of training opportunities in the CI field.

When examining **internal circumstances**, six new elements of influence emerge that significantly impact both employees and company culture. These elements highlight the importance of the social, relational, cultural, and emotional dimensions of this phenomenon. To overlook the internal circumstances is to ignore the vital soft side of change. Practitioners assert that while the technical aspects may shape the process, it is the social dimension that poses the greatest challenge in the face of CI development. Recognizing this reality is crucial for creating a successful and productive workplace environment.

- **Ambition and Curiosity (EF.I9).** Throughout the entire process of CI development, Practitioners strongly believe that nurturing ambition and curiosity is essential to driving innovation and effectively tackling challenges.
- **Training, Learning, and Research (EF.I10).** Practitioners claim that CI brings forth not only new knowledge and areas of expertise but also valuable experiences that demand additional research. Training, Learning, and Research are crucial for effectively understanding and implementing the diverse initiatives associated with this significant phenomenon.
- **Culture Change and Mentalities (EF.I11).** CI represents a significant transformational change that has far-reaching implications, impacting every facet of an organization. This shift influences not only the core values that define the company's culture but also alters established routines and workflows.
- **Sense of Global Change (EF.I12).** Construction Industrialization strives to foster global change, and for this transformation to be truly impactful, it must engage and unite communities worldwide. Whether from the perspective of industry professionals or those who benefit from it, it is essential to recognize industrialization as a force that shapes cities and improves people's lives. Fostering this understanding among workers and participants in the construction industrialization process helps create a shared vision of progress and innovation.
- **Intellectual Humility (EF.I13).** The transition to industrial thinking involves converting operations, processes, and decades-old construction practices, which requires Managers to broaden their intellectual limits to acquire new information and ideas.

5.2.6. Discussion and Implications for Theory and Practice

This paper, as a contribution to theory and practice, addresses the limitations across conceptual, systematic, empirical, and practical dimensions identified in the Literature Review (Section 2). A theoretically robust and empirically grounded tool for supporting construction managers in CI development is proposed (Table IV).

By systematically tackling the specific limitations of previous research, this study offers several novel contributions. It advances theoretical interpretation commonly found in earlier studies, building upon the foundational work of Costa et al. (2023, 2024) to offer a more comprehensive and empirically supported characterization of the Construction Industrialization process.

While Costa et al. (2023, 2024) laid an important theoretical foundation, this paper extends it through empirical insights, emphasizing CI's multidimensional nature and incorporating aspects previously underexplored in the literature. For instance, rather than confining CI to narrow, project-based interpretations (Table I), this study embraces it as a multifaceted, holistic, and strategic transformation process, particularly highlighting its socially embedded nature, which has been largely overlooked in existing literature.

Furthermore, this study addresses the typical fragmentation found in existing tools by integrating key aspects such as Drivers (factors initiating change), Changing Practices (actions or processes that constitute the change), and additional Elements of Influence. This integration offers a systematic and holistic perspective on CI.

Moreover, prior studies often failed to capture the full complexity of CI, limiting their applicability across sectors and contexts due to conceptual fragmentation. Therefore, a key contribution is also bridging the gap between theoretical models and practical applications of CI. By incorporating cross-sectoral and international perspectives, this study reveals the limitations of current theories when applied across diverse contexts.

Table IV presents a comprehensive list of directives outlining the changing practices companies must adopt to navigate the CI transition. This list highlights the complexity and interdependence of Drivers, the Changing Practices, and Elements of Influence that shape them – a perspective uncommon in the existing literature (Section 2). This broader understanding is a novel contribution to literature, significantly enhancing the external validity and practical relevance of CI theory for a wider range of organizations and sectors.

Academically, this paper offers a novel and more precise characterization of the CI process, as detailed in Table IV. It aims to unify divergent interpretations of the CI transition (Section 2) by explicitly employing and distinguishing the concept of Construction Industrialization from related terms. Without such a cohesive theoretical foundation, efforts to measure CI adoption, assess its impacts, or design effective strategies and policies remain fragmented and inconclusive, as verified in the existing literature.

In addition, this study goes beyond addressing past limitations and makes novel contributions that redefine CI theory and practice. Especially, it presents CI development along a large list of unique insights that the literature has not yet covered, but which are relevant in the practical context since they reflect its full reach and holistic view of the CI paradigm. As a result of this study, four main areas for reorientation in CI theory are identified, which are not presented in prior works.

The foundation of CI is an organizational transformation. One of the most important contributions of this study to CI literature is the shift in attention from industrialized building projects to organizational transformations, which is supported by empirical evidence. As previously stated in Subsection 5.1, Practitioners vehemently endorse this shift, whereas the literature has not yet devoted sufficient attention to it. As such, this paper offers a starting point for managers, decision-makers, and academics to start operating and researching with such a mind shift. It is crucial to consider both hard and soft dimensions, as they affect everything from routines to behaviors and the way work is done.

Scholars have long argued that CI extends beyond product innovation (thought modulation) and process improvements (such as prefabrication and industrial construction) (Hosseini et al., 2018; Luo et al., 2020). Moreover, these authors have cautioned that this narrow perspective has hindered a comprehensive understanding of CI and its consistent adoption within the industry. This study reinforces that view, demonstrating through case study findings that CI must be understood as both a technical and social process, one inherently tied to a paradigm shift in the construction industry. This interpretation has been largely absent in the current literature, and this paper aims to spark further debate and research on the subject.

The societal impact predominance. The impact of humanist values on Changing Practices and Elements of Influence is significant and has been observed over two years. This paper provides a deeper reflection on the societal impact of the CI phenomenon, addressing a gap in the literature where studies and syntheses have been lacking. So far, societal concerns have been introduced

into the CI literature with a focus on environmental issues (Dang et al., 2020; Wang et al., 2020; Li et al., 2018) and people's safety (Goulding et al., 2015; Zakaria et al., 2018; Bendi et al., 2020). Notably, the primary challenges faced by the case sectors are those that have a direct influence on the industry as social systems. Practitioners emphasize the importance of examining work environments (CP.D12) and social relations (CP.D13), as well as the beliefs (EF.I11; EF.I12), abilities (EF.I9; EF.I13), and dispositions of workers (EF.I10).

To the best of the authors' knowledge, such a broad perspective, considering both the company and the worker as two levels of societal impact, has been underexplored in the current literature. Moreover, none of the models listed in Table I consider this perspective on CI development as a dimension, except for the authors' previous works, which incorporate this aspect of change into the industrialization literature.

Furthermore, this empirical study shows that CI impacts individuals across various communities, including those who work in the industry, live in a city, are part of a regulatory body, or belong to another community. The construction industry is an integral part of a society's aesthetic, historical, intellectual, and cultural growth. People's behavior and the construction industry's attitudes must be taken into account for the revolution that CI implies, according to this empirical study. CI development influences and is influenced by society. The adoption and acceptance of CI are also influenced by societal preconceptions and beliefs. According to the case study findings (aligned with CP.D16), further research is needed in this area, as it remains an underexplored aspect of the CI field.

The thinking about industrialization for "*operational excellence*". A third area of discovery is the condition of "operational excellence," which has been vaguely discussed in the construction literature as its constitution as a construct. "Operational Excellence" is a term used in the field of industrial engineering to refer to management practices that help companies achieve efficiency gains and enhance customer satisfaction. Traditional construction is often defined by inefficient processes that result in lower productivity. During site visits, it was observed that "producing with the same methods and fabrication processes in a controlled environment only brings back the same problems that the construction industry has been facing for many decades, without solving them. This is not what is desired!". Practitioner A1 mentions that CI aims to "achieve excellence in construction from both a design and construction perspective, while also having a positive impact on society and the environment". As a result, the pursuit of "operational

excellence" does not seem applicable to conventional construction due to ongoing challenges such as poor performance, high costs, inadequate safety management, long construction times, excessive resource usage, and waste production (Goh & Loosemore, 2017; Zhang et al., 2022).

The role of building aesthetics and modular buildings "*ready to use*". The notion of "*ready to use*" construction aims to promote mass customization, which is still a rather confusing concept in practice, according to Practitioners. It encourages innovation, expands technological boundaries, and promotes the development of new types of constructive systems. Moreover, while industrialized construction must ensure supply uniformity and production repetition, it must also allow for freedom of aesthetics and selection. However, there are still uncertainties in practice, and the international team developing the Living Lab is working hard to perfect this "*ready-to-use*" constructive system. Nonetheless, each building involves a specific site with different conditions, and local architectural objectives are also different, as stated by one of the experts interviewed. Therefore, to understand industrialized construction, which requires collaboration among industries to create a "*ready-to-use*" solution, it is crucial to understand each sector and its change objectives as well.

This study also supports a multidisciplinary approach for CI, hoping that future research will embrace a more refined but broader look at CI, with new disciplines that can improve and help the CI process. Especially, this study acknowledges the CI transition as fundamentally an organizational process rather than simply a change in a building project (as commonly outlined in the previous literature). This conceptual shift is a critical contribution, not only advancing the academic field but also providing a robust strategic guide for industry Practitioners.

The identification of Drivers, Changing Practices, and Elements of Influence, supported by empirical data, also significantly offers a robust foundation for future studies in this field. Further studies are needed to address these aspects accordingly.

Lastly, this paper stresses the relevance of developing intra-sectoral and geographic diversity in academic articles. CI is a global phenomenon; therefore, fostering international cooperation and learning is essential for progress. By encouraging research sharing and open dialogue, we can significantly strengthen and enrich CI theory.

Practically, the findings presented in Table VI have immediate effects on the different sectors studied, particularly by understanding their within- and cross-case perspectives about the phenomenon and how each sector understands the CI development process. Moreover, given that

sectoral diversity is a key issue in this study, the integration of all sectoral perspectives into a single tool enables a comprehensive and unified understanding of CI development from a broad industry perspective, as intended. This study highlights that sectoral priorities differ significantly. However, CI is inherently a transformative industry-wide phenomenon, requiring each sector not only to implement internal changes but also to actively support and facilitate changes in other sectors. By consolidating these sector-specific priorities and perspectives within a common framework, this study enables each sector to reassess its role in advancing CI and to engage with others in meaningful collaboration and cooperation.

Moreover, each of the three key aspects – Drivers, Changing Practices, and Elements of Influence - is expanded upon, providing a systematic and detailed agenda for Practitioners in the CI adoption. Practitioners must develop a greater understanding of the key drivers behind each company's operations, including the broader implications for their industry. They need to recognize how their work practices and organizational habits contribute to—or hinder—the transition toward CI.

The identification of novel practices and the social and contextual factors affecting CI are significant contributions. These insights offer managers a valuable opportunity to educate their teams and shape strategies that support a more sustainable, industrialized approach. This study particularly highlights that all entities involved in the construction industry have a significant influence on CI development. Therefore, it is crucial to build further synergies, engage in new debates, and implement further innovations in products, processes, and operations. Collaboration, investment, and innovation are key to the implementation process. Ultimately, the authors of this study hope that their work on the CI transition will lead to greater acceptance and adoption in practice.

5.2.7. Conclusion

This research aimed to explore the perspective of Practitioners from different sectors involved in the construction industry regarding its Drivers, Changing Practices, and Elements of Influence.

This empirical study was guided by three research questions toward a deeper knowledge of the CI phenomenon. Regarding CI Drivers, this study presents a new perspective on social drivers from the viewpoints of society and its workforce. Furthermore, concerning the Changing Practices, this study emphasizes the importance of fortifying the link between Organizational Dimensions and developing Principles. The process of improving the Elements of Influence has been slowed by

social issues. These empirical findings require additional research on change dynamics, habits, and external influences in CI implementation. This study has further added knowledge regarding the CI transition process, leading to four important areas to redirect the CI theory when the key aspects are associated.

Some possible future paths for this study are as follows. First, in the Industrial Engineering and Management (IEM) field, it would be interesting to bring in Practitioners from IEM, drive Industrialization with their knowledge, and ensure that manufacturing principles are fully and completely implemented in Construction. Second, in the societal area. It would be interesting to understand how to assess the impact of Industrialization at the societal level. Still associated with the humanities, changing mindsets, changing habits, and changing stipulated ways of working, identified as immutable, is a great challenge. An in-depth study on applied social psychology, Industrialization becomes interesting. Third, on extending this study to (on-site) industrial sectors, such as aeronautics and shipping. Such exercise may allow researchers to understand how other organizations' industrial processes were planned and operationalized for industrialization. Lastly, on the environmental issue. It is encouraged to research green supply chain management practices and explore CI associated with the Circular Economy topic.

As with any research, some limitations need to be acknowledged. The main limitation is related to the empirical study sample. The empirical study was limited to Practitioners in the Architecture, Engineering, Traditional Construction, and Manufactured Construction cases; however, the paradigm shifts from construction to manufacturing imply global and impactful shifts from individual companies and fragmented supply chains to an entire industry that has to align on this purpose. The empirical study lacks the contribution of developers, suppliers, clients, consumers, and regulatory bodies, which, as found in the empirical results, have a high impact, both positive and negative, on the Construction Industrialization process. Future research should then study these stakeholders' perspectives.

Another limitation is related to the sample selection and, particularly, the fact that the Practitioners are part of the Portuguese Government's Funding Agenda, which might introduce bias into the study. To ensure impartiality and minimize bias, the Authors adopted strategies such as maintaining a passive observational role in meetings and using a consistent research framework throughout interviews. Practitioners were asked to reflect on their experiences rather than on the

literature. Potential bias in data analysis was addressed by maintaining a chain of evidence to ensure unbiased interpretation.

Lastly, it is important to emphasize that the primary objective of this paper is to contribute to the ongoing debate surrounding the development of a comprehensive, industry-wide understanding of the CI process. Specifically, this work focuses on identifying the key elements that constitute a CI process—the "what" that must be considered during its development. The detailed exploration of "*how*" these elements should be implemented, adapted, or optimized in practice falls outside the scope of this study and is intended to be addressed in future research, as well as in practical applications and professional debates.

Chapter 6

Conclusion

This last Chapter closes this research project. It was designed to draw together and summarize the conclusions of the research. First, a synopsis of this thesis is developed by revising the Doctoral Project's main contributions and by providing an explicit answer to the four previously stated research questions. Then, theoretical and managerial implications are discussed. The main limitations of the research and avenues for future research close this chapter.

6.1. Thesis Synopsis

The motivation for this Doctoral Project stems from a personal desire to contribute to the CI phenomenon. This study was initiated in response to a significant lack of comprehensive knowledge recognized by academia and industry regarding CI development.

Four gaps were addressed in this Doctoral Project (Chapter 1): (1) the lack of a common understanding of CI; (2) the lack of a comprehensive conceptualization of the CI phenomenon and its theoretical bases; (3) the lack of a framework that can effectively capture the complex nature of CI and guide Practitioners in their CI efforts; (4) the lack of empirical studies that attempt to achieve a greater understanding of the CI process.

This Doctoral Project explored the phenomenon of Construction Industrialization to answer the main research question: ***"How to assist construction Managers in a comprehensive Construction Industrialization development process?".***

Two main perspectives have been analyzed: i) the concept of CI and what it entails as one of the major transformational processes in the construction sector, and ii) Practitioners' experiences in the field, bringing an empirical perspective to the research. The goal is to provide Scholars and Practitioners with a solid framework to address the main CI development issues, ultimately driving progress and innovation in the field.

Four additional research questions were formulated:

RQ1: How has research defined and operationalized the concept of Construction Industrialization to date?

RQ2: How can Organizational Change and Change Management theories assist a comprehensive CI development process?

RQ3: How has the Construction Industrialization phenomenon been perceived in practice, both in terms of its definition and its development process?

RQ4: How can the phenomenon of Construction Industrialization be conceptualized to fill the current gaps in the literature and advance its understanding by linking theory and practice?

This research takes an abductive research approach and is structured into three parts: a conceptual part (RQ1 and RQ2), an empirical part (RQ3), and a third part that intersects theory and practice in a combined understanding (RQ4). While Chapters 3 and 4 address the conceptual part, Chapter 5 develops the other two.

The conceptual part of the study develops two systematic literature reviews. A first review, on CI that provides a comprehensive conceptualization of the phenomenon and its theoretical basis (Chapter 3). A second chapter, Chapter 4, integrates organizational change and change management theories into the CI debate to provide novel theoretical lenses.

In the empirical part of the study, a multiple case study is employed to examine Practitioners' perspectives (Chapter 5). Four data sources (interviews, meetings, reports, and site visits) were used. Two years of study were analyzed in the context of a Funding Governmental Agenda. An international sample was purposely selected to ensure the inclusion of diverse cross-sectoral and geographic representation. Architecture, Engineering, Traditional Construction, and Manufactured Construction were the sectors studied. Spain, England, and Portugal are the countries that compose the sample.

The third part of the study (Chapter 5) intersects theory and practice, revealing novel insights often overlooked in existing literature. This intersection captures the complexities and practical nuances of the field, leading to the emergence of new constructs that improve the comprehensive understanding of the CI development process. A definition of Construction Industrialization and a

transformation model are developed to clarify CI's complex nature and provide the necessary guidance to Practitioners when crafting their CI efforts.

Across the three parts of the study, therefore, the evolution of both the concept and the associated models is presented, showing their progressive development and refinement throughout the successive parts of the research process.

6.2. Major Research Contributions

This research presents thirteen major research contributions that advance the theory and practice of CI. A discussion of the research questions guiding this study highlights its main contributions.

RQ1: How has research defined and operationalized the concept of Construction Industrialization to date?

(1) Identification of the gaps both in the CI definition and conceptualization.

Chapter 3 highlights the limited number of studies aimed at defining the CI phenomenon and its related terms. It also points out a significant gap: the lack of comprehensive tools to enable the development of an effective CI process. Scholars argue that the fragmented nature of CI research poses considerable challenges, indicating a need for greater maturity and theoretical advancement in this field. These findings present an interesting starting point for this research, emphasizing its significance and originality.

(2) Development of a conceptual CI definition and conceptualization based on the available literature on CI.

Chapter 3 takes an important step in developing a CI definition and conceptualization of the CI process based on the findings from the Systematic Literature Review. Significantly, this study is the first to define the CI phenomenon itself rather than simply its related terms. The definition developed in Chapter 3 forms the theoretical foundation for the rest of the Doctoral Project. Additionally, Chapter 3 introduces a conceptual framework that adopts a comprehensive, system-level approach to understanding the intricate dynamics of companies involved in the CI

phenomenon. This framework, akin to the definition, sets the stage for promising future research opportunities.

(3) Introduction of organizational change conceptualization in the CI literature.

Chapter 3 concludes by outlining a clear direction for future research. It emphasizes the significance of studying organizational change theory to improve the existing understanding of how the CI phenomenon must be managed within organizations. This call for research has been thoughtfully addressed in this Doctoral Project, with further development in Chapter 4. Furthermore, this call for research acknowledges the dynamic and evolving nature of the CI phenomenon.

RQ2: How can Organizational Change and Change Management theories assist a comprehensive CI development process?

(4) Identification of the studies that intersect the Organizational Change and Change Management theories and the CI topic.

Chapter 4 presents a Systematic Literature Review that examines the intersection between the field of CI and theories of Organizational Change and Change Management. Although a limited number of studies were identified, the Scholars of these studies emphasized the relevance of this intersection for enhancing the existing understanding of the CI phenomenon. The findings suggest that incorporating change management principles into CI initiatives can enhance the effectiveness and sustainability of CI efforts. By bridging these two fields, organizations can develop more comprehensive strategies that not only drive efficiency but also address the human and structural challenges associated with change – a perspective that has been lacking in the CI field.

(5) Identification of fragmentation in the understanding of CI development, even in studies that intersect Organizational Change and Change Management theories and the CI topic.

Chapter 4 also shows the divergence among Scholars regarding the CI phenomenon, despite their use of organizational change and change management theories. Whether aiming to understand CI

in the context of organizational change or to outline the change process based on content and context, Scholars vary in their perspectives and approaches. Moreover, while some studies focus exclusively on either the hard or soft aspects of change, others attempt to address both, though with differing interpretations. This inconsistency has impeded progress and requires immediate attention. One possible reason for these inconsistencies is the absence of a systematic literature review that bridges the CI and OT fields. Without such a review, existing research remains fragmented, leading to gaps in understanding and limiting the potential for interdisciplinary insights. Chapter 4 addresses this gap by developing the first SLR that integrates these two fields.

(6) Development of an improved understanding of the CI phenomenon as a transformational change.

Chapter 4 presents the phenomenon of Construction Industrialization as a broad, multi-level, and multidisciplinary concept, framing it as a transformational change. To the best of the Author's knowledge, this chapter represents the first comprehensive academic examination of CI's depth, scope, and detail over time. Understanding this complexity is essential for establishing a solid conceptual model and guiding future empirical research effectively.

(7) Development of an Organizational Transformation-Oriented Model for the Construction Industrialization.

Chapter 4 develops a transformation model and brings a comprehensive CI framework, which has long been sought after. It thoroughly examines the core aspects of Process, Content, and Context. The model highlights the necessity for both soft and hard sides of change to work in harmony, ensuring a complete understanding of Scholars (e.g., Al-Haddad & Kotnour, 2015, and Gallego & Calderón Hernández, 2021) who have long argued that overlooking any side, or their interrelationship, can jeopardize strategic transformation. This contribution is significant not only for academic literature but also for practical applications, as it provides a consolidated foundation for future research and offers valuable insights for Practitioners seeking to leverage CI within organizational bases. In this thesis, the research contribution lies in advancing prior theoretical knowledge through the abductive research process followed in this study. By integrating key findings from Chapters 3 and 4, this contribution sustains the empirical study.

RQ3: How has the Construction Industrialization phenomenon been perceived in practice, both in terms of its definition and its development process?

(8) Exploration of the CI phenomenon in an empirical study, both in terms of the CI concept and the CI development process.

Chapter 5 provides valuable insights that enrich existing literature. This Doctoral Project provides the first empirical analysis of Practitioners' perspectives on Construction Industrialization. It explores four critical sectors of construction—Architecture, Engineering, Traditional Construction, and Manufactured Construction —while drawing knowledge from multiple countries, including Portugal, Spain, and England. As a result, divergent perspectives are reached that, in the end, only contribute to a better understanding of the CI phenomenon and process.

(9) Identification of similarities and differences between the Practitioner's viewpoints from a sectoral perspective.

Chapter 5 highlights the importance of understanding the CI phenomenon from a comprehensive, industry-wide perspective by examining the similarities and differences in viewpoints among various Practitioners. Key differences in priorities were noted: architects focus on design, planners on both design and engineering, traditional construction emphasizes the external environment and supply chain, while manufactured construction prioritizes industrial production and organizational change. Despite these differences, some areas of consensus emerge across the four sectors. For instance, there is a shared understanding that social and cultural barriers often precede technical challenges when adopting the CI's new practices.

(10) Acknowledgement that all Practitioners recognize CI development as dependent on the mutual relationship between CI principles and change dimensions.

Chapter 5 highlights the Practitioners' perspective that CI entails organizational change. Practitioners across the industry recognize a strong connection between CI and Organizational Change and Change Management theories. This reflects an acknowledgment that successful innovation requires not only technical advancements but also a structured approach to managing the human and organizational dimensions of change.

RQ4: How can the phenomenon of Construction Industrialization be conceptualized to fill the current gaps in the literature and advance its understanding by linking theory and practice?

(11) Development of a CI definition intersecting practical and theoretical perspectives.

Chapter 5 provides a refined definition of the CI phenomenon. It bridges theoretical insights with practical applications, integrating findings from Chapters 3, 4, and 5 with the valuable perspectives of industry Practitioners. The findings reveal that CI represents a critical shift from traditional construction methods to more efficient practices. Unlike earlier studies that primarily focused on *"production"*, this research frames CI as a comprehensive management strategy that aligns design principles, organizational dimensions, and contextual influences. To fully leverage CI's benefits, embracing both technical advancements and sociocultural changes is essential. Additionally, Practitioners highlight that the advantages of industrialization extend well beyond individual projects, making this research a noteworthy contribution to the existing literature.

(12) Characterization of the CI development process intersecting practical and theoretical perspectives.

Chapter 5 is a critical Chapter for construction Managers, guiding them in strengthening their Construction Industrialization initiatives through an organizational transformation model. Building on the foundational theories presented in Chapters 3 and 4, this chapter not only provides practical strategies but also deepens theoretical understanding. The transformation model highlights three core aspects: (1) Process, (2) Content, and (3) Context. These aspects clarify essential rationales and factors crucial for understanding the development process of Construction Industrialization. Each identified dimension is supported by empirical evidence, and the new insights from this study enrich the literature on Construction Industrialization, emphasizing the model's crucial role in driving successful initiatives. This Doctoral Project makes a substantial contribution to both academic knowledge and industry practices across all core aspects—(1), (2), and (3)—affirming its significance in today's construction landscape.

(13) Identification of new dimensions to enrich and redirect the CI theory

Chapter 5 offers new dimensions into both literature and practice through the CI concept and CI process clarification. It presents CI not merely as a process, but as a powerful catalyst for both soft and hard sides of change. At its foundation, CI drives organizational transformation, underscoring its significant societal impact. This chapter also invites Scholars and Practitioners to reimagine Industrialization as a pathway to excellence. Furthermore, it emphasizes the essential role of aesthetics in building design and advocates for modular buildings that are "*ready to use*". Embracing these new dimensions can lead to substantial advancements in the current approach to the CI phenomenon.

6.3. Overview of the Central Research Question

From the above research contributions, the Author is ready to answer the main research question that guides this study, and which was the basis for its beginning: "*How to assist construction Managers in a comprehensive construction industrialization process?*".

This Doctoral Project asserts that a comprehensive understanding of the CI process requires a clear grasp of its underlying concept. As stated in Chapter 1, a well-defined phenomenon enhances clarity regarding its scope, boundaries, and key constructs (Stock & Boyer, 2009).

Therefore, this thesis aims to explore the phenomenon of CI by developing:

1) A structured and comprehensive definition of the phenomenon of Construction Industrialization that redirects both academic debate and industry perspectives;
2) The characterization of the CI development process through a transformation model that helps to capture the complex nature of CI and can provide the necessary guidance to Practitioners when crafting their CI efforts.

Additionally, this thesis traces the development of these two elements, starting with an examination of the Construction Industrialization literature (Chapter 3) and advancing to a more nuanced theoretical model that incorporates organizational change and change management theories (Chapter 4). Additionally, valuable insights from industry Practitioners are integrated and intersected with the conceptual perspective (Chapter 5), ensuring a well-rounded perspective.

Combining definition and process provides a comprehensive understanding of how CI should be interpreted and implemented. This alignment ensures coherence with the broader body of knowledge, industry best practices, and the practical communication of guidelines. Moreover, it facilitates the refinement of theory and the identification of innovative approaches by clearly identifying the key constructs of a phenomenon.

In this context, theory and practice rely on the same reasoning and language to address a phenomenon that remains complex, somewhat ambiguous, and fraught with uncertainties and narrow perspectives. When these aspects – conceptualization and development - are misaligned, uncertainty increases, leaving the true complexity of the phenomenon, emphasized in Chapter 1, open for further exploration. As noted by Stock and Boyer (2009) in Chapter 1, the absence of valid constructs and widely accepted definitions hinders the development of sound theory, leading to theoretical ambiguity.

As a result, the new definition developed in this thesis is:

> ***"Construction Industrialization is a new form of production and management, driven by the adoption of several individual and integrated construction, industrial engineering, and management innovations in a process of technical and sociocultural change, whose objective is to improve productivity in the construction industry and societal sustainable development".***

By offering a comprehensive understanding of CI—situated within the current construction industry landscape—this thesis challenges previous interpretations and distinguishes CI from related or overlapping concepts. Establishing a clear, widely accepted definition will help mitigate conceptual ambiguity, confusion, and the fragmented nature of CI interpretations. A strong theoretical foundation, embraced by both academia and practice, is essential for the systematic advancement of knowledge in this field.

Alongside the development of the definition, a transformational model is also developed. Such a transformation model combines the previous definition, the transformational model introduced in Chapter 4, with the summary table from Chapter 5. Figure 6.1 presents the transformation model that encapsulates the various dimensions of the transition from traditional construction methods to the phenomenon of CI. This integrative model offers a thorough perspective on the innovations within the "*production and management*" aspects of CI, particularly in relation to CI adoption, as defined in this thesis.

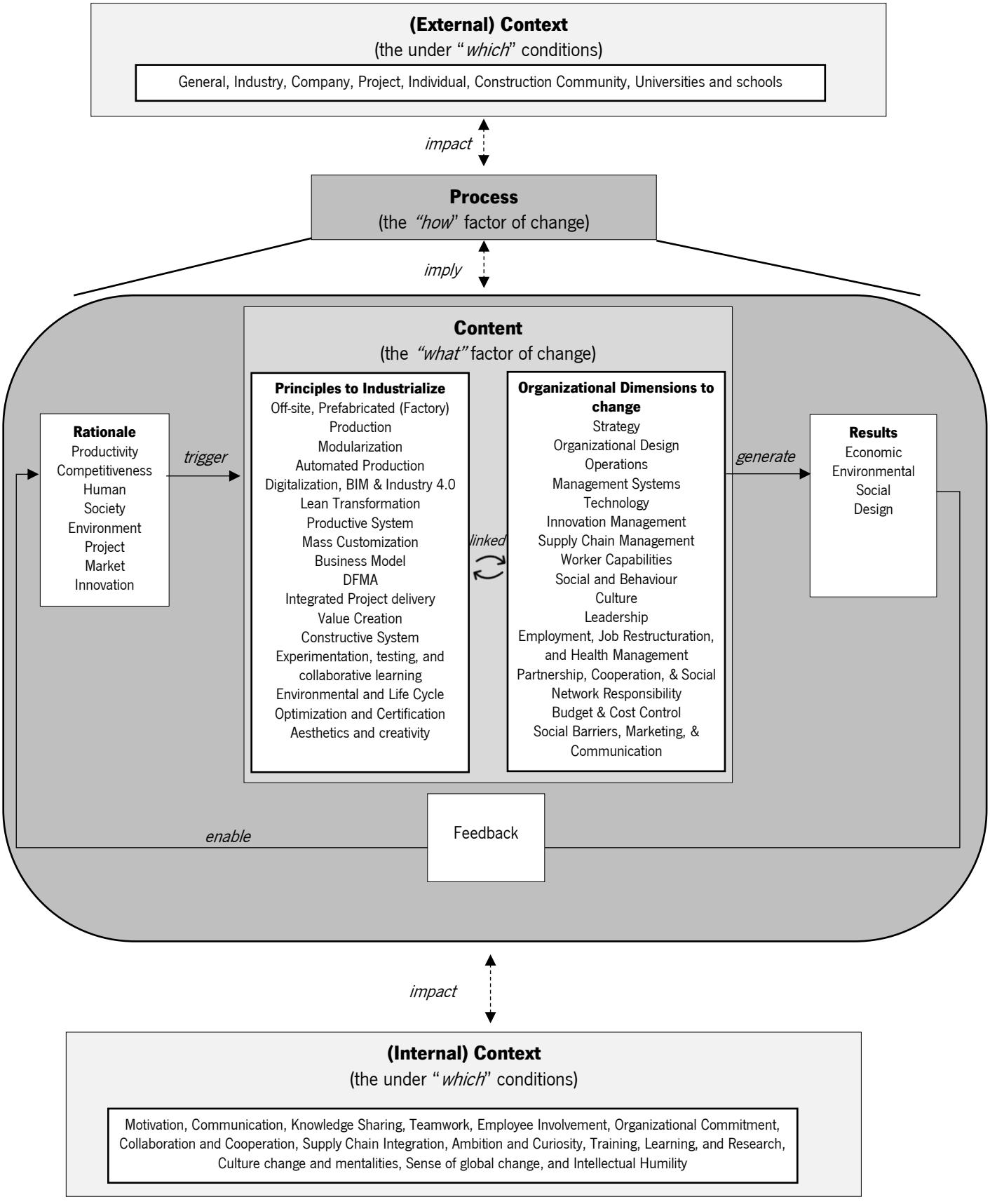


Figure 6.1: The final Organizational transformation-oriented framework for the Construction Industrialization development process that links theory and practice

At its core and aligned with the abductive research approach adopted in this thesis, the transformation model introduces key constructs that provide insights into the evolution of CI and how its development can be systematically applied in real-world settings. These constructs frame the CI development into key aspects that can be studied and applied across diverse contexts.

These key aspects include Drivers and Results, Changing Practices, and Elements of Influence, all of which are essential for the successful implementation of the CI phenomenon, according to this research. The significance of these key aspects and related constructs, in understanding the CI phenomenon, is fundamental in framing the complexities of CI in a way that enables companies to navigate the rapid changes within the industry while improving the overall effectiveness of its implementation.

Additionally, the transformation model includes a set of Design Principles, which are universally applicable across different sectors and regions, recognizing the diversity within the global construction industry. These principles align with the broader scope of "*several individual and integrated construction, industrial engineering, and management innovations*" as outlined in the thesis definition.

One key contribution of this transformation model, compared to existing ones, is its emphasis on the interconnectedness of technical and social changes within construction companies to understand and implement a CI process. In this thesis's definition, CI is interpreted as a "*process of technical and sociocultural change*".

This perspective is based on findings from a comprehensive research approach, which suggests that the successful implementation of CI requires more than just technological advancements, as typically emphasized in CI literature. Instead, the success of CI also depends on organizational transformation and the cultural shifts that accompany it, and these must be addressed concurrently.

For instance, construction companies need to align their strategies with emerging technologies while simultaneously adapting their organizational cultures and operational practices to accommodate these changes. This alignment is critical for maintaining a competitive edge and fostering innovation. In this way, the model offers a systematic and descriptive approach to simultaneously addressing and improving both technical and sociocultural aspects of change.

The transformation model also stresses the importance of contextual awareness. It highlights that the processes driving Construction Industrialization cannot be fully understood without considering

the specific factors that influence specific regions, market conditions, cultural environments, and individual beliefs. Successful CI implementation requires a deep understanding of these contextual factors, as they play a pivotal role in shaping both the challenges and opportunities that arise in different parts of the world, as evidenced by the empirical study.

Lastly, the transformation model (Figure 6.1), which integrates the perspectives of both Practitioners and academics, offers a new understanding of the expectations surrounding the implementation of the phenomenon under study. The focus on societal improvement—often neglected in favor of prioritizing cost, time, and productivity—is one of the key findings from the empirical study. This revised understanding expands beyond the traditional three dimensions of sustainability to also encompass design, providing a more holistic view. It aims to guide academics, policymakers, and Practitioners in their efforts to study, teach, promote, regulate, implement, and contribute to the phenomenon from a more comprehensive and inclusive perspective, recognizing the profound impact it has on businesses, industries, and society at large.

6.4. Implications for Theory and Practice

The findings of this Doctoral Project carry important theoretical implications that not only enhance current understanding but also open up new avenues for future research in the CI field. One of the primary motivations behind this thesis was to ensure its practical relevance, addressing the calls from academics for research that is comprehensive, mature, and truly beneficial to Practitioners in their CI efforts. As a result, this study offers numerous practical implications that merit attention. Below, the contributions of this research are articulated as actionable insights specifically designed for two key stakeholders: Scholars and Managers.

6.4.1. Implications for Theory

Four implications for theory are listed, which are considered extremely important for the direction that literature should take in future publications.

1. Distinction between the definitions of CI and related terms.

The main finding of this thesis is that Construction Industrialization should not be equated with Off-site Construction, Prefabricated, or Modular Construction. This misconception, perpetuated by Scholars, has created considerable ambiguity, hindered theoretical development, and resulted in practical misunderstandings. While many existing works treat these terms—as well as others referenced in this document—as interchangeable with CI, recent studies, including this one, contend that they are merely components of a broader phenomenon. The perspectives of Practitioners discussed in Chapter 5 highlight this distinction. Therefore, this study aims to provide a comprehensive understanding of CI, addressing the historical gaps in the literature. For some time, Scholars have advocated for further research to establish a more unified and holistic perspective on CI, moving beyond fragmented and superficial analyses. This study represents a significant step toward achieving the depth of understanding that the field urgently requires.

2. Understanding that CI development involves technical and social changes.

This study aims to shift the focus of the literature toward new areas of knowledge, specifically in Organizational Change and Change Management theories. It seeks to establish a connection between the soft and hard sides of transformational change. Existing CI literature often overlooks this social dimension, emphasizing mainly technical aspects. However, based on the empirical findings, the literature should adopt a dual focus on social discovery and practical applications.

3. Recognition of the limitations of current CI models.

A third implication for Scholars is the importance of CI models in developing their understanding of CI implementation. The definition and characterization of the industrialization process must be closely aligned. Scholars should align their studies with established interpretations of the concept. When this alignment occurs, we achieve a stronger synergy between theory and practice, leading to increased efforts in the field of Construction Industrialization and facilitating a deeper understanding of the discipline.

4. **Adoption of a more practical perspective in the CI body of knowledge, examining diversity and multiculturalism to develop, refine, and test theory.**

The last message is the relevance of developing intra-sectoral and geographic diversity in academic articles. Many studies have been limited to single countries, constraining CI theory to fragmented geographical perspectives. This leads to varied interpretations depending on location. Hossein et al. (2018) warn of an "*endemic problem*" stemming from insufficient focus, debate, and collaboration among Scholars. CI is a global phenomenon; therefore, fostering international cooperation and learning is essential for progress. By encouraging research sharing and open dialogue, we can significantly strengthen and enrich CI theory.

6.4.2. Implications for Managers

In addition to the new definition and model that support the CI development process, five more implications for Managers are highlighted.

1. **Acknowledgement of the CI phenomenon as fundamentally an organizational process rather than simply a change in a building project.**

This study provides an in-depth analysis of how Construction Industrialization profoundly affects the construction industry as a whole. It highlights the various ways this phenomenon influences not only individual companies but also supply chain processes and day-to-day operational routines. In the literature, there is often a tendency to concentrate exclusively on the construction project itself, but this narrow perspective is increasingly recognized as inadequate. Such a limited focus contributes to stagnation in both academic research and practical advancements. However, the construction project should be viewed as merely the end product of a much larger and complex set of organizational transformation processes. These transformations are essential for laying the groundwork necessary to achieve successful project outcomes. This thesis underscores the importance of understanding these underlying processes and dynamics, emphasizing that effective preparation and adaptation are crucial for the industry to move forward and fully leverage the benefits of Construction Industrialization.

2. **Realization that CI is both a technical and a social change.**

This thesis presents a significant advancement in the understanding of change, highlighting the critical importance of the soft side of change in the CI development process. Theories surrounding Organizational Change and Change Management emphasize that both the hard and soft aspects must coexist harmoniously. When either side or their interrelationship is neglected, it can result in unsuccessful organizational transformations. Notably, the soft side of change has received insufficient attention in the existing literature on CI. Nevertheless, it has been recognized by Organizational Change and Change Management Scholars as the most complex dimension of change. To create effective change initiatives, organizations need to research and use strategies that consider both sides of change. Many studies have missed this important approach. By focusing on the reasons for change as well as the resistance to it, organizations can better understand the change process. This knowledge can help them design specific initiatives that promote acceptance and tackle any challenges, leading to more successful and lasting outcomes.

3. **Realization that the CI process is influenced by social factors, which, according to empirical research, represent the biggest challenges in CI development.**

The phenomenon of Construction Industrialization encompasses more than prefabrication, off-site construction, and modularization. These more limited perspectives have faced considerable scrutiny and critique from industry Practitioners who have engaged in empirical research. Empirical findings show that CI signifies a profound transformation in the methodologies and routines employed within the construction sector, with a strong focus on fostering cooperation and collaboration among various stakeholders. To gain a comprehensive understanding of CI, it is essential to recognize that the softer dimensions—such as interpersonal skills, communication styles, and collaborative behaviors—are of even greater significance than the technical aspects that often dominate discussions. While Practitioners regard technical decisions as critical for the adoption of CI, they frequently identify that the most substantial challenges to successful implementation are linked to these softer dimensions. For CI to be effectively and sustainably adopted within organizations, it is imperative for Managers to prioritize and address these softer dimensions. This entails developing a culture that promotes teamwork, flexibility, and effective communication. By doing so, organizations can better navigate the complexities of implementing

CI and ensure that their teams are well-equipped to meet the various challenges that arise during this transition. Ultimately, a holistic approach that integrates both technical and softer elements will facilitate a successful and transformative implementation of Construction Industrialization.

4. Understanding that CI affects industry productivity and has broader societal implications.

This thesis provides a comprehensive analysis of how the drive to enhance construction productivity—a topic that has frequently been the subject of criticism, as discussed in Chapter 1—serves as a fundamental catalyst for the phenomenon under study. However, this Doctoral Project also underscores that the ramifications of CI extend far beyond mere productivity metrics, encompassing significant societal impacts that warrant attention. A primary focus of this research is the enhancement of living conditions within communities, which is critical for fostering social well-being. The thesis stresses the increased awareness of environmental issues that can lead to more sustainable construction practices and buildings. Moreover, it stresses the urgent need for effective responses to contemporary challenges such as housing shortages and the demand for better housing quality. These themes resonate deeply within the insights shared by Practitioners actively engaged in the field. The construction industry possesses considerable capacity to fulfill essential societal needs regarding both the accessibility and quality of housing. Practitioners assert that embracing Industrialization within construction processes is vital for achieving these results.

5. Understanding that building is different from producing a building and that this goes far beyond a move from production to off-site.

This study underscores the important distinction between "*constructive systems*" and "*productive systems*", a differentiation not adequately addressed in the existing literature. These terms are often used interchangeably, leading to confusion. The Author experienced this firsthand during a meeting involving two target audiences: one centered on the construction system and the other focused on the production system. In that meeting, the term "*standard*" was mentioned, which, although seemingly straightforward, sparked disagreement. For the audience focused on the construction system, "*standard*" referred to traditional construction solutions generally associated with lower costs, but not necessarily the best options for project repetition. Conversely, from the perspective of the audience concerned with the productive system, "*standard*" implied safety and

consistency in project repetition. This example underscores the relevance of being mindful of language when defining a new construction system, as perceptions can vary significantly. The Author highlighted the necessity for careful consideration of terminology and the need to adapt discourse for different audiences. Achieving a common understanding requires intentional efforts from leadership, who must embody multiple roles, including those of civil, structural, or mechanical engineers, as well as process, operational, or productive Managers.

6.5. Research Limitations

This research has contributed to the debate on CI conceptualization and the CI process. Nevertheless, as with any research, some limitations need to be acknowledged. Some topics have been covered in previous chapters; however, a summary is provided below, organized by the chapters developed in this thesis.

Chapter 2 related to the Methodology

The first limitation is related to methodologies. Qualitative, Case Research, and Abductive studies are suitable methodologies frequently used to explore complex phenomena in-depth, but they come with certain potential limitations.

One potential limitation is bias in Case Research, which can arise from several factors, such as the researcher's proximity to the phenomenon, potentially leading to preconceived notions or personal interpretation of case data. This bias can distort the findings and compromise the objectivity of the research. Another challenge associated with the Case Research process is the interpretation of data. Data collection involved interviews, meetings, observations, site visits, and reports, which can be subjective and open to various interpretations. To mitigate this, a directed content analysis was employed to ensure a structured and systematic process, minimizing the risk of misinterpretation. Finally, there is the issue of generalizability. To address this limitation—and the previous two—and to enhance the credibility of the research, tactics of construct validity, external validity, and reliability are outlined in Table 2.2, thereby strengthening the overall trustworthiness of the research process and its conclusions.

The second limitation pertains to the decision regarding the empirical sample, specifically the number of cases selected. In this multiple case study, four sectors were examined: Architecture,

Engineering, Traditional Construction, and Manufactured Construction. However, the results may vary significantly depending on the context. For example, incorporating a more diverse range of companies—ranging from small to large enterprises—and involving stakeholders with varying roles, such as those who construct buildings, supply materials, make decisions, and conceptualize designs, could offer valuable new insights. By engaging with these different stakeholders, it may be possible to draw new conclusions that better reflect the complexities of the industry. This would enhance the generalizability of the study's findings across the entire construction sector.

Chapters 3 and 4 related to the Conceptual part

The main limitation is related to the filter criteria used in the SLRs. Specifically, only journal articles were included in the analysis. Consequently, conference papers, book chapters, white papers, company reports, and magazine articles were excluded from the study. This criterion was consistently applied throughout the chapters and across the PhD project to maintain objectivity and rigor in the findings.

Chapter 5 related to the empirical part, as well as the intersection of theory and practice

The main limitation pertains to the context of the empirical study. CI is still a relatively emerging concept within the construction industry, and its implementation has encountered significant complexities. This Doctoral Thesis concludes prior to the completion of the Governmental Funding Agenda, meaning the outcomes of this agenda are not yet known. As such, the study focuses on the initial phase: the development of a CI process informed by existing knowledge and insights. This thesis and its contributions are situated within a context where CI development is still in progress. The perspectives of Practitioners are grounded in this evolving landscape. Full implementation and completion of the CI process will occur beyond the scope of this thesis, during which new challenges, practices, influencing factors, and refined perspectives may emerge, further enriching the understanding of CI. Future research should be conducted after the Governmental Funding Agenda concludes, allowing for a comparison of findings. Such a study could provide deeper insights into the challenges, opportunities, and practical implications of CI, enhancing both theoretical and applied knowledge of the phenomenon. Moreover, as CI's strategic role within

organizations continues to evolve, further exploration is necessary to fully understand its potential across different industries and organizational contexts.

6.6. Avenues for Future Research

In the previous chapters, some avenues for future research have already been introduced. More research opportunities can be addressed, and with them, new openings for new areas, new studies, and new developments can be developed. They are divided into extensions to (1) the conceptual part and (2) empirical developments.

Extensions to the conceptual part

A promising area of research involves expanding our understanding of the CI phenomenon and its process to other on-site industrial sectors, such as aeronautics and shipping. This exploration could provide valuable insights into how different companies design and operationalize their industrial processes from an industrialization perspective. Therefore, this future research suggestion may expand the transformation model developed in this Doctoral Project.

A second avenue in the CI literature focuses on exploring the particular topic of the soft side of change and its impact on shifting perceptions, attitudes, and behaviors toward the design, production, and use of industrialized buildings. Changing mindsets, habits, and established ways of working—often considered unchangeable—presents a significant challenge according to the Practitioners (Chapter 5). Additionally, having leaders who can envision and drive this transformation in an industry that is typically resistant to change is a crucial factor. Ensuring the commitment of workers who possess the necessary skills and an ambitious mindset, and who can engage everyone involved in the goal of Industrializing Construction, is essential. Therefore, a comprehensive study on applied social psychology related to industrialization is vital.

A third avenue for future research has to do with the notion of multidisciplinarity associated with the CI phenomenon, stressed in this thesis. As shown in this Doctoral Project, CI is talking about a transformation that includes the expected Architecture, Engineering, and Construction disciplines, but also Industrial Engineering and Management, as well as Social Sciences. Two research opportunities come out of this. One in Industrial Engineering and Management, since it would be interesting to bring in experts in this field, and look at construction, critique, and improve

processes; drive Industrialization with their knowledge, and ensure that manufacturing principles are fully, and completely, implemented in Construction. A second, on the education design programs. Specifically, this Doctoral Project warns to think about the current programs that should be restructured in construction management in order to instill industrial thinking in Builders, and with that study, knowledge and capabilities have to be modified for the long-term industry to look at Construction as an Industry.

Empirical developments

The first opportunity for future research is related to testing the developed transformation model for the first time in a new context, location, and/or sector. Particularly, further research could build on the results of this study by applying them to a broader sample of construction stakeholders, including subcontractors, construction firms, developers, suppliers, clients, and consumers. Such an approach would help validate, expand, test, and refine the findings, ultimately strengthening the theory developed in this study.

Complementary, it would be very interesting to continue studying the Governmental Funding Agenda, and the Living Lab project, which underpins the empirical studies and is expected to be completed in 2025, becoming a rich case of modular building construction, with all the industrial thinking. As it covers vast subjects and a wide range of entities, both design, supply, and construction, as well as universities and certification companies, there are many courses to which the necessary research could be directed. More publications in renowned journals are also expected as part of this research.

The last opportunity includes examining the CI phenomenon by incorporating the perspectives and expertise of organizational change academics and Practitioners for the first time. This approach seems pertinent because it brings a fresh, interdisciplinary angle to the study and application of CI. Organizational change experts have deep knowledge of how construction companies evolve, adapt, and manage transformation processes. By involving them in CI research, this collaboration can lead to a more nuanced understanding of CI's role in organizations, particularly in how it can drive or support change initiatives. Moreover, these experts can provide insights into how CI practices might be integrated with broader organizational strategies, both technically and socially. This could enhance not only the understanding of CI but also its implementation in organizations, making it more adaptable, efficient, and impactful.

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Appendixes

Appendix A: The Clarification of the Content and Form of the Definition and the Transformational Model Throughout the Chapters

Improving the clarity of the definition and its structure, along with refining the transformational model presented in the chapters, is crucial for supporting the reading of this thesis and understanding its evolution.

Two major contributions are expected from this research: CI definition and CI framework for its development process – Chapter 2. However, from a theoretical point of view, an evolution in their content and form is noticed along the Chapters. This evolution arises in the natural course of the research, first with the literature on CI (Chapter 3) and its extension to theories of Organizational Change and Change Management (Chapter 4), and later, the introduction of the empirical part in the research (Chapter 5). The discussion begins with the evolution of the definition, followed by an analysis of the evolution of the process.

Definition

The initial conceptual definition (Chapter 3) was developed to answer the first research question: *"How has research to date defined and operationalized the concept of Construction Industrialization?"*

Chapter 3 was structured around three broad themes: (1) what CI is, (2) what it entails, and (3) for what end (Figure A.1). These themes were designed to answer the fundamental theoretical questions of what, how, and why. This integrated vision is currently omitted from the literature and serves as the basis for an integrated, comprehensive, and structured definition of the phenomenon.

(1) What it is? + (2) What it entails? + (3) What end?

Figure A.1: Definitional structure

Throughout the research, there is a consistent line of connection. In Chapter 5, the research empirically explores Practitioners' perspectives on CI along these three themes: (1), (2), and (3). The empirical study, therefore, aimed to understand the prevailing perspectives on (1) how CI is perceived (the interpretation of what CI is), (2) how it is carried out (the key elements of what it entails), and (3) what gains (the benefits of what purpose) it is expected to offer. In this way, while the content is evolutionary, the form of presenting and structuring the definition remained consistent throughout the research project.

Process

Regarding the framework to assist in the Construction Industrialization development process, this, compared to the definition, was the one that showed the greatest evolution in content and form. In the first phase of this research (related to RQ1, Chapter 3), a unified and integrated conceptual framework of CI is developed, building a holistic approach at the system level to explain how companies do business in the CI phenomenon. This framework includes ten design principles, five influencing factors, and nineteen initiatives grouped into five organizational dimensions. We identified these as the central elements for analyzing and understanding the complexity inherent in the CI development process in this Doctoral Project.

- Design principles cover CI transformation's general (and unique) principles that can be applied in any context (or country).
- CI influencers are the critical factors that may positively or negatively impact the decision to implement such a transformation.
- CI initiatives are a set of actions that organizations must undertake to promote the effective industrialization of the construction industry.

Hence, in a primary conceptual framework (Chapter 3), these three elements constitute an essential output for the CI framework by highlighting the various elements that make up the phenomenon and structuring them to lay the fundamental foundation to explain and guide the CI field based on the available literature.

Chapter 4 improved the understanding of the Construction Industrialization development process in terms of content and structure. Different approaches with different elements have been deployed along the change management models (Al-Haddad & Kotnour, 2015), dictating how each transformation is conceptualized. Three identifiable and interrelated elements are considered the core aspects for such conceptualization – planning a transformational change. Process, Content, and Context are those elements. The evolution verified in the form of the framework follows the studies developed by Self et al. (2007), Al-Haddad & Kotnour, (2015), and Arazmjoo & Rahmanseresht (2020).

- The Process of change means that an organizational transformation typically follows a rationale of thinking to implement CI (the "*how*" factor of change).
- The Content of change explains the dimensions that underpin such implementation (the "*what*" factor of change).
- The Context of change means that each organizational transformation is positively or negatively impacted by its external environment and internal circumstances (under "*which*" conditions).

A closer look at each element and how it is approached in Organizational Change and Change Management theories is developed in the second part of this Doctoral Project (related to the RQ2 in Chapter 4), and it adapts the content and form of the initial framework.

So, rather than an archaic framework, CI transformation is understood as a process, and here the theories of Organizational Change and Change Management, about the "*how"* factor of change show four phases that describe the transformation effort within a dynamic and open environment. The phases are the Rationale for change, the Process for transforming the industry to the CI phenomenon, the expected Results, and the Feedback loop.

An open-system organizational transformation-oriented model toward Construction Industrialization is developed in Chapter 4 with the Organizational Change and Change Management theories. From a content perspective, the premise is based on understanding organizational change, not as the solution to implementing CI, but as the laudable support in this odyssey: Organizational Change and Change Management theories teach about how to transform, whereas the CI field teaches how to industrialize. These two research fields are actively intertwined, and the conceptual model's foundation must reflect this. Therefore, the design principles initially identified remain intact in Chapter 4, but the initiatives and the elements of influence are reargued. While the Initiatives address the content of the change (the "*what*" factor of change), the Elements of Influence are considered within the context (under "*which*" conditions).

Figure A.2 anticipates the result of Chapter 4. It provides a better contextualization of how the insights gathered in Chapter 3 are interconnected with the outputs of Chapter 4.

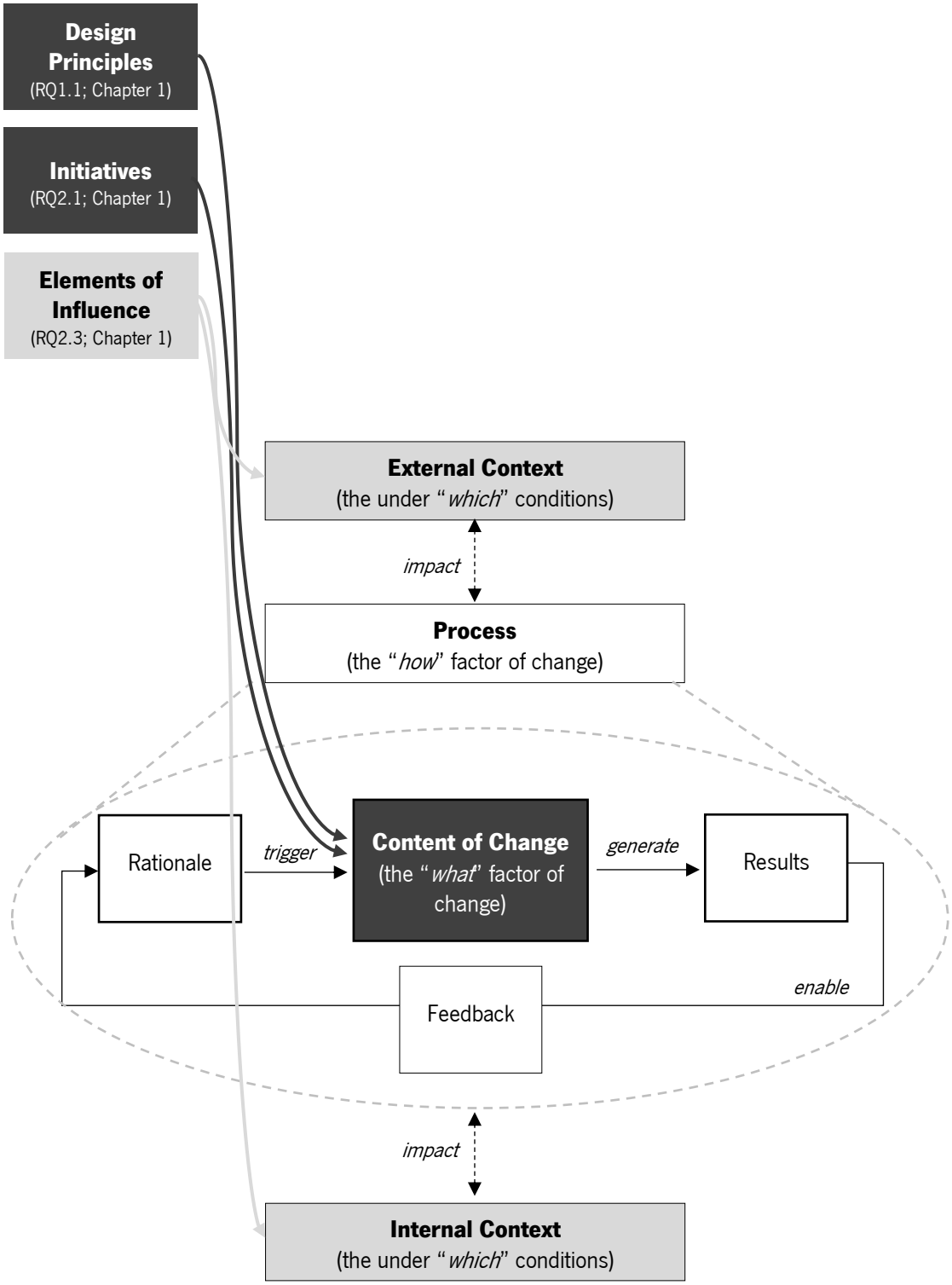


Figure A.2: The connection between the content in Chapters 3 and 4 relates to the development framework for the CI process

Appendix B: The List of Papers Reviewed in Chapter 3

Table B.1: List of 102 papers included in the SLR in Chapter 3 *(sorted alphabetically by title)*

No.	Article Name	Journal	Year
1	A BIM-lean framework for digitalisation of premanufacturing phases in offsite construction	Engineering, Construction and Architectural Management	2021
2	A Building Project-Based Industrialized Construction Maturity Model Involving Organizational Enablers: A Multi-Case Study in China	Sustainability	2020
3	A conceptual development framework for prefabricated construction supply chain management: An integrated overview	Sustainability	2020
4	A definition and valuation of the UK offsite construction sector	Construction Management and Economics	2010
5	A holistic review of off-site construction literature published between 2008 and 2018	Journal of Cleaner Production	2018
6	A methodology for the optimal modularization of building design	Automation in Construction	2016
7	A new framework of industrialized construction in China: Towards on-site industrialization	Journal of Cleaner Production	2020
8	A novel mathematical optimisation model for the scheduling of activities in modular construction factories	Construction Management and Economics	2020
9	A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation	Journal of Cleaner Production	2018
10	A Systematic Review of Emerging Technologies in Industrialized Construction	Journal of Building Engineering	2021
11	Adaptable industrial building system: Construction industry perspective	Journal of Architectural Engineering	2012
12	An examination of a modular supply chain: A construction sector perspective	Supply Chain Management	2011
13	An off-site construction readiness maturity model for the Indian construction sector	Construction Innovation	2021
14	An Ontology and Multi-Agent Based Decision Support Framework for Prefabricated Component Supply Chain	Information Systems Frontiers	2020
15	Assessing off-site readiness in construction organisations: cases from India	Construction Innovation	2021
16	Barriers of implementing modern methods of construction	Journal of Management in Engineering	2014
17	Barriers to promoting prefabricated construction in China: A cost-benefit analysis	Journal of Cleaner Production	2018
18	Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach	Journal of Cleaner Production	2018

Table B.1: List of 102 papers included in the SLR in Chapter 3 (sorted alphabetically by title) *(continue)*

No.	Article Name	Journal	Year
19	Best practices for implementing industrialized construction projects: lessons from nine case studies	Construction Innovation	2021
20	Building information modelling-based framework to contrast conventional and modular construction methods through selected sustainability factors	Journal of Cleaner Production	2019
21	Business Design Modeling for Industrialization in Construction: Cooperative Approach	Journal of Architectural Engineering	2012
22	Business models in industrialized building of multi-storey houses	Construction Management and Economics	2014
23	Buyer-supplier relationships in industrialized building	Construction Management and Economics	2014
24	Categorizing modularization strategies to achieve various objectives of building investments	Construction Management and Economics	2018
25	Classification of production systems for industrialized building: A production strategy perspective	Construction Management and Economics	2014
26	Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore	Journal of Cleaner Production	2020
27	Conceptual framework of the evolution and transformation of the idea of the industrialization of building in Japan	Construction Management and Economics	2014
28	Contextual, structural and behavioural factors influencing the adoption of industrialised building systems: a review	Architectural Engineering and Design Management	2018
29	Continuous improvement of the industrialised housebuilding order fulfilment process	Construction Innovation	2020
30	Cost analysis for sustainable off-site construction based on a multiple case study in China	Habitat International	2016
31	Critical evaluation of off-site construction research: A Scientometric analysis	Automation in Construction	2018
32	Critical review of the research on the management of prefabricated construction	Habitat International	2014
33	Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization	Journal of Construction Engineering and Management	2014
34	Critical success factors for management of the early stages of prefabricated prefinished volumetric construction project life cycle	Engineering, Construction and Architectural Management	2020
35	Critical success factors for modular integrated construction projects: a review	Building Research and Information	2020
36	Critical success factors for project planning and control in prefabrication housing production: A China study	Sustainability	2018
37	Decision-making model for the evaluation of industrialized housing systems in Ethiopia	Engineering, Construction and Architectural Management	2020
38	Demystifying the concept of offsite manufacturing method: Towards a robust definition and classification system	Construction Innovation	2019

Table B.1: List of 102 papers included in the SLR in Chapter 3 (sorted alphabetically by title) *(continue)*

No.	Article Name	Journal	Year
39	Design for manufacture and assembly in construction: a review	Journal of Building Engineering	2021
40	Developing a construction business model transformation canvas	Engineering, Construction and Architectural Management	2020
41	Developing a Fuzzy Multi-Criteria Evaluation Model for Prefabrication Development Maturity of Construction Firms	IEEE Access	2020
42	Developing work breakdown structure matrix for managing offsite construction projects	Architectural Engineering and Design Management	2018
43	Digital construction: From point solutions to IoT ecosystem	Automation in Construction	2018
44	Digital technology utilisation decisions for facilitating the implementation of Industry 4.0 technologies	Construction Innovation	2020
45	Effect of stakeholder collaborative management on off-site construction cost performance	Journal of Cleaner Production	2018
46	Evaluating supplier management maturity in prefabricated construction project-survey analysis in China	Sustainability	2018
47	Exploring a body of knowledge for promoting the sustainable transition to prefabricated construction	Engineering, Construction and Architectural Management	2020
48	Exploring the challenges to industrialized residential building in China	Habitat International	2014
49	Holistic Review and Conceptual Framework for the Drivers of Offsite Construction: A Total Interpretive Structural Modelling Approach	Buildings	2019
50	Identifying supply chain capabilities of construction firms in industrialized construction	Production Planning and Control	2021
51	Industrialised house-building – development and conceptual orientation of the field	Automation in Construction	2015
52	Industrialized construction in the Swedish infrastructure sector: Core elements and barriers	Construction Management and Economics	2014
53	Industry 4.0 and supply chain process re-engineering: A coproduction study of materials management in construction	Business Process Management Journal	2020
54	Integrating resource production and construction using BIM	Automation in Construction	2010
55	Interactions between building information modelling and off-site manufacturing for productivity improvement	International Journal of Managing Projects in Business	2019
56	Key constraints and mitigation strategies for prefabricated prefinished volumetric construction	Journal of Cleaner Production	2018
57	Key factors influencing the decision to adopt industrialised building systems technology in the Malaysian construction industry: an inter-project perspective	Architectural Engineering and Design Management	2018
58	Lean and agile integration within offsite construction using discrete-event simulation: a systematic literature review	Construction Innovation	2016

Table B.1: List of 102 papers included in the SLR in Chapter 3 (sorted alphabetically by title) *(continue)*

No.	Article Name	Journal	Year
59	Lean Methodologies and Techniques for Modular Construction: Chronological and Critical Review	Journal of Construction Engineering and Management	2019
60	Lean thinking and industrial 4.0 approach to achieving construction 4.0 for industrialization and technological development	Buildings	2020
61	Lean transformation in a modular building company: A case for implementation	Journal of Management in Engineering	2013
62	Making a case for offsite construction in China	Engineering, Construction and Architectural Management	2010
63	Managing for continuous improvement in off-site construction: Evaluation of lean management principles	Engineering, Construction and Architectural Management	2012
64	Managing short-term efficiency and long-term development through industrialized construction	Construction Management and Economics	2014
65	Methodological-Technological Framework for Construction 4.0	Archives of Computational Methods in Engineering	2020
66	Mirror-breaking strategies to enable digital manufacturing in Silicon Valley construction firms: a comparative case study	Construction Management and Economics	2020
67	Modelling in off-site construction supply chain management: A review and future directions for sustainable modular integrated construction	Journal of Cleaner Production	2021
68	Modular Construction: Determining Decision-Making Factors and Future Research Needs	Journal of Management in Engineering	2020
69	Modularisation strategies in the AEC industry: a comparative analysis	Architectural Engineering and Design Management	2020
70	Modularization Business Case Analysis Model for Industrial Projects	Journal of Management in Engineering	2019
71	New offsite production and business models in construction: priorities for the future research agenda	Architectural Engineering and Design Management	2015
72	Offsite construction in the Australian low-rise residential buildings application levels and procurement options	Engineering, Construction and Architectural Management	2021
73	Off-site construction optimization: Sequencing multiple job classes with time constraints	Automation in Construction	2016
74	Off-site construction planning using discrete event simulation	Journal of Architectural Engineering	2012
75	Offsite construction: Developing a BIM-Based optimizer for assembly	Journal of Cleaner Production	2019
76	Offsite Manufacturing Research: A Systematic Review of Methodologies Used	Construction Management and Economics	2021
77	Offsite production: A model for building down barriers A European construction industry perspective	Engineering, Construction and Architectural Management	2011
78	Optimal logistics planning for modular construction using two-stage stochastic programming	Automation in Construction	2018

Table B.1: List of 102 papers included in the SLR in Chapter 3 (sorted alphabetically by title) *(continue)*

No.	Article Name	Journal	Year
79	Optimal process integration architectures in off-site construction: Theorizing the use of multi-skilled resources	Architectural Engineering and Design Management	2018
80	Optimizing decisions in advanced manufacturing of prefabricated products: Theorizing supply chain configurations in off-site construction	Automation in Construction	2017
81	Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis	Journal of Cleaner Production	2018
82	Parametric and Generative Design techniques in mass-production environments as effective enablers of Industry 4.0 approaches in the Building Industry	Automation in Construction	2018
83	Perceptions of offsite construction in the United States: An investigation of current practices	Journal of Building Engineering	2020
84	Process-Oriented Framework to Improve Modular and Offsite Construction Manufacturing Performance	Journal of Construction Engineering and Management	2020
85	Product Architecture Model for Multistory Modular Buildings	Journal of Construction Engineering and Management	2016
86	Production system classification matrix: Matching product standardization and production-system design	Journal of Construction Engineering and Management	2015
87	Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall	Automation in Construction	2018
88	Quantitative evaluation and ranking of the critical success factors for modular integrated construction projects	International Journal of Construction Management	2020
89	Recipes for Cost and Schedule Successes in Industrial Modular Projects: Qualitative Comparative Analysis	Journal of Construction Engineering and Management	2016
90	Relationship between BIM Implementation and Performance of OSM Projects	Journal of Management in Engineering	2019
91	Resource efficiency in industrialized housing construction – A systematic review of current performance and future opportunities	Journal of Cleaner Production	2021
92	Site logistics planning and control for engineer-to-order prefabricated building systems using BIM 4D modeling	Automation in Construction	2019
93	Smart factories for single-family wooden houses – a practitioner's perspective	Construction Innovation	2021
94	Supply-chain transparency within industrialized construction projects	Journal of Building Engineering	2014
95	The impacts of industrialization on construction subcontractors: a resource based view	Construction Management and Economics	2017
96	Toward productivity in future construction: Mapping knowledge and finding insights for achieving successful offsite construction projects	Journal of Computational Design and Engineering	2021
97	Towards a decision support for modular integrated construction: An integrative review of the primary decision-making factors	International Journal of Construction Management	2019

Table B.1: List of 102 papers included in the SLR in Chapter 3 (sorted alphabetically by title) *(continue)*

No.	Article Name	Journal	Year
98	Towards a more extensive application of off-site construction: a technological review	International Journal of Construction Management	2020
99	Towards adopting off-site construction in housing sectors as a potential source of competitive advantage for builders	Architectural Engineering and Design Management	2020
100	Trending topics and themes in offsite construction (OSC) research: The application of topic modelling	Construction Innovation	2019
101	Understanding off-site readiness in Indian construction organisations	Construction Innovation	2020
102	Understanding Stakeholders in Off-Site Manufacturing: A Literature Review	Journal of Construction Engineering and Management	2019

Appendix C: The Diverse Terms Interchangeably Used with the CI Phenomenon and Their Clarification in this Doctoral Project

The phenomenon of CI has been used in various parts of the world to varying degrees, and previous Scholars have defined it using different terms applied to other contexts and countries. "*Interchangeably*" is a word commonly used to group all the terms in the same meaning. Off-site Construction (OSC) (Arashpour et al., 2016; Hussein et al., 2021), Industrialized house-building (IHB) (Lessing et al., 2015), Industrialized Building System (IBS) (Viana et al., 2017), Industrialized Construction (Wang et al., 2020), Prefabricated Construction (PC) (Liu et al., 2020), Panelized Construction, Modular Construction (MC) (Zhang et al., 2020), Modular Integrated Construction (MIC) (Wuni & Shen, 2020d) and Prefabricated Prefinished Volumetric Construction (PPVC) (Hwang et al., 2018; Wuni & Shen, 2020; Wuni & Shen, 2020b) are some of those terms. Boundaries about those terms are blurred, and subtle differences must be clarified. Table C.1 shows some definitions presented in the literature to employ such terms. Subsequently, a discussion will be undertaken concerning the distinction of each term within the context of this thesis.

Table C.1: Overview of some definitions presented in the literature for different CI-related terms

Term	Reference	Definition
Off-site Construction	Arashpour et al. (2016)	*"is a unique hybrid of manufacturing operations and on-site construction activities"*
	Wuni & Shen (2019b)	*"is a construction technique involving the planning, design, production, and assembly of building components at a location other than their final installed location to support the rapid and efficient construction of structures."*
	Wuni & Shen (2020b)	*"is a new way of working and thinking within the modular (off-site) construction sector."*
	Hussein et al. (2021)	*"is an innovative construction method of dividing a whole structure into a number of prefabricated sections produced in a factory environment and transported to the construction site for direct installation"*
Industrialized Building System	Gan et al. (2017)	*"has various synonymous terms such as industrialized construction, prefabrication, pre-assembly, modern method of construction, off-site manufacturing, off-site production, and off-site construction. The main contexts of these terms refer to three typical groups of activities, namely, producing building components at a factory within highly controlled environments, delivering prefabricated components to construction sites, and assembling components to form building structures"*

Table C.1: Overview of some definitions presented in the literature for different CI-related terms *(continue)*

Term	Reference	Definition
Prefabricated Prefinished Volumetric Construction	Hwang et al. (2018)	*"are modules complete with finishes for walls, floors, and ceilings are built and manufactured in off-site factories (mostly 85-90 percent of the project work) and then transported to the construction site for installation."*
	Wuni & Shen (2020b)	*"is a construction business model whereby building components are manufactured in a specialized off-site factory and subsequently transported to a job site for final assembly and installation"*
Industrialized Construction	Wang et al. (2020)	*"is a form of modern manufacturing, transportation, installation, and scientific management of construction, which differs from the decentralized, low-level, and low-efficiency handicraft production in the traditional construction industry."*
	Qi et al. (2020)	*"is a method of construction that promotes the advancement of the process from design through construction by employing intelligent manufacturing and automation techniques."*
	Qi et al. (2021)	*"is an adaptation of traditional construction by integrating manufacturing design and optimization tools to solve complex challenges in construction projects."*
	Wuni et al. (2021)	*"is a construction technology that uses more advanced manufacturing techniques, automation and innovative processes in construction, where projects are designed for substantial portions to be manufactured offsite as modules in a specialized controlled factory environment and then transported to a site for installation (...) Industrialized Construction with associated supply chain arrangements and digital technologies are pursued as part of the integrated solutions to the ills of the traditional construction approach."*
Prefabricated Construction	Luo et al. (2020)	*"is emerging as an alternative method to design, produce and build structures more efficiently and sustainably."*
	Zhang, et al. (2022)	*"should be an organizational process with a continuity of production through a well-integrated construction organization."*
Panelized Construction	Altaf et al. (2018)	*"prefabricated home building (...) as the prefabricated construction process, also referred to as panelized construction, can reduce waste and construction time compared to traditional stick-built construction"*
Modular Construction	Shin et al. (2022)	*"is a form of off-site construction that refers to a method of constructing buildings by modularizing them into panels or volumetric units."*

Table C.1: Overview of some definitions presented in the literature for different CI-related terms *(continue)*

Term	Reference	Definition
Modular Integrated Construction	Wuni & Shen (2020d)	*"is the most complete form of Off-site Construction involving the greatest integration of factory-made value-added prefabricated prefinished volumetric modules"*
	Tsz Wai et al. (2021)	*"is the highest prefabrication level where 80–90% of the construction work is implemented off-site in a controlled manufacturing facility."*
Industrialized house-building	Lessing et al. (2015)	*"is used for describing a strategically different process- and product-oriented alternative to traditional project-oriented house-building methods and principles.*

The complexities of CI transition and the plethora of terms used in literature have created ambiguity surrounding the CI phenomenon. As mentioned in Chapter 1, there is no common understanding about CI, nor is there a consensus on each term.

By way of explanation and to differentiate the terms, the literature typically looks at OSC (Liu et al., 2019), IHB (Grenzfurtner & Gronalt, 2020), IBS (Asri et al., 2016), and PC (Hong et al., 2018) terms if the production system involves the use of mass-produced standardized construction components that are transported to a construction site and assembled into a structure.

Other terms emerge as a result of differentiating the level of off-site prefabrication and, as a result, the percentage of building completion, namely Panelized Construction (non-volumetric preassembly), Modular Construction, and Modular Integrated Construction (the highest order of prefabricated construction where 80-90% of a whole building can be engineered in an off-site factory) (Li et al., 2020), also known as Prefabricated Prefinished Volumetric Construction (Wuni & Shen, 2020c). In this Doctoral Project, those terms are components of a broad phenomenon. This clarification will allow for a clearer understanding of the previously mentioned concepts.

Recent discussions have highlighted the limited nature of CI definitions, which may lead to a biased understanding of the phenomenon (Hosseini et al., 2018). CI has developed into a multi-level, multi-disciplinary, and multi-dimensional phenomenon, exposing numerous opportunities to revolutionize the industry and work processes. However, the limited vision in defining this broad phenomenon has significantly hindered its theory development and practical adoption.

Therefore, a more comprehensive definition is provided when the term "*industrialized construction*" comes to be used, or when its interchangeable terms have been used in the last few years. CI is understood as a new way of thinking, building, and managing in the Construction Industry (Wang et al., 2020; Zhang et al.,

2020; Lekan et al., 2020). Wang et al. (2020) defined CI as "*a new form of modern manufacturing, transportation, installation, and scientific management of construction* (...)". Terms that are generally oriented towards an explanation of off-site production also have comprehensive definitions. This is the case with the definition put forward by Wuni & Shen (2020b), which defines OSC as "*a new way of working and thinking within the modular (off-site) construction sector*". This is also the case of Lessing et al. (2015) and Wuni & Shen (2020b), who, in different terms, stressed a strategic dimension rather than the typical operational one. In today's context, the existing definitions need additional scrutiny, as the concept of off-site production now encompasses much more than before, as evidenced in the latest research.

Appendix D: The Role of Change Management Literature And The Notion Of Change In This Research

The comprehensive theories of Organizational Change and Change Management offer a sought-after perspective on the phenomenon (Porras & Silvers, 1991). These theories highlight the importance of effective planning and implementation of change, offering a strategic viewpoint for Managers (Al-Haddad & Kotnour, 2015).

Additionally, they present a holistic approach for Practitioners and Decision-makers to guide their organizations through challenges and facilitate desired changes (Bigdeli et al., 2017). Nonetheless, it is relevant to note that the existing literature on Construction Industrialization has yet to fully incorporate these critical theories.

Drawing on such vast knowledge seems essential if the construction industry is to have a cohesive direction and a solid foundation for its transformation journey. And, unlike before, the emphasis has shifted from operational issues to organizational management and organizational change theories.

Organizational Change and Change Management theories emphasize the importance of planning for and implementing change, providing a global vision for Managers. Additionally, these theories present a holistic approach for Practitioners and Decision-makers to guide their organizations through challenges and facilitate desired changes. However, it's worth noting that the literature on Construction Industrialization has yet to fully integrate these critical perspectives.

The significance of this Doctoral Project largely stems from its potential to advance the understanding of Construction Industrialization. The existing literature on CI needs to be revised to capture this phenomenon's unique and complex nature. Therefore, it was essential to push the theoretical boundaries by incorporating theories of Organizational Change and Change Management.

If industrialization is the goal, how to get there should be the genesis of numerous literary and entrepreneurial reflections. In these reflections on this phenomenon that is not new, but that takes on a new significance, Practitioner and Academic initiatives have only lately advocated a new and improved understanding of the phenomenon under study.

Nowadays, it is well established that CI has the potential to transform the way of working and thinking in the construction industry (Wuni & Shen, 2020), rather than being characterized as the off-site transfer of work – as acknowledged in Chapter 1 and Appendix B. Moreover, nowadays, the lack of supportive models in such a journey is also well acknowledged in the literature (Chapter 1).

At the time of theory development from an organizational perspective, Lessing (2015) marks a turning point in CI literature. However, efforts to develop an integrated view of CI as a business shift are scarce. Even in

2019, Liu et al. (2019) call for more research on the effects of organizational management on the implementation of Off-Site Construction, a term often used interchangeably for CI.

As long as literature and practice do not agree, and do not come to the same understanding of what Construction Industrialization means, what its implementation process entails, and for what end has been implemented, ambiguities will persist, and the advancement of theory will be compromised. The theories of Organizational Change and Change Management aim to help blur these ambiguities comprehensively and soundly.

Researching Organizational Change and Change Management theories and bringing this theoretical and practical knowledge into the discussion aims to study the change process towards the phenomenon of the Construction Industrialization development process and contribute to theory and practice. A clear lack of study on transformational change in CI is identified, and this research, both for the value of the theories and for the urgency of understanding it, tries to respond to this gap. The construction industry is under pressure to implement this phenomenon. As with any industry or change, a well-thought-out plan is crucial for maximizing its benefits. Understanding how to plan and manage construction companies to succeed in this phenomenon can be considered one of the key modern issues in both literature and practice. This Doctoral Project aims to fill such a gap.

Appendix E: The List of Transformation Models Systematically Reviewed in Section 4.2.

Table E.1: List of Organizational Transformation Models

No.	Article Name or Model Name (grey literature)	Source (Journal or website)	Year	Added in Subsection 4.2.
1	Transformational and Coercive Strategies for Planned Organizational Change: Beyond the O.D. Model	Organization Studies	1988	Yes
2	Management science and organisational change	Omega	1992	Yes
3	A Causal Model of Organizational Performance and Change	Journal of Management	1992	-
4	Dynamics of Planned Organizational Change: Assessing Empirical Support for a Theoretical Model	Academy of Management Journal	1993	-
5	Information Systems Strategies and the Management of Organizational Change – a Strategic Alignment Model	Journal of Information Technology	1993	Yes
6	Understanding Organizational Transformation Using a Dissipative Structure Model	Human Relations	1989	Yes
7	Organizational therapy: Relating a psychotherapeutic model of planned personal change to planned organizational change	Journal of Managerial Psychology	1998	Yes
8	Emotion during Organizational Transformations - An Interactive Model of Survivor Reactions	Group & Organization Management	2000	Yes
9	The roles of TQM and BPR in organisational change strategies: a case study investigation	International Journal of Quality & Reliability Management	2000	Yes
10	Diversity Management in Organizational Change: Towards a Systemic Framework	Systems Research and Behavioral Science	2003	-
11	Process model for organisational change: a study of Estonian companies	Journal of Business Economics and Management	2004	-
12	Another look at the role of emotion in the organizational change: A process model	Human Resource Management Review	2005	Yes
13	ERA Model: A Customer-Orientated Organizational Change Model for the Public Service	Total Quality Management & Business Excellence	2006	Yes
14	The Triangular Model for Dealing with Organizational Change	Journal of Change Management	2007	-
15	Transformational change in health care systems: an organizational model	Health Care Management Review	2007	-

Table E.1: List of Organizational Transformation Models *(continue)*

No.	Article Name or Model Name (grey literature)	Source (Journal or website)	Year	Added in Subsection 4.2.
16	Successful Change Management	Total Quality Management and Business Excellence	2007	-
17	Employee Commitment and Support for an Organizational Change: Test of the Three-Component Model in Two Cultures	Journal of Occupational and Organizational Psychology	2007	Yes
18	A Process Model of Organizational Change in Cultural Context (OC3 Model): The Impact of Organizational Culture on Leading Change	Journal of Leadership and Organizational Studies	2009	-
19	A framework for organisational change management in lean manufacturing implementation	International Journal of Services and Operations Management	2012	Yes
20	A theoretical framework of organizational change	Journal of Organizational Change Management	2013	
21	Empirical Development of a Model of Performance Drivers in Organizational Change Projects	Journal of Change Management	2014	Yes
22	A process model of managing organizational change during business process redesign	Business Process Management Journal	2014	Yes
23	Integrating the organizational change literature: a model for successful change	Journal of Organizational Change Management	2015	-
24	An integrative model of IT-enabled organizational transformation: A multiple case study	Management Decision	2015	Yes
25	Modeling the cultural dynamics of resistance and facilitation: Interaction effects in the OC^3 model of organizational change	Journal of Organizational Change Management	2015	Yes
26	Using Kotter's Eight-Stage Process to Manage an Organisational Change Program	Systemic Practice and Action Research	2015	-
27	Organisational change towards servitization: A theoretical framework	Competitiveness Review	2017	-
28	Kurt Lewin's change model: A critical review of the role of leadership and employee involvement in organizational change	Journal of Innovation and Knowledge	2018	-
29	A Systemic Organizational Change Model in the Occupational Health Management	Journal of Change Management	2019	Yes
30	A systems model of organizational change	Journal of Organizational Change Management	2019	-
31	A multi-dimensional meta-heuristic model for managing organizational change	Management Decision	2020	Yes
32	A critical analysis of organizational change process	Business Process Management Journal	2020	-

Table E.1: List of Organizational Transformation Models *(continue)*

No.	Article Name or Model Name (grey literature)	Source (Journal or website)	Year	Added in Subsection 4.2.
33	Digital Transformation of Industrial Organizations: Toward an Integrated Framework	Journal of Change Management	2021	-
34	An alternative model for the comprehension of organizational transformation in emerging economies	Journal of Accounting and Organizational Change	2021	-
35	McKinsey's 7-S Framework	https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/enduring-ideas-the-7-s-framework	-	-
36	The Star Model	https://www.jaygalbraith.com/images/pdfs/StarModel.pdf	-	-
37	Nadler-Tushman Congruence Model	https://www.mindtools.com/adofd5j/the-nadler-tushman-congruence-model	-	-
38	Organizational design framework – the transformation model	https://centerod.com/framework/	-	-
39	Deloitte Capability Hexagon TM	https://www2.deloitte.com/us/en/pages/operations/articles/operating-models-that-navigate-business-volatility.html	-	-
40	Systems Model of Change Management and Continuous Change Process Model	https://www.managementstudyguide.com/systems-model-of-change-management.htm	-	-

Appendix F: The Case Study Protocol

This protocol describes the field procedures to be followed for the case study. It follows the guidelines established in the most prominent papers (Eisenhardt, 1989; McCutcheon & Meredith, 1993; Voss et al., 2002; Spens & Kovács, 2006; Edmondson & Mcmanus, 2007; Yin, 2012). The subsequent subsections will describe the research context and the methods employed for data collection.

1. Empirical research context

The case study aims to collect information from two perspectives and will be developed following a theory-elaboration path (in line with Chapters 1 and 2):

- Perspective on Construction Industrialization definition and conceptualization;
- Perspective on the Construction Industrialization development process.

2. Research Design

To develop the case study, the Author concentrated on the following topics: (A) the research purpose (in line with Chapter 2); (B) the type of research design employed; (C) the prior theory that supports an abductive research approach; (D) the logical connections between theoretical constructs and the data; (E) the sources of data utilized and (F) the sampling methodology applied.

(A) Research Purpose in line with Chapter 2

As explained in Chapter 2, the empirical study conducted in this thesis has two main purposes:

1. **Refining the existing theory.** This purpose involves reevaluating the initial constructs by integrating theoretical perspectives with practical applications. The constructs may either remain unchanged or undergo further revision.
2. **Expanding Existing Theory.** This purpose involves deepening the understanding of the phenomenon and incorporating an empirical aspect to improve insight into the CI phenomenon. This exploration may lead to the development of new constructs.

(B) Type of research design

A holistic multiple case study research design should be selected. The Author will examine four sectors: Architecture, Engineering, Traditional Construction, and Manufactured Construction (the cases). The unit of

analysis is the CI phenomenon and its development process. This means that different sectors (contexts) each with their view of the CI process will be the subject of study. As for the number of cases, a multiple case study provides greater confidence in a study's findings than single cases by its cross-case comparisons that can strengthen the conclusions drawn from each case (Yin, 2012).

(C) Prior theory

Abductive studies use a prior theory, as referred to in Chapter 2. According to Miles and Huberman (1994), the pre-existing theory specifies who and what will (and will not) be studied. Two significant outcomes are expected to be developed (supported and expanded) from this case study. These are:

> Outcome 1: The development of a **structured and comprehensive definition** of the phenomenon of Construction Industrialization.
>
> Outcome 2: The characterization of the **CI development process** through a transformation model that helps to capture the complex nature of CI and can provide the necessary guidance to Practitioners when crafting their CI efforts.

Regarding "Outcome 1." (definition), a definition was developed in Chapter 3 (Paper I) and is used in the second part of the research design (Chapter 3) to be empirically elaborated:

> *"CI is a new form of production and management, driven by the adoption of several individual (but interrelated) construction, industrial engineering, and management innovations whose objective is to improve the productivity and the sustainable development in the construction industry."*

Regarding "Outcome 2." (the CI development process), which intersects with Organizational Change and Change Management theories, an initial list of constructs related to the Construction Industrialization development process is developed in Chapter 3 and presented in Table F.1. Three key aspects are addressed: Drivers, Changing Practices, and Elements of Influence

Table F.1: Initial list of constructs regarding the Construction Industrialization development process

Aspect and respective RQ	Correspondence	Significance of the data collection and analysis phases	Initial Constructs
Drivers (D)	Rationale	Reasons (triggers) behind the decision to implement a CI process.	D1: Productivity of the Industry D2: Competitiveness of the company D3: Individual human development D4: Quality of life and well-being of society D5: Environmental concerns D6: Performance of each project, in terms of time, cost, and quality
	Results	Expected consequences that are generated (or expected to be generated) by the CI process.	
Changing Practices (CP)	Principles to Industrialize (P)	General (and unique) principles of a CI transformation that can be applied in any context (or country).	CP.P1: Off-Site, Prefabricated (Factory) Production CP.P2: Modularization CP.P3: Automated Production CP.P4: Digitalization CP.P5: Lean Transformation CP.P6: Production System CP.P7: Mass Customization CP.P8: Business Model CP.P9: Design a Building as a Product CP.P10: Integrated Project Management CP.P11: Value Creation
	Dimensions to transform (D)	Hard and soft dimensions of change need to be embraced to assist in the transformation toward CI.	CP.D1: Strategy CP.D2: Organizational Design CP.D3: Operations CP.D4: Innovation Management CP.D5: Management Systems CP.D6: Technology CP.D7: Supply Chain Management CP.D8: Worker Capabilities CP.D9: Social & Behaviors CP.D10: Culture CP.D11: Leadership
Elements of Influence (EF)	External and Internal Environmental Conditions (E)	Influencing factors (internal and external) with positive/negative impact on the Construction Industrialization process.	EF.E1: General Environment EF.E2: Industry EF.E3: Company EF.E4: Project EF.E5: Individual
	Internal Circumstances (I)	Aspects of human and social behavior and relations with a crucial role in the Construction Industrialization process.	EF.I1: Supply Chain Integration EF.I2: Collaboration and Cooperation EF.I3: Communication EF.I4: Teamwork EF.I5: Knowledge Management EF.I6: Motivation EF.I7: Employee involvement EF.I8: Organizational Commitment

(D) Logic linking theoretical constructs to data

Consolidating the search for an elaborated definition and a transformation model, the Author should collect data from six aspects:

1. CI **Interpretation**;
2. The **Rationale** for change;
3. The **Principles** to industrialize;
4. The Organizational **Dimensions** to transform;
5. The expected **Results**;
6. The influencing **Context**.

Table F.2 details these aspects of Interpretation, Rationale, Principles, Dimensions, Results, and Context, that need to be addressed. It includes the respective goals for the empirical study, the questions to be asked, and the data sources utilized for data collection. A total of fifteen questions will be asked using different data sources for each aspect to achieve data triangulation.

Table F.2: Framing the empirical research

Aspects to study	Goal	Questions	Data Sources
I.Interpretation	To document each interviewee's understanding of the concept of Construction Industrialization.	1. What exactly do you mean by "*Industrialization of Construction*"? 2. For you, Construction Industrialization is synonymous with... 3. Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place.	- Interview - Direct observation (meetings) - Site visits - Reports
II.Rationale	Identify the reasons behind the decision to implement an industrialization process.	4. About your company, what factors do you consider to be the reasons for starting an industrialization process? 5. What factors do you consider to be the reasons for the sector to want to industrialize? 6. About yourself, what motivates you to want to contribute to the Construction Industrialization process?	- Interview - Direct observation (meetings) - Site visits - Reports
III.Principles to Industrialize	Explore the differences that represent and characterize an industrialization process.	7. Likert-scale measurement 8. Open questions in the interview protocol to complement the initial list	- Interview - Likert-scale evaluation - Direct observation (meetings) - Site visits - Reports
IV.Dimensions to transform	Explore the organizational changes that need to be made when implementing an industrialization process.	9. Likert-scale measurement 10. Open questions in the interview protocol to complement the initial list	- Interview - Likert-scale evaluation - Direct observation (meetings) - Site visits - Reports
V.Results	Explore the expected impacts of an industrialization process.	11. Likert-scale measurement 12. Open questions in the interview protocol to complement the initial list	- Interview - Likert-scale evaluation - Direct observation (meetings) - Site visits - Reports
VI.Context	Identify the factors (internal and external) that have a positive/ negative influence on an industrialization process.	13. Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process? 14. Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face? 15. Why is Construction Industrialization still a difficult challenge to implement?	- Interview - Direct observation (meetings) - Site visits - Reports

Two papers aim to be developed to present the empirical findings from the multi-case study conducted in this Doctoral Project: one paper focuses on the concept, while the second examines the process (Chapter 5). Both papers include the same data collection process, and the data analysis has been consolidated to address both perspectives—the concept and the process. This combined analysis offers insights into the depth, complexity, and scope of the CI phenomenon.

The fifteen questions explored in this empirical study provide a rich insight into the phenomenon of Construction Industrialization. Each question contributes uniquely to the existing understanding, and together, they facilitate a comprehensive analysis that captures the complex and transformational nature of this phenomenon. This in-depth exploration aligns with the objectives of this thesis, highlighting its significance in the field. The following explanation details how the questions and their corresponding answers aim to be integrated within the two papers to form a cohesive understanding.

The first paper focuses on elaborating the CI definition presented in Chapter 3. As a result, it addresses three main topics.

> Firstly, it explores how CI is perceived, which aligns with the Interpretation (aspect I, Table F.1) and is addressed by incorporating Questions 1 and 2 from Table F.2. Such interpretation then is confronted with the theoretical idea in the definition developed in Chapter 3: "*CI is a new form of production and management".*
>
> Secondly, it explores how CI should be performed, specifically what the CI process entails. This exploration considers the scope, depth, and complexity associated with the content of the change. In this first paper, the name used is "*key constituents*" and addresses Question 3 from Table F.2. Such exploration then is confronted with the theoretical idea in the definition developed in Chapter 3: "*driven by the adoption of several individual (but interrelated) construction, industrial engineering, management innovations".*
>
> Thirdly, it explores the gains or benefits expected from CI. This topic emphasizes the rationale for change (aspect II, Table F.2) and the anticipated results (aspect V, Table F.2), connecting the reasons for CI with the expected outcomes. It also confronts the theoretical idea in the definition developed in Chapter 3: "*whose objective is to improve the productivity and the sustainable development in the construction industry".*

The second paper focuses on the CI process. It employs a start list as recommended in the abductive literature (Chapter 2), which is based on the organizational transformation model presented in Chapter 4. The paper systematically explores several aspects (Table F.2) related to the CI process.

> Firstly, it explores the Rationale for Change (aspect II, Table F.2) and the expected results (aspect V, Table F.2), which identifies the drivers and the impacts that initiate a CI effort.

Secondly, it examines the Changing Practices essential for developing a CI process that effectively integrates the Principles of industrialization (aspect III, Table F.2) with the (organizational) Dimensions of change (aspect IV, Table F.2).

Thirdly, it examines the Elements of Influence, which relate to the context (aspect VI, Table F.2) and can have either a positive or negative impact on a CI initiative

In this second paper, novel and unanticipated insights may emerge empirically that can refine, adapt, and enhance the initial theoretical conceptualization (Dubois & Gadde, 2002; Borgström, 2012; Towers et al., 2020).

(E) Data Sources

As noted in Table F.2, four sources of data collection will be used in the empirical study: semi-structured interviews using a survey questionnaire, direct observation of meetings, site visits, and reports analysis.

(F) Sample Selection

Only Practitioners with decision-making and leadership positions in a Governmental Funding Agenda and those who contribute to a new Living Lab under development integrate the sample. All the selected Practitioners will collaboratively conceptualize, produce, and assess a new constructive system consisting of five distinct building types at the Living Lab. Different hierarchical levels should be approached in this study. The theoretical saturation in this study follows the guidelines suggested by Scholars who argue that engaging fewer than 20 respondents enables the Researcher to establish and maintain close relationships, thereby enhancing open and thoughtful information sharing.

3. Preparing data collection process

The data collection process is detailed in the case study protocol, which emphasizes (A) the elaboration and testing of an effective interview script, and (B) the importance of inviting participants to engage in this study. Additionally, the data sources and their applications have been thoroughly addressed in the previous subsection.

(A) Develop a primary interview script and conduct pilot interviews

The interview protocol consisted of two main sections. The first section aimed at obtaining general interviewer information. The second section was divided into two groups of questions: one that included

open questions about the meaning of Construction Industrialization and another that included questions derived from the constructs. The interview protocol is presented in Appendix G.

As recommended by Saunders et al. (2008), three Practitioners were independently interviewed as part of a pilot study to validate an interview protocol and test the understandability and duration of the interviews. These Practitioners were selected based on their role in their company's industrialization process, and their backgrounds included Civil Engineering, Mechanical Engineering, and Industrial Engineering and Management.

(B) Ask for participation in the study

Before each interview, including both the pilot interviews and the interviews with the seventeen Practitioners, every participant was sent an email describing the research aims and providing the interview protocol.

> *Dear XXX,*
>
> *In the last few years, I have been studying the paradigm of Construction Industrialization, as part of the PhD program in Industrial and Systems Engineering, at the University of Minho.*
>
> *From the research done so far, there is no clear understanding of this paradigm. My work has been precisely on the path of reflection, on the concept and its application.*
>
> *This email serves specifically as a step along the path of reflection leading to a common understanding. To this end, I request your collaboration in conducting an interview (lasting approximately 60 minutes), which will be used in the constitution of a case study base.*
>
> *The interviews aim to explore the process of Construction Industrialization: its understanding as a concept, and then the whole odyssey that begins with it. Attached I share the questions that will be addressed during the course of the interview as well as the confidentiality agreement.*
>
> *What we want is to bring the practical "voice", from the field, into the literature; to bring the experience, the opinion, and the practical knowledge, from the various sectors, and backgrounds, into a single, holistic view.*
>
> *Your "voice" is essential to the development of this research project and to the understanding of this phenomenon.*
>
> *I thank you for your attention and look forward to your availability for the interview.*
>
> *I would also ask for your help in identifying workers in your company who might be a valuable contribution to our study, and who are available to participate in this study. The criterion for the selection of interviewees lies precisely in people who are involved in the decision, or the implementation, of an Industrialization process.*

4. Collecting evidence

Data collection was carried out over two years (from January 2022 to January 2024). Four data sources (interviews, meetings, reports, and site visits) were used, as previously noted. At least two paper Authors participated in all the interviews. Each interview must be first transcribed and then coded.

5. Analyzing evidence

The data analysis process should include two steps: a within-case analysis focused on each case (sector), followed by a search for cross-case patterns – in line with Eisenhardt, (1989) and Barratt et al. (2011).

(A) Within-case analysis

In the within-case analysis, interview raw data were systematically organized for each sector across six aspects of Table F.2: Interpretation, Rationale, Principles, Dimensions, Results, and Elements of Influence. A dedicated table was created for each aspect, summarizing key details, including the sector, the respective interview question(s) from Table F.2, the Practitioner's identification number, the raw data (of part or whole) response, and a final column presenting the within-case analysis.

A three-order coding method was then applied. The first-order codes were derived directly from the raw data, clustered based on the six aspects. These initial codes subsequently informed the second-order codes, which reflected theory-centric interpretations. These interpretations were carefully intersected with the initial list of constructs to ensure empirical adequacy.

A significant feature of the abductive research approach is its capacity to refine and expand the initial list of constructs. Second-order themes that were not aligned with any of the existing priori constructs were grouped into newly emerging aggregated themes (Zott & Huy, 2007). The third-order coding stage then established the final list of constructs within the six aspects. This structured approach ensured a rigorous and thorough within-case analysis.

(B) Cross-case analysis

A cross-case analysis was carried out after the within-case analysis. A horizontal contrasting technique was implemented to identify similarities and differences in CI perspectives across different sectors, as recommended by Fisher & Aguinis (2017). Open-ended interview responses and empirical findings from 5-point Likert scale questions were systematically organized to assess the empirical adequacy of the initial theory across sectors. The cross-case analysis aimed to identify common constructs across different cases

while also providing a deeper understanding of how these constructs—both revised and newly identified—differed across sectors.

To ensure a comprehensive understanding, additional data from meeting observations, site visits, and reports were incorporated. This multi-source approach, including the creation of relevant tables, enabled a thorough consolidation of empirical findings. As a result, the analysis provided a robust and nuanced examination of CI perspectives across various sectors and multiple data sources.

(C) Findings Reporting

The coding process culminated in a compilation of constructs that more accurately and simply reflect the empirical realities associated with the phenomenon, as suggested by Maitlis (2005). A definition is refined, and a transformation model is elaborated with a new, and improved list of constructs and perspectives. Additionally, a refined list of constructs associated with the CI development process is developed.

Appendix G: The Interview Guide

1) We began the interview by getting to know the interviewee

AGE

☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ >51

ACADEMIC BACKGROUND

☐ Architecture ☐ Civil Engineering ☐ Mechanical Engineering ☐ Industrial Engineering and Management ☐ Other: _____

HIERARCHICAL LEVEL TO WHICH YOU BELONG (within your company)

☐ **CEO** (President, Chairman) ☐ **Executive Board** (Management/ Administration) Intermediate Position (Manager/ Architect/ Construction Manager, Project Manager, Team Leader) ☐ **Operative** (Laborer)

YEARS OF WORK IN THE CURRENT COMPANY

☐ <5 ☐ 6-10 ☐ 11-15 ☐ 16-19 ☐ >20

YEARS OF EXPERIENCE IN TRADITIONAL CONSTRUCTION (in your company and other companies)

☐ <2 ☐ 3-5 ☐ 6-10 ☐ 11-15 ☐ 16-19 ☐ >20

YEARS OF EXPERIENCE IN MODULAR CONSTRUCTION (in your company and other companies)

☐ No experience ☐ <2 3-5 6-10 ☐ 11-15 ☐ 16-19 ☐ >20

DEGREE OF RESPONSIBILITY IN THE CONSTRUCTION INDUSTRIALIZATION PROCESS

☐ **Decision maker** on the strategy and direction of the Industrialization process. ☐ **Responsible** for the execution of the Industrialization process. ☐ **Member of the team** of the Industrialization process. ☐ **Support** in the management and *backoffice* of the Industrialization process.

LEVEL OF EXPERTISE IN MODULAR CONSTRUCTION PROJECTS

☐ Beginner ☐ Intermediate/ Advanced ☐ Expert

We then go on to questions and answers, where it is thought that sharing experiences and reflections on the topic is necessary to enrich and surround the entire discourse.

THE UNDERSTANDING

To discuss the Industrialization of Construction is to bring different views of the Architecture, Engineering, and Construction sectors into a single understanding. Thus, our first questions are the following:

1. What exactly do you mean by "*Industrialization of Construction*"?
2. For you, Construction Industrialization is synonymous with....
3. Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place.

THE RATIONALE

Reflecting on industrialization entails considering what motivates this effort, as well as the reasons behind it. The topic is divided into three levels: company, sector, and person, for reasons that may or may not be communicated. As a result, we ask:

1. About your company, what factors do you consider to be the reasons for starting an industrialization process?
2. What factors do you consider to be the reasons for the sector to want to industrialize?
3. About yourself, what motivates you to want to contribute to the Construction Industrialization process?

THE CONTEXT

We, like any other industry or group of individuals, are influenced by the world around us. Various internal and external factors, as expected, have an influence on the Construction Industrialization process. As a result, we ask:

1. Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process?
2. Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face?
3. Why is Construction Industrialization still a difficult challenge to implement?

THE PROCESS

Industrialization implies change; it implies breaking away from a method of idealization, and working towards something new, and improved. This content of change is broken down into two elements in our research:
- By the essential principles that together characterize the holistic implementation of a Construction Industrialization process.
- By the organizational and human dimensions that are specifically impacted by the implementation of these same principles.

10 principles and 11 dimensions (identified based on the literature) will be confronted with practical knowledge. Together, we intend to arrive at an improved list of both principles and dimensions.

1. Regarding the principles, we would like you to rate them on a scale of 1 to 5, with 1 representing total disagreement that this principle characterizes a process of Industrialization of Construction and 5 representing total agreement that this principle characterizes a process of Industrialization of Construction (put an "*X*" on the answer).

Principles	Impact Level				
	1 Total disagreement	2 Low level of agreement	3 Medium level of agreement	4 High level of agreement	5 Full agreement
Implement an OFF-SITE MANUFACTURING process (outside the construction site).					
Use MODULARIZATION in the idealization and manufacture of the building, as well as in its distribution and assembly.					
Ensure AUTOMATION, and MECHANIZATION in the manufacturing process to replace manual labor with machines.					
Ensure DIGITALIZATION OF PROCESSES AND PROJECTS (BIM).					
Implement a MANAGEMENT PHILOSOPHY focused on operational excellence by reducing non-value adding activities (waste) in production (Lean).					
Develop a NEW PRODUCTION SYSTEM focused on the organization and management of production, which ensures flexibility, efficiency, speed, and agility.					
Ensure MASS CUSTOMIZATION (ability to offer customizable products with low production costs).					
Establish a new BUSINESS MODEL.					
DESIGN THE BUILDING AS A PRODUCT, where manufacturing, logistics, assembly, and disassembly concerns need to be considered at the design stage.					
Ensure an INTEGRATED PROJECT MANAGEMENT, across the various sectors, and with the various project entities.					
Ensure a VALUE CREATION along the three levels of Sustainability (Economic, Social and Environmental).					

2. Do you believe this list is complete? If not, what additional principles do you believe are missing?
3. Do you have any recommendations or comments for this list?
4. Select two of the principles and elaborate on your experience of their implementation, or lack of implementation.
5. Now consider the 11 organizational and human dimensions. As a result, we ask that you rank them on a scale of 1 to 5, with 1 corresponding to a dimension that has no influence on the implementation of the Construction Industrialization process and 5 corresponding to a dimension that has a complete impact on the implementation of the Construction Industrialization process (put an "*X*" on the answer).

Dimensions	Impact Level				
	1	2	3	4	5
	Total disagreement	Low level of agreement	Medium level of agreement	High level of agreement	Full agreement
Redefining the business STRATEGY.					
Redesign of the ORGANIZATIONAL STRUCTURE at the level of infrastructures (factories, centers...), and decision levels.					
Redefinition of OPERATIONS, at product and production process level, and their management.					
Encouraging INNOVATION, both in materials and engineering solutions, as in processes, and in the way of communicating and working with other entities.					
Restructuring the MANAGEMENT SYSTEMS that support, organize and connect processes and people.					
Improvement/investment in TECHNOLOGY and automated solutions.					
Reorganization of the SUPPLY CHAIN and its processes.					
Acquisition of new KNOWLEDGE and SKILLS.					
Focus on SOCIAL and HUMAN BEHAVIORS in order to contribute to a change of habits and mindset.					
Development of a CULTURE of learning, cooperation, ambition and mutual help.					
Ensuring effective LEADERSHIP, capable of charting, sustaining, and ensuring an effective Industrialization process.					

6. Do you believe this list is complete? If not, what additional dimensions do you believe are missing?
7. Do you have any recommendations or comments for this list?
8. What aspects of the human and social behavior, and relations, do you believe are crucial for an industrialization process both internally and with external stakeholders (suppliers, customers, architects, etc.? (Teamwork, collaboration, cooperation, ...)
9. Do you consider that all principles and dimensions can exist independently, or do they have a unique relationship that supports each other in the Industrialization Process?

THE RESULTS

We identified 7 expected Results of a construction industrialization process based on the literature.

1. Please score them on a scale of 1 to 5, with 1 representing total disagreement that this outcome is expected from a Construction Industrialization process and 5 representing total agreement that this outcome is expected from a Construction Industrialization process (put an "*X*" on the answer).

Results	Level of agreement				
	1	2	3	4	5
	Total disagreement	Low level of agreement	Medium level of agreement	High level of agreement	Full agreement
Improve PRODUCTIVITY of the industry.					
Improve the COMPETITIVENESS of the company.					
Boost HUMAN DEVELOPMENT.					
Improve the quality of life and well-being of WORKERS.					
Improve the quality of life and well-being of SOCIETY.					
Addressing ENVIRONMENTAL concerns.					
Improve the INDIVIDUAL PERFORMANCE OF EACH PROJECT, in terms of time, cost and quality.					

2. Do you believe this list is complete? If not, what additional result do you believe are missing?
3. Do you have any recommendations or comments for this list?

THE FUTURE

Finally, we will conclude our interview by asking:

1. How do you see the future of Construction Industrialization?
2. Is there anything else you would like to share on the topic of Industrialization that worries you, that challenges you, and that could contribute to this investigation?

Appendix H: The Ethical Conduct, Confidentiality, And Privacy Norms

The interview document outlined the important topics of Ethical Conduct, Confidentiality, and Privacy, and was shared with Practitioners when they were invited to participate in the empirical study. The topics were the following (English version):

- Interviewees should not begin participating in a study unless they can freely and self-determine their permission.
- Interviews will be recorded with the interviewees' consent; if permission is refused, notes will be taken.
- The interviewee has the option of declining to answer any question that he or she deems irrelevant.
- During the interviews, each interviewee is allowed to respond to questions using his or her professional expertise, experience, and personal opinion. They can use examples to help or explain their answer, as well as provide general or particular comments about the question's topic and context.
- All information supplied by interviewees in the course of research should be kept private.
- We are devoted to assuring dependability and rigor in research efforts, operating precisely, deliberately, and with attention to detail; and in conveying results, reporting them properly, completely, and impartially.
- In the research environment, only personal data that was truly necessary for the study's conduct were collected.

Appendix I: The Detailed Data Analysis Process

Given the extensive volume of data and transcripts generated throughout this study, this appendix summarizes the reasoning behind the data analysis process. Selected examples are shown to illustrate the approach taken in analyzing and interpreting the data. Such a selective presentation developed in this appendix appears to be the best decision in this thesis, as it ensures clarity in the data analysis process while effectively communicating key aspects of the research without overwhelming the reader with excessive detail.

As outlined in the case study protocol, data were systematically collected over a two-year period from four primary sources:

1. **Interviews** – Conducted with key Practitioners across the four sectors (cases) to gain firsthand insights and perspectives about the CI phenomenon. Seventeen interviews were conducted.
2. **Meetings** – Documented discussions and deliberations that contributed to the research findings.
3. **Site visits** – Observations from direct engagement and conversations with the study environment.
4. **Reports** – Official documents and archival records that provide supporting evidence.

The data analysis process begins with the analysis of interview data, which serves as the primary source of information. This is followed by an examination of secondary sources, including meeting notes, site visit observations, and relevant reports.

i. Interview data

Although the interview questions were designed to provide an overall understanding of the CI phenomenon, the analysis was structured into two papers: Paper IV, which addresses the conceptualization of CI, and Paper V, which examines the CI process. Table I.1 presents the main aspects analyzed, the corresponding interview questions, and the specific paper in which each topic was addressed. The table also indicates the appendix tables that present and further elaborate on the results associated with each question.

Table I.1: Papers IV and V related interview questions

Aspects to study	Questions and respective Paper	Table summarizing the results in the present Appendix
I.Interpretation	1. What exactly do you mean by "*Industrialization of Construction*"? **(Paper IV)** 2. For you, Construction Industrialization is synonymous with... **(Paper IV)** 3. Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place. **(Paper IV)**	Table I.2
II.Rationale	4. About your company, what factors do you consider to be the reasons for starting an industrialization process? **(Paper IV)** 5. What factors do you consider to be the reasons for the sector to want to industrialize? **(Paper IV)** 6. About yourself, what motivates you to want to contribute to the Construction Industrialization process? **(Paper IV)**	Table I.3 and Table I.4
III.Principles to Industrialize	7. Likert-scale measurement **(Paper V)** 8. Open questions in the interview protocol to complement the initial list **(Paper V)**	Table I.4 (Likert-scale measurement results) Table I.8 (open questions answer)
IV.Dimensions to transform	9. Likert-scale measurement **(Paper V)** 10. Open questions in the interview protocol to complement the initial list **(Paper V)**	Table I.6 (Likert-scale measurement results) Table I.8 (open questions answer)
V.Results	11. Likert-scale measurement **(Paper V)** 12. Open questions in the interview protocol to complement the initial list **(Paper V)**	Table I.7 (Likert-scale measurement results) Table I.8 (open questions answer)
VI.Context	13. Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process? **(Paper V)** 14. Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face? **(Paper V)** 15. Why is Construction Industrialization still a difficult challenge to implement? **(Paper V)**	Tables I.12-13

All the interview transcripts were thoroughly analyzed to develop a comprehensive coding structure. Initially, first-order codes were derived directly from the raw data (words underlined in the example tables shown below), capturing key concepts as they emerged. These first-order codes were then refined and organized

into second-order codes, which identified broader themes and relationships among the first-order codes. Finally, the second-order codes evolved into third-order codes, culminating in a final list of potential constructs that could contribute to the study's initial theories and constructs.

Each interview transcript was imported into NVIVO 15 software for efficient data management and analysis. In the first phase, summaries of the transcripts were generated using an artificial intelligence tool, providing an overview of the key concepts in each interview. An example of such a summary is presented in the figure below (Figure I.1).

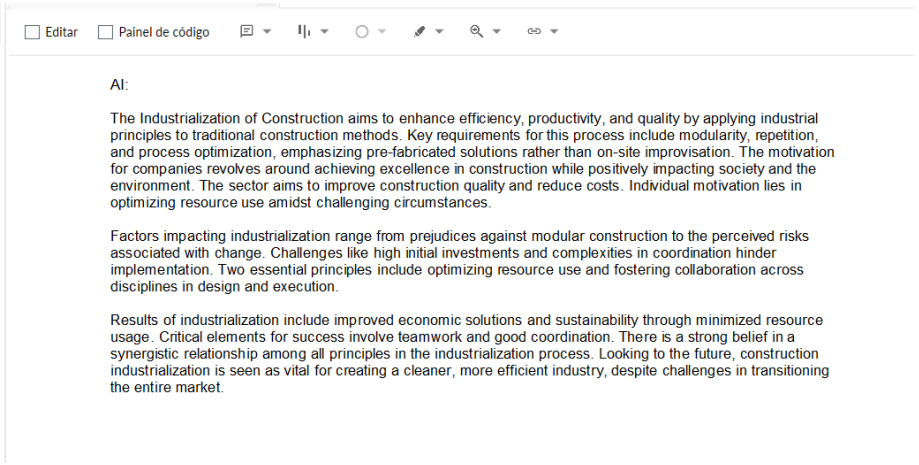


Figure I.1: Resume of Practitioner A1 interview using Artificial Intelligence in NVIVO 15 software

A manual within-case analysis was also performed, enabling a more detailed and systematic examination of each answer. This method likely involved carefully reviewing and analyzing responses one by one, rather than treating the data as a whole. It also allows for a more thorough understanding of the data on an individual level. Tables I.2-4 show how the interview answers were examined and how the within-case and cross-case analyses were developed.

Table I.2: Raw data from interviews concerning questions related to **CI interpretation**

Sector	Question	Practitioner	Part of the Answer	Within-case analysis
Architecture	What exactly do you mean by "Industrialization of Construction"?	A1	*"To me, construction industrialization aims to increase efficiency, productivity, and quality in construction by incorporating principles and methods from the industrial processes."*	**Both Practitioners** develop a shared understanding focused on changes in the productive system, due to industrial processes, mechanization, repetition, and modularity.
		A2	*"That the construction process is carried out with components and processes that are mechanized."*	
	For you, Construction Industrialization is synonymous with...	A1	*"Construction Process Optimization"*	
		A2	*"Mechanization with repetition."*	
	Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place.	A1	*"Modularity, repetition, and optimization of the different processes involved in construction. Solutions are mainly studied and fabricated beforehand and not improvised on-site."*	
		A2	*"A high degree of mechanization and repetition in both the manufacturing of building components and construction processes."*	
Engineering	What exactly do you mean by "Industrialization of Construction"?	E1	*"Moving off-site"*	**Both Practitioners** develop a shared understanding focused on changes in the productive system, similar to architecture analysis. E1 adopts a more pragmatic manufacturing approach, while E2 also introduces the role of digital tools in the CI development process.
		E2	*"Process through which the construction industry improves its production, aiming to reduce costs, increase quality, decrease execution time, and increase the sustainability of the construction process."*	
	For you, Construction Industrialization is synonymous with...	E1	*"A manufacturing approach to construction"*	
		E2	*"Standardization, less waste, better quality control, better efficiency, fewer delays, fewer errors, increased reliability."*	
	Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place.	E1	*"Avoidance of on-site construction"*	
		E2	*"Digital tools are ever more present, and how the data they generate is used leads to the conclusion that the inefficiency of the construction industry can be addressed with a more industrialized process during construction. The major problem with the construction industry stems from needing to set up a "factory" to construct each building. This is a highly bespoke process that is industrialized ad hoc. Supply chains are procured differently for each building, increasing overheads and leading to numerous mistakes and inefficiencies. Digital tools provide an easy and inexpensive way for information to flow more freely. This will lead to fewer information asymmetries, aligning what factories produce with what construction needs and incentivizing less adaptive work on-site and more preparation work off-site.*	

Table I.2: Raw data from interviews concerning questions related to **CI interpretation** *(continue)*

Sector	Question	Practitioner	Part of the Answer	Within-case analysis
Traditional Construction	What exactly do you mean by "Industrialization of Construction"?	TC1	*"Industrializing construction involves reducing man-hours in the process by completing on-site tasks in a factory setting."*	**The three Practitioners** develop a shared understanding focused on changes in the productive system, similar to architecture and engineering analysis. TC2 also introduces the modularity concept.
		TC2	*" Industrialization involves examining a building to identify the components that can be produced in a factory. It requires an understanding of how these elements connect and how they should be assembled on-site. The goal is to ensure that everything is manufactured in a factory setting."*	
		TC3	*"Industrialization refers to applying modern manufacturing techniques to construction."*	
	For you, Construction Industrialization is synonymous with...	TC1	*"Mass production"*	**Distinct perspectives** within and across sectors: TC1 focuses on production, TC2 on results, and TC3 on the product.
		TC2	*"Schedule"*	
		TC3	*"Product systematization"*	
	Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place.	TC1	*"It means having a high degree of manufacturing, where around 80-90% of jobs are done in a factory environment, and in series. Industrialization also means thinking about quality and materials. It involves robotization, automation, and manufacturing processes. The human contribution has more to do with controlling the equipment to work. It's also important to say that producing houses is different from producing cars. We must, however, think about mass customization. Industrialization is also about thinking about how to deliver the products, and how they are attached, and installed; above all, so that it is simple and intuitive. You don't need a high level of knowledge to be able to produce. Industrialization is also about providing added value to the entire value chain."*	**The three Practitioners** develop a shared understanding focused on changes in the productive system, similar to architecture and engineering analysis.
		TC2	*"When we can do a lot of the work that is typically done on-site, it's done in a factory. Industrialization is also about having teams that can take the owner's projects and transform them into modular construction when the projects don't arrive thought out like that. The industrialization process also ends when we have catalog solutions, as in the automotive industry. Finally, one last requirement has to do with orography, where urban planning needs to adapt the building to the terrain, and modular construction by catalogue. The process ends when the industry becomes agile."*	
		TC3	*"It covers several aspects: standardization, mass construction, and advanced technologies such as BIM, robotics, and 3D printing. There is an emphasis on improved management and sustainability. The goal is to reduce the environmental impact of centralization and shorten project timelines as part of an industrialization process."*	

Table I.2: Raw data from interviews concerning questions related to **CI interpretation** *(continue)*

Sector	Question	Practitioner	Part of the Answer	Within-case analysis
Manufactured Construction*	What exactly do you mean by "Industrialization of Construction"?	MC6	*"Industrializing construction refers to equipping the sector with the ability to apply technical and construction solutions in a controlled environment (off-site). This approach enables innovation in traditional construction methods, which, in many areas of the industry, have remained technologically stagnant for decades."*	**All Practitioners** develop a shared understanding focused on changes in the productive system (align with the other three sectors)
		MC7	*"The industrialization of construction has been underway for many years. Currently, the challenge is to increase the percentage of construction work done off-site, minimizing on-site activities to the essentials. However, industrializing the construction process goes beyond simply changing the location of the work. It involves modifying construction systems—such as structures and cladding—as well as construction processes, like assembly lines and assembly techniques. Additionally, it requires standardizing solutions and dimensions to ensure that the cost-to-quality ratio of the finished product meets the expectations of all parties involved in the process."*	
	For you, Construction Industrialization is synonymous with...	MC2	*"Efficiency and quality."*	**Different perspectives** but aligned with those of other sectors.
		MC4	*"Constructive System Optimization"*	
		MC10	*"Process Optimization/More Efficient Processes"*	
	Indicate what requirements you consider necessary to say that there is a process of Industrialization of Construction in place.	MC9	*"Industrialization of construction is synonymous with building systems. Prefabrication is not enough. Or the systematization of construction. Construction systems refer to precisely developing new ways of building, which must integrate knowledge, materials, and know-how. There has to be something that can unite different products from different companies. It's about creating an operating rule. Industrializing without a strategy is better, but the end product needs to integrate these products. Integration of knowledge."*	**Different perspectives** but aligned with those of other sectors.
		MC5	*"Moving as many works as possible to Off-Site. Industrialization also means defining a new production system. And this must be thought out in an integrated and systematic way; and both internal and external logistics must be thought out at the same time."*	

**This table presents only a selection of responses.*

Table I.3: Raw data from interviews concerning questions related to **CI Rationale**

Sector	Question	Practitioner	Part of the Answer	Within- and Cross-case and Analysis
Architecture	About your company, what factors do you consider to be the reasons for starting an industrialization process?	A1	*"Achieve excellence in construction both from a design and a construction perspective while providing a positive impact on both society and the environment."*	About the company, **they shared distinct perspectives:** A1 offered a societal viewpoint, while A2 focused on operational aspects. About the sector, **both Architecture Practitioners** answered focus on sustainable solutions, better quality buildings, and lower costs. About themselves, **both Architecture Practitioners** emphasize environmental improvement, and A2 highlights the impact of digital tools in engineering.
		A2	*"Rather than starting an industrialization process, we design buildings that are composed of modules composed of industrialized components because it makes the whole design and construction process more efficient and delivers better results."*	
	What factors do you consider to be the reasons for the sector to want to industrialize?	A1	*"Improve the quality of construction, and at the same time, with the aspiration of reducing costs."*	
		A2	*" To minimize costs, deliver higher quality buildings, minimize the required manual labor in construction sites, and minimize the environmental impact.."*	
	About yourself, what motivates you to want to contribute to the Construction Industrialization process?	A1	*"We are in a difficult moment, and resources need to be carefully addressed and utilized. The incorporation of industrialization processes in construction and design can help optimize their use. Designers should be aware of these processes and embrace them so that design can finally be part of the solution."*	
		A2	*" To make buildings that were not possible before, thanks to the use of technology, and to do so with a minimum environmental impact."*	
Engineering	About your company, what factors do you consider to be the reasons for starting an industrialization process?	E1	*"Client and project requirements and suitability"*	Regarding the company, both **Engineering Practitioners** responded with market pressures (distinct from Architecture analysis). About the sector, **both Engineering Practitioners** answered focus on sustainable solutions for better buildings at lower costs while improving efficiency (similar to Architecture analysis). About themselves, **Engineering Practitioners shared distinct perspectives**. E1 emphasizes environmental improvement, while Practitioner E2 highlights the impact of digital tools in engineering (both perspectives are similar to Architecture analysis).
		E2	*"Industrialization of construction, although delayed and moving slowly in comparison with other industries, is inevitable. Companies must adapt or die."*	
	What factors do you consider to be the reasons for the sector to want to industrialize?	E1	*"Decarbonization, reduction of waste improvements in efficiency"*	
		E2	*"Better efficiency, which will lead to better buildings at a lower cost."*	
	About yourself, what motivates you to want to contribute to the Construction Industrialization process?	E1	*"The above [decarbonization, reduction of waste, improvements in efficiency]"*	
		E2	*"The usage of digital tools and information as a driving factor."*	

Table I.3: Raw data from interviews concerning questions related to **CI Rationale** *(continue)*

Sector	Question	Practitioner	Part of the Answer	Within- and Cross-case and Analysis
Traditional Construction	About your company, what factors do you consider to be the reasons for starting an industrialization process?	TC1	*"There is a lack of labor or it is too expensive; (...) costs."*	**All Practitioners develop shared perspectives** and align with the perspectives of other sectors.
		TC2	*"better schedule and costs!"*	
		TC3	*"The demand for human resources is not keeping pace. For sustainability reasons, reducing deadlines can enhance efficiency and productivity."*	
	What factors do you consider to be the reasons for the sector to want to industrialize?	TC1	*"Reputation, improved employment opportunities, labor shortages, sustainability, costs, and reduced dependence on sector variables."*	
		TC2	*"Our industry is completely stagnant. I'm sick of it. The methods have been the same for 100 years."*	
		TC3	*"The construction industry has yet to experience a modern transformation."*	
	About yourself, what motivates you to want to contribute to the Construction Industrialization process?	TC1	*"sustainability"*	
		TC2	*"innovation; challenge"*	
		TC3	*"Cost reduction, longer deadlines (the customer will choose the deadline), a step towards sustainability, and improved product quality."*	
Manufactured Construction	About your company, what factors do you consider to be the reasons for starting an industrialization process?	MC6	*"Awareness of the significant and ongoing challenges facing the construction industry."*	**All Practitioners develop shared perspectives** and align with the perspectives of other sectors
		MC7	*"1. Provide workers with comfort by minimizing the time they spend away from home. 2. Increase the speed of construction to better respond to societal and market needs. 3. Strive for greater efficiency and quality in construction practices. 4. Recognize that, with rising labor costs, off-site construction may be a more economical solution in the long term compared to traditional on-site methods. 5. Commit to adhering to Life Cycle Assessment (LCA) principles. 6. Consider disassembly from the design stage onward. 7. Reduce the uncertainties associated with traditional construction projects, such as weather conditions and delays caused by various suppliers and installers."*	

Table I.3: Raw data from interviews concerning questions related to **CI Rationale** *(continue)*

Manufactured Construction *(continue)*	What factors do you consider to be the reasons for the sector to want to industrialize?	MC10	*"Cost, sustainability, quality"*
		MC9	*"There is a trend in fashion: modular construction is seen as the solution to many challenges."*
	About yourself, what motivates you to want to contribute to the Construction Industrialization process?	MC1	*"About me and the people I interact with, it's clear that we are all motivated by change. There is a significant paradigm shift happening, and this inspires people to take action. Our goal is to do something different and better—something that hasn't been accomplished before. Just as the industrial revolution transformed society, I believe we are entering a new era in construction that can similarly be described as an industrial revolution. People feel inspired to be a part of this transformative change."*
		MC8	*"I enjoy learning because I have always wanted to be at the forefront of knowledge. I don't mind the discomfort of admitting when I don't know something. We are already behind, and it's important to take action. We can approach things differently, and we can do more and achieve better results."*

Table I.4: Cross-case analysis of the **synonyms** shared in the interviews

Concepts/Key themes	**Sectors**	**Case, respondent synonyms, and practitioner code (linked with Table I)**
Constructive System	TC; MC	TC: "Product Systematization" (TC3) MC: "Product Systematization" (MC1); "Constructive System Optimization" (MC4; MC5; MC6); "Modularization" (MC3);
Production System	A; E; TC; MC	A: "Construction Process Optimization" (A1); "Mechanization with Repetition" (A2) E: "Manufactured Approach" (E1); "Standardization" (E2) TC: "Mass Production" (TC1), "Schedule" (TC2) MC: "Efficiency and quality" (MC2); "Industrial Thinking" (MC8); "Process Optimization" (MC10)
Industry Change	MC	MC: "Integration of economies of products and knowledge" (MC7); "Sustainability and Competitiveness" (MC9)

The results from the five Likert-scale evaluations were analyzed using tables that summarize the level of agreement among Practitioners and sectors for each construct, along with the design principles, changes in practice, and outcomes. This is followed by an exploration of whether Practitioners suggest adding additional constructs to the original list proposed in this research. Tables I.5-7 present the Practitioners' ratings for each construct on a five-point Likert scale, highlighting their level of agreement or disagreement regarding the relevance or importance of each construct.

Table I.5: Summary of Likert Scale Results from Interviews on **Design Principles**

Constructs	Sector	Total agreement	Low level of agreement	Medium level of agreement	High level of agreement	Full agreement
CP.P1: Off-Site, Prefabricated (Factory) Production	Architecture				A1;A2	
	Engineering			E1		E2
	Traditional Construction			TC3		TC1;TC2
	Manufactured Construction					MC1;MC2;MC4; MC5;MC6;MC7;MC8;MC10
CP.P2: Modularization	Architecture				A1;A2	
	Engineering			E1		E2
	Traditional Construction			TC3	TC1	TC1;TC2
	Manufactured Construction				MC3;MC9; MC7	MC1;MC2; MC4; MC5; MC6 MC8; MC10
CP.P3: Automated Production	Architecture			A1		A2;
	Engineering			E2	E1	
	Traditional Construction			TC3		TC1;TC2
	Manufactured Construction			MC9	MC4;MC7	MC1;MC2; MC3;MC5;MC6;MC8;MC10
CP.P4: Digitalization	Architecture				A1; A2	
	Engineering					E1;E2
	Traditional Construction			TC3;		TC1;TC2
	Manufactured Construction					MC1;MC2;MC3;MC4;MC5;MC6;MC7; MC8;MC9;MC10
CP.P5: Lean Transformation	Architecture			A1;		A2
	Engineering			E1; E2		TC1
	Traditional Construction			TC2	TC3	
	Manufactured Construction				MC4;MC6	MC1;MC2;MC3; MC5;MC7;MC8;MC9;MC10
CP.P6: Production System	Architecture		A1			A2
	Engineering			E1	E2	
	Traditional Construction				TC3	TC2;TC1
	Manufactured Construction				MC1; MC4; MC9	MC2;MC3;MC5; MC6;MC7;MC8;MC10
CP.P7: Mass Customization	Architecture			A1	A2	
	Engineering			E1;E2		
	Traditional Construction		TC2	TC1	TC3	
	Manufactured Construction				MC1;MC3;MC4; MC5;MC6;MC7; MC9	MC2; MC8; MC10
CP.P8: Business Model	Architecture		A1	A2		
	Engineering			E1;E2		
	Traditional Construction			TC3		TC1
	Manufactured Construction			MC1; MC8	MC3;MC4;MC5; MC7;MC9;MC10	MC2; MC6
CP.P9: Design the building as a product	Architecture				A1;A2	
	Engineering				E1	E2
	Traditional Construction				TC1	TC2;TC3
	Manufactured Construction			MC7		MC1;MC2;MC3; MC4;MC5;MC6;MC8;MC9; MC10
CP.P10: Integrated Project Management	Architecture				A1;A2	
	Engineering				E1;E2;	
	Traditional Construction				TC3;TC1	TC2
	Manufactured Construction			MC9	MC5; MC10	MC1;MC2;MC3;MC4; MC6;MC7;MC8
CP.P11: Value Creation	Architecture					A1;A2
	Engineering				E1;E2	
	Traditional Construction					TC1;TC2;TC3
	Manufactured Construction				MC4;MC6; MC7	MC1; MC2;MC3; MC5;MC8;MC9; MC10

Table I.6: Summary of Likert Scale Results from Interviews on **Organizational Dimensions**

Constructs	Sector	Total agreement	Low level of agreement	Medium level of agreement	High level of agreement	Full agreement
CP.D1: Strategy	Architecture				A1;A2	
	Engineering			E1	E2	
	Traditional Construction				TC2;TC3	TC1
	Manufactured Construction			MC1	MC2;MC;MC4;MC5;MC7; MC8;MC9;MC10	MC6
CP.D2: Organizational Design	Architecture				A1	A2
	Engineering			E1		E2
	Traditional Construction				TC1;TC3	TC2
	Manufactured Construction				MC2;MC3;MC4; MC9	MC1;MC2;MC5;MC6; MC7;MC8;MC10
CP.D3: Operations	Architecture				A1	A2
	Engineering			E1		E2
	Traditional Construction				TC2 TC3	TC1
	Manufactured Construction				MC1;MC4;MC9;	MC2;MC3;MC5;MC6; MC7;MC8;MC10
CP.D4: Innovation Management	Architecture					A1;A2
	Engineering			E1		E2
	Traditional Construction				TC1; TC3	TC2
	Manufactured Construction				MC1;MC6;MC9	MC3;MC4;MC5; MC6; MC7;MC8;MC10
CP.D5: Management Systems	Architecture			A1	A2	
	Engineering			E1	E2	
	Traditional Construction		TC1	TC2;TC3		
	Manufactured Construction				MC1;MC2; MC3;MC4;MC5; MC9; MC10	MC6; MC7; MC8
CP.D6: Technology	Architecture				A1;A2	
	Engineering			E1; E2;		
	Traditional Construction				TC2; TC3	TC1
	Manufactured Construction				MC1;MC2; MC9;MC10	MC3;MC4;MC5;MC6;MC7; MC8
CP.D7: Supply Chain Management	Architecture				A1;A2	
	Engineering			E1	E2	
	Traditional Construction				TC2;TC3	TC1
	Manufactured Construction			MC2	MC1;MC6; MC9	MC3;MC4;MC5;MC7;MC8; MC10
CP.D8: Worker Capabilities	Architecture				A2	A1
	Engineering			E1	E2	
	Traditional Construction				TC3	TC1;TC2
	Manufactured Construction				MC1;MC6; MC8;MC9	MC2;MC3;MC4;MC5;MC7; MC10
CP.D9: Social & Behaviors	Architecture				A1;A2	
	Engineering			E1; E2		
	Traditional Construction			TC1	TC2 TC3	
	Manufactured Construction				MC1;MC6; MC7;MC9;MC10	MC2;MC3;MC4;MC5;MC8
CP.D10: Culture	Architecture				A2	A1
	Engineering			E1; E2		
	Traditional Construction			TC3	TC1;TC2	
	Manufactured Construction				MC1;MC4;MC6; MC9;MC10	MC2;MC3;MC5;MC7;MC8
CP.D11: Leadership	Architecture				A1	A2
	Engineering			E1; E2		
	Traditional Construction			TC3		TC1;TC2
	Manufactured Construction				MC1;MC3;MC5; MC6;MC9	MC2;MC4;MC5;MC7;MC8; MC10

Table I.7: Summary of Likert Scale Results from Interviews on **Results**

Constructs	Sector	Total agreement	Low level of agreement	Medium level of agreement	High level of agreement	Full agreement
D1: Productivity of the Industry	Architecture				A	A2
	Engineering				E1	E2
	Traditional Construction				TC3	TC1;TC2
	Manufactured Construction				MC7	MC1;MC2;MC3; MC4;MC5;MC6; MC8;MC9;MC10
D2: Competitiveness of the Company	Architecture				A1	A2
	Engineering				E1;E2	
	Traditional Construction				TC3	TC1;TC2
	Manufactured Construction				MC5;MC6;MC8	MC1; MC2;MC3;MC4; MC7;MC9;MC10
D3: Individual human development	Architecture			A2		A1
	Engineering				E1;E2	
	Traditional Construction			TC3	TC2	TC1
	Manufactured Construction			MC5	MC1;MC4;MC6; MC9; MC10	MC2; MC3;MC7;MC8
D4: Quality of life and well-being of society	Architecture			A2		A1
	Engineering				E1;E2	
	Traditional Construction			TC3		TC1;TC2
	Manufactured Construction				MC1; MC3;MC4; MC5;MC6; MC7;MC10	MC2; MC8;MC9
D5: Environmental concerns	Architecture				A2	A1
	Engineering			E2	E1	
	Traditional Construction				TC3	TC1;TC2
	Manufactured Construction				MC3;MC4; MC5;	MC1; MC2;MC6;MC7; MC8;MC9;MC10
D6: Performance of each project, in terms of time, cost, and quality	Architecture				A1	A2
	Engineering				E1;E2	
	Traditional Construction			TC2	TC3	TC1
	Manufactured Construction				MC5	MC1; MC2;MC3;MC4; MC6;MC7;MC8; MC9;MC10

Paper V highlights that Practitioners suggested further refinements and enhancements to the initial theories and constructs that were primarily analyzed. As outlined in Chapter 5 and detailed in the interview guide (Appendix G), Practitioners were asked whether they would propose any additional constructs to be included in the research. While some did not provide suggestions, others contributed valuable insights (see Table I.8). In some cases, Practitioners emphasized the importance of certain constructs that had already been defined. Then, the suggestions were first categorized as first-order codes, which were then grouped into second-order major themes. Finally, a cross-case analysis is conducted to identify new constructs not included in the original list.

Table I.8: Suggestions provided by the Practitioners in the interview

Suggestions	Practitioner	Excerpt	Impact on the initial theory
Results			
Initial List			
Environmental	TC1; A1	*"Environmental sustainability must be a global priority. Adopting sustainable and efficient building practices is essential to reduce environmental impact and promote long-term ecological resilience".*	**Must refine** an existing construct
Societal	A2	*"To address housing poverty, we must provide low-cost options for low-income individuals, while ensuring quality."*	**Must refine** an existing construct
Project	E2	*"Improving the time-to-market for buildings should be one of the key expectations of Industrial Construction.*	**Must refine** an existing construct
New ones			
Innovation	TC2	*"Driven by a desire to innovate and lead change, making a meaningful difference in the construction industry*	**Resulted** in a new construct
Cost Control	TC2	*"Cost Control"*	**Resulted** in a new construct
Supply Chain	MC3	*"Transparency in the supply chain"*	**Resulted** in a new construct
Theoretical Boundaries	A2	*"Expand Theoretical Boundaries"*	**Resulted** in a new construct
Design Principles			
Environment	A1	*"This phase would concentrate on finding ways to minimize resources used and waste produced. (...) However, not only factors such as economy are involved in this critical optimization phase, more sustainable materials are achieved thanks to the possibility of minimizing the use of resources and waste production, resulting in more sustainable solutions."*	**Resulted** in a new construct
Digitalization	E2 TC3 MC10	*"full digitalization of processes and projects"* *"BIM has to feature prominently on this list."* *"Digitalization has to be linked to Industry 4.0, and that should be on this final list."*	**Refined** an existing construct
Customization	A2	*I also think that it would be interesting to add a point on the ability to customize and modify the building once it's built.*	**Reinforced** an existing construct
Design concern	A2	*The only thing I would recommend is being careful with the point of "designing buildings as products". When buildings are designed in this way, good and bad design decisions get built and replicated across our cities. If some of those design decisions are bad decisions, the negative impact of buildings can be huge and very difficult to correct, since buildings usually stay in our cities for over 100 years.*	**Refined** an existing construct
Experimentation and test	A2	*"I would add the need to test solutions, in a learning by doing manner, rather than implementing strategies that an organization has acquired through the knowledge of others."*	**Resulted** in a new construct
Organizational Dimensions			
People's knowledge development	A1 A2	*"I really like the concept of integrating CULTURE and TRAINING at the core of the business. Allowing people to grow professionally and personally through continuous learning programs can have a very positive impact on the construction industrialization process."* *"I would add one mentioning the importance that people in the companies (management, engineering, or design) should have the correct set of skills and knowledge to undertake the industrialization process.*	**Reinforced** an existing construct
Marketing	TC1	*"Explore the consumer side and doubts"*	**Resulted** in a new construct

Table I.9 presents the responses (priorities) from each interviewed practitioner for each element of influence. The symbol "●" indicates the elements that were identified by the Practitioners. The frequency data in Table I.9 reflects how many Practitioners recognized each element of influence as relevant. Additionally, the number of sectors listed allows for a cross-case analysis, helping to determine whether a particular element of influence is highlighted by Practitioners from only one sector or by multiple sectors. Table I.10 shows some raw data from interviews concerning questions related to the CI Context.

Table I.9: Analysis of Practitioners' correspondence for each Element of Influence ("●" verified in the interview)

Initial List of Elements of Influence	Frequency	Number of Sectors	Practitioner Code																	
			Architecture		Engineering		Traditional Construction			Manufactured Construction										
			A1	A2	E1	E2	TC1	TC2	TC3	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10	
External and Internal environmental conditions																				
EF.E1: General Environment	2	2			●		●													
EF.E2: Industry	8	4	●			●	●		●		●					●	●	●		
EF.E3: Company	4	4	●		●				●									●		
EF.E4: Project	7	4	●		●			●		●			●	●	●					
EF.E5: Worker	2	2							●									●		
Internal Circumstances																				
EF.I1: Supply Chain Integration	7	4		●		●	●	●									●	●	●	
EF.I2: Collaboration and Cooperation	5	4		●		●	●						●	●						
EF.I3: Communication	3	3		●		●									●					
EF.I4: Teamwork	4	3		●		●										●		●		
EF.I5: Knowledge Sharing	3	2							●					●		●				
EF.I6: Motivation	2	2							●			●								
EF.I7: Employee involvement	3	1											●			●	●			
EF.I8: Organizational Commitment	1	1												●						

Table I.10: Raw data from interviews concerning questions related to the **CI Context**

Sector	Question	Practitioner	Part of the Answer	Within- and Cross-case and Analysis
Architecture	Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process?	A1	*"Prejudice has a negative impact. People often refer to modular construction as low-quality building systems."*	Regarding the influencing factors, **both Practitioners** mentioned social barriers. When discussing the most serious challenges, **both Practitioners** referred to the changing needs within the construction industry. As for CI remaining a difficult challenge, **both Practitioners** pointed to the many factors influencing the industry and emphasized the need for a multidisciplinary approach involving diverse teams.
		A2	*"Positive impact: The will in a company to want to industrialize, but most importantly, learning through testing rather than talking and listening. Negative impact: The lack of talent, flexibility, and ambition in a company, as well as sticking to the way things have always been done. But on the other side, to be naïve about the challenges ahead for the industrializing processes."*	
	Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face?	A1	*"Change is often seen as a dangerous move since it might not always be successful. "*	
		A2	*"It is very difficult to say which are the most influential factors because it depends on each case. Technological development is a crucial one that sometimes does not depend on the will of a company to industrialize, but in general, I would say the most challenging barrier is to industrialize an industry (construction) with the number of variables that it has."*	
	Why is Construction Industrialization still a difficult challenge to implement?	A1	*"Many factors influence here, big initial investment, specialized teams, a multidisciplinary approach, and coordination complexity in the design process until the modular system is in place, etc."*	
		A2	*"Because construction is a tremendously complex industry with many variables: each building involves a specific site with different conditions, different regulations apply, briefs are also different, and local architectural objectives are also different. However, there are many parts of buildings that have been "industrialized", from bricks to kitchens to facades."*	

Table I.10: Raw data from interviews concerning questions related to the **CI Context** *(continue)*

Sector	Question	Practitioner	Part of the Answer	Within- and Cross-case and Analysis
Engineering	Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process?	E1	*"risk"*	**The engineering Practitioners differ in their perspectives**. E1 adopts a more technical viewpoint but references the change risk, while E2 focuses on the interconnections and externalities affecting each stakeholder.
		E2	*"Because of the long supply chain in construction, there are externalities to each stakeholder that cannot be offset without a push from the industry as a whole. Think of the BIM implementation. If a construction company wants to align its process with a BIM methodology, it needs designs to be produced in BIM and its partners and suppliers to also use the process. Since the shared value of BIM is much greater than the value generated for each stakeholder alone, this leads to an externality where there is a group incentive, but separately, any company that pursues BIM will be at a disadvantage against its competition. In these cases, a comprehensive approach is needed. This means that regulators or industry-wide associations need to push the process, ensuring all stakeholders align with industrialization together."*	
	Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face?	E1	*"Above"*	
		E2	*"Yes. This is the most influential factor."*	
	Why is Construction Industrialization still a difficult challenge to implement?	E1	*"Above"*	
		E2	*"Again, due to the externality addressed above."*	

Table I.10: Raw data from interviews concerning questions related to the **CI Context** *(continue)*

Sector	Question	Practitioner	Part of the Answer	Within- and Cross-case and Analysis
Traditional Construction	Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process?	TC1	*"Social and Political Pressures"*	**All Practitioners mentioned social and societal barriers** to the CI implementation.
		TC2	*"The company's culture and its openness to change."*	
		TC3	*"Prejudice Stemming from Quality; When it comes to connecting the components, it's still something we need to carefully consider."*	
	Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face?	TC1	*"Acculturation and Pedagogy in Educational Institutions; Pedagogy with Professionals and Consumers; Promote and Market These Products"*	
		TC3	*"Have a solid industry for industrial construction."*	
	Why is Construction Industrialization still a difficult challenge to implement?	TC1	*"Primarily, we must understand public perceptions and communicate in a way that aligns with them. It is essential to raise awareness and build a positive image of industrial construction. By effectively addressing misconceptions and highlighting its benefits—such as efficiency, sustainability, and innovation—we can foster greater public interest and, ultimately, strengthen the demand for industrial construction."*	
		TC2	*"Culture – Mindset; change management; initiation of investment. Resistance to change (a major challenge). A tendency to work in a traditional way. Resistance to change from the client. We are often unable to get prefabricated elements approved on site — it's seen as something unusual."*	
		TC3	*"because there are so many doubts about the process and its advantages"*	

Table I.10: Raw data from interviews concerning questions related to the **CI Context** *(continue)*

Sector	Question	Practitioner	Part of the Answer	Within- and Cross-case and Analysis
Manufactured Construction	Which external or internal influencing factors, in your opinion, have a significant positive or negative impact on the Construction Industrialization process?	MC7	*"A negative factor is the assumption that industrial construction simply means building prefabricated houses. There is a necessary shift in mindset that must take place."*	**All Practitioners** mentioned social and societal barriers **to the CI implementation.**
		MC8	*"A paradigm shift for prosecutors as well."*	
	Do you agree that these influencing factors are the most challenging barriers to overcome during the industrialization process? If not, what are the most serious challenges we face?	MC1	*"Mental and social question"*	
		MC9	*"There is limited knowledge about industrial construction, and clients remain hesitant."*	
	Why is Construction Industrialization still a difficult challenge to implement?	MC2	*"Clients are very hesitant about industrial construction, associating it with low quality and prefabricated houses. They don't understand that it can be used to achieve diverse outcomes, from luxury hotels to affordable housing. This is the challenge we aim to address: the housing problem across Europe, using modular construction."*	
		MC7	*"The industry has inertia toward this change because it requires transforming supply chains, products, and construction systems."*	

ii. Analysis of secondary field notes and their Impact on the Initial CI Definition and CI Transformation Model Constructs

Secondary sources of data played a crucial role in this study, serving as an essential tool for gathering valuable insights. These sources provided the Author with the opportunity to observe the ongoing dialogue, discussions, and concerns within various settings.

Tables I.11–I.13 present representative excerpts and conclusions gathered from three key data sources: 20 observed meetings, five site visits, and ten analyzed reports, respectively. For each source, the tables include the date of data collection, the setting and purpose of the collection, the sectors involved, a summary of relevant excerpts, and an analysis of how these conversations and perspectives contributed to shaping the final framework and findings of the study.

Table I.11: Some raw data from the reports analyzed

Number	Date	Setting	Excerpts
1	02/11/2022	Governmental Funding Agenda report	Topics addressed: • Seven Work packages were defined: design, materials, products, automation, digitalization, human resources skills, and management.
2	01/01/2023	Living Lab conceptual design report	Excerpt: "*Modular buildings utilize off-site lean manufacturing techniques to create prefabricated modules for larger building solutions. These structures are manufactured in the safe and controlled setting of a manufacturer's site, delivered to the site, eventually intermediate stored, and erected into a final building design.*" Assumptions: • Offsite prefabrication means faster turnaround, addressing the demand for shorter lead times. • Offsite manufacturing enables higher execution quality. • And higher productivity due to more standardized approaches with less material and labour effort • The planning complexity is lower due to fewer stakeholders involved in the value chains well as fewer single execution steps. • The end-of-life scenario can be better addressed due to the more systemized building approach. • Health and safety are enhanced due to controlled factory environments.
3	27/01/2023	Governmental Funding Agenda report	Excerpt: • "*The Funding Agenda aims to develop and industrialize a new disruptive concept - modular construction - capable of responding to the growing needs of the market and the new challenges facing the sector today, particularly in terms of sustainability and environmental protection.*"
4	12/03/2023	Living Lab report	Topics addressed: • "*Be modular; but no seemed as modular*," • "*Modular is not a constraint; is an opportunity*" "*Design strategies for the building: flexibility and adaptability, stability, detailing, and simple load path*"

Table I.11: Some raw data from the reports analyzed *(continue)*

Number	Date	Setting	Excerpts
5	08/09/2023	Discussion of the key requirements and Constraints for the Living Lab	Topics addressed: • To design a modular building system demonstrating innovative modular design across 4 separate uses • Building to be a test for various modular manufacturing techniques and services design • Innovative Technical solutions • Eco materials / Eco design: sustainable materials and systems. Design to be as sustainable as possible • Aspiration for innovative digital infrastructure. IoT solutions – ensuring different levels of service • Work on site to be minimized (in particular, façade installation) • External expression: For modular design to be celebrated and visibly expressed in the architecture and detailing • Residential components to be habitable Building to be used by workers (Portuguese, Foreign, and refugees)
6	22/09/2023	Dstgroup thesis about the DFMA approach	Topics addressed: • The Role of DFMA in the CI process; • The concept of modularity in construction and how to achieve an appropriate level of granularity; The challenges associated with adopting the DFMA approach in the CI context, particularly related to technology, expertise, mindset, and the relationships between various entities involved in the process.
7	3/10/2023	Living Lab report	Topics addressed: • Whole Life Carbon Assessment • Smart Buildings & IoT Control Strategy • Circular Design and Materials Strategy Structural Engineering
8	17/10/2023	Proposal for Evaluating Building Quality	Topic addressed: "*It is essential to include economic, environmental, social, and design dimensions in the assessment indicators.*"
9	03/11/2023	Suggestion of good practices for CI	Topics addressed: • Early approval of project specifications and requirements, defined as "*early material and design freezing*" • Implementation of a new construction system • Effective production planning, including logistics and supply chain management The production phase encompasses flows, planning, internal logistics, and quality control
10	12/12/2023	Review of the main challenges of modular construction	Topics addressed: • Acquiring machinery and equipment to automate the production process in the factory. • Defining the factory layout and workflow. • Implementing Lean principles in factory operations. • Emphasizing the importance of full alignment among all parties involved in the financing agenda. • Fostering a collaborative culture to quickly identify and resolve issues. • Highlighting the significance of employee involvement and commitment. • Recognizing that sharing knowledge is essential for collective learning. • Emphasize aesthetics and creativity in designing an appealing Living Lab. "*Always striving to reinvent the concept of infinity.*"

Table I.12: Some raw data from the site visits

Number	Date	Setting	Some excerpts
1	01/08/2023	Factory visit	*"Producing with the same methods and fabrication processes in a controlled environment only brings back the same problems that the construction industry has been facing for many decades, without solving them. This is not what is desired!"* *"We need to produce differently in the factory; the processes have to be balanced. We have to be as productive as possible."* *"Breaking down the building into modules is also one of the challenges."*
2	04/08/2023	Factory visit	*"CI depends on automation. We need machines. We also need to look for new solutions for materials and products."* *"With CI control, the whole process, step by step."* *"Industrialization involves robotization and mechanization. Machines and robots."* *"Industrialization needs a lot of research into materials. A lot of sharing of knowledge in the various areas. People who aren't in a very specific area. We're all going to have to know a little bit about everything."* *"One of the biggest difficulties we had was the delivery of materials. The suppliers delivered the whole order in one go and didn't apply just in time to our needs."*
3	28/09/2023	Factory visit	*"Change the mindset. The way we organize. The manufacturing process. We need a detailed vision, □ from the outside in, from the inside out."* *"I don't think the human component and the quality of life of the workers are discussed much. It's one of the most important things. The comfort of going home every day. Personal life balance."* *"A change of paradigm and mindset. We can't want to industrialize and continue to think the way we think about traditional construction."*
4	12/02/2024	Factory visit	*"It was difficult for me at first, but now I just want to work here, in a controlled environment, with fixed hours, and without being exposed to the weather. It's a very different quality of life" (operational sharing)*
5	20/06/2024	Living Lab Prototype visit	*"We want to reach many markets; the humanitarian part for us is a topic; this construction will make a difference in the future."* *"Thinking about the construction system is what will set us apart. It will bring flexibility and adaptability from an engineering point of view, while at the same time bringing creativity through design and architecture. This is our goal."* *"DFMA is essential; it has to be an essential tool for linking the construction system to the production system."* *"By putting this building system on the market, one topic to study is social barriers."*

Table I.13: Some raw data from the observed meetings

Number	Date	Setting and Purpose	Sectors involved	Some excerpts or hot topics
1	12/01/2021	Living Lab First Workshop	The four sectors	*"The challenge is to develop a new constructive system"; "Modular construction impacts on People, Building and Systems"*
2	09/02/2022	Update on Architecture and Structural Developments	The four sectors	"*Bring creativity in the design"; "Play with the forms of modular construction"; "Do not restrict the forms to the parallelepiped*"
3	02/11/2022	Governmental Funding Agenda Workshop	Traditional construction and the manufactured construction sectors	*"Seven Work packages were defined: design, materials, products, automation, digitalization, human resources skills, and management."*
4	31/01/2023	Live Cycle Assessment (LCA) and LEED certification	The four sectors	*"A set of guidelines was established"; "CI must apply such certifications in its implementation"*
5	13/02/2023	Transportation challenges	Traditional construction and the manufactured construction sectors	*"Transportation is a big concern because of the dimensions and the costs that imply"; "transportation cost can compromise the economic benefit that is expected from industrialized construction"; "Managers must be excellent in cost control"*
6	23/02/2023	Update on Architecture and MEP developments	The four sectors	"*Constructive System status presentation"; "decision matrix on what to test in each building*"
7	03/03/2023	Energy meeting	The four sectors	"*Alternative Sources of energy"; "Ecological modernization"; Building Physics" and "Water reuse systems*".
8	09/03/2023	Update on Architecture and MEP developments	The four sectors	"*Constructive System status presentation*";
9	21/03/2023	Living Lab - Architecture + Integration with Disciplines	The four sectors	"Architecture; BIM" "Coordination, cooperation, and collaboration"
10	24/03/2023	IoT	The manufactured construction and the Traditional Construction	"more efficient buildings" "alexa"
11	04/05/2023	Improvements in the building project	The manufactured construction and the Traditional Construction	*"DFMA" "new materials, new solutions – innovation"*
12	13/06/2023	Status of Living Lab	The manufactured construction	*"Marketing and communication to sell the new 'ready-to-use' product; beauty; surprise"*
13	13/09/2023	Best practices	The four sectors	*"Definition of the dimensions and type (2D/3D) of the modules must take into account the requirements of the production equipment, handling, storage, and transportation restrictions, characteristics of the construction site and on-site assembly equipment, production time/contracted time, production cost/selling price, environmental sustainability of the process, quality issues, and worker safety."*
14	14/09/2023	Design	The manufactured construction	*"Modeling should guide a DfMA analysis to define optimal sub-assemblies, based on the interactions between the constituent elements of the product - minimization and optimization of interfaces - Component-based Design Structure Matrix (DSM);"*

Table I.13: Some raw data from the observed meetings *(continue)*

Number	Date	Setting and Purpose	Sectors involved	Some excerpts or hot topics
15	14/09/2023	Supply Chain	The Manufactured Construction	*"Definition of the most suitable supply chain for the project, based on a risk assessment of suppliers and products for the efficiency of the modular construction project. "*
16	15/09/2023	Best practices	The Manufactured Construction	*"- Greater engineering effort;* *- Greater planning effort;* *- Early approval of project specifications and requirements (in the literature, defined as "early material and design freezing")."*
17	17/09/2023	Factory	The Manufactured Construction	*"Smart Factory/Internet of Things"*
18	21/11/2023	Living Lab - Prototype follow-up meetings	The Manufactured Construction and the Traditional Construction	*"Collaboration between all entities in an industrial project is crucial for the project's success and efficiency."* *"BIM plays an essential role in coordinating and analyzing design mismatches, and is the link point for this expected coordination between specialists."*
19	09/01/2024	Living Lab Production Management	The Manufactured Construction	"*DFMA should guide modular construction thinking; how to build; which sub-assemblies, which assemblies; what requirements; how to reduce the number of different materials; how to guarantee the same fittings for different solutions*"
20	09/01/2024	Manufactured construction business with the living lab	The Manufactured Construction	"*This paradigm shift is a change on a social level at all levels. We need to understand what the social barriers are. What are the expectations, preferences, and perceptions of clients, builders, architects, developers, and everyone else involved in construction, and society as a whole, in order to understand what we have to overcome?* *first, to satisfy what the market wants, and second, to ensure that our strategy and communication are aligned with this will.*"

Table I.14: List of revised and new Drivers, Changing Practices, and Elements of Influence

List of constructs derived from the empirical study	Cases	Sources	Revised/New constructs
Drivers			
Improve the quality of life and well-being of Workers (less physical effort in performing the work, with more safety, and less impacted by weather conditions)	A;E; TC; MC	Interview and secondary sources	Revised Society (D4)
Desire to act on humanitarian crise through a quick response, with low cost.	A; E; TC; MC	Interview and secondary sources	Revised Society (D4)
Achieving a new employment scenario in the construction industry, with a new conception of employment	TC;MC	Interview and secondary sources	Revised Society (D4)
Improve the quality of life in cities (less time in the yard, less noise, reduced traffic, freeing up cities)	A;E;TC;MC	Interview and secondary sources	Revised Society (D4)
Desire to CI be a "step towards a better and cleaner future" [in industry, and the world]	A;E;TC;MC	Interview and secondary sources	Revised Environment (D5)
Answer to Client and Market demand for affordable housing due to the cost and time-to-market of the Project (Building).	A;E;TC;MC	Interview and secondary sources	Revised Project (D6)
Answer to market pressures	A;E;TC;MC	Interview and secondary sources	New
Desired to be involved in innovations in the industry	A;E;TC;MC	Interview and secondary sources	New
Client service pos construction	TC;MC	Interview and secondary sources	New
Expand technological boundaries from conceptualization to construction, pushing the boundaries of architectural, engineering, and constructive possibilities.	A;E;TC;MC	Interview and secondary sources	New
Transparency on the supply chain	MC	Interview and secondary sources	New
Excellent in cost and budget control	TC;MC	Interview and secondary sources	New
Design Principles			
Ensure fully integrated and digitally designed manufacturing processes using BIM software	E;TC		Revise Digitalization (CP.P4)
"Industry 4.0"	E; TC; MC		Revise Digitalization (CP.P4)
Design for Manufacturing and Assembly	TC;MC		Revise Design a building as a product (CP.P9)
Fulfill a new constructive system	A;E;TC;MC		New
Ensure experimentation, testing, and collaborative learning.	A;E;TC;MC		New
Environmental and Life Cycle Optimization and Certification	A;E;TC;MC		New
Ensure aesthetics and creativity.	A;E;C;MC		New
Organizational Dimensions			
Employment, job restructuring, and health management	TC;MC		New
Partnership, Cooperation, and Social Network Responsibility	A;E;TC;MC		New
Partnership, Cooperation, and Social Network Responsibility	TC;MC		New
Budget and cost control	TC		New
Risk Management	TC		New
Social Barriers, Marketing, and Communication	TC;MC		New

Table I.14: List of revised and new Drivers, Changing Practices, and Elements of Influence *(continue)*

List of constructs derived from the empirical study	Cases	Sources	Revised/New constructs
External and Internal environmental conditions			
Externalities	A;E;TC;MC		Revised Industry (EF.E2)
Supply Market	A;E;TC;MC		Revised Industry (EF.E2)
Modular Construction Market	A;E;TC;MC		Revised Industry (EF.E2)
Market	A;E;TC;MC		Revised Industry (EF.E2)
Construction Community	A;E;TC;MC		New
Universities and Schools	TC; MC		New
Internal Circumstances			
Ambition and Curiosity	A;E;TC;MC		New
Training, Learning, and Research	A;E;TC;MC		New
Culture Change and Mentalities	A;E;TC;MC		New
Sense of Global Change	A;E;TC;MC		New
Intellectual Humility	TC		New