Doctoral Dissertation

A Study on the Influence of Developmental Culture, Industry 4.0, and the Circular Economy on the Competitive Advantage of the Thai Manufacturing Industry

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September 2024

ABSTRACT

The manufacturing sector, especially in a developing country such as Thailand, needs to increase competitiveness and move toward sustainable development. The transition to a Circular Economy (CE) and Industry 4.0 can be considered an important factor in achieving these targets. Manufacturing companies in a developing country are often subject to resource limitations, which can restrict the efficient transition. To promote a successful transition, firms should understand the factors that influence this transition and its impact on competitive advantage. However, there are still limited empirical studies addressing the influence of organizational culture on this transition and linking cultural aspects together with the transition to a firm's competitive advantage. Therefore, this study examines the effects of organizational culture, i.e., developmental culture, on the implementation of Industry 4.0 and CE for competitive advantage in the context of the Thai manufacturing sector. The findings are based on primary data collected using a survey questionnaire. The data was analyzed using Structural Equation Modeling (SEM). In total, 354 survey responses from participants in the Thai manufacturing sector were used for the analysis. The findings demonstrate that developmental culture contributes positively to Industry 4.0 and CE adoption and to a firm's competitive advantage. The adoption also leads to enhanced competitive advantage. Industry 4.0 positively supports CE implementation in the Thai manufacturing sector. The findings help manufacturing companies understand the necessary cultural characteristics, aiding the transition. This study contributes to the literature by providing inputs to support Industry 4.0 and CE advancement, which eventually can lead to sustainability improvement.

Keywords: Developmental culture, Industry 4.0, Circular Economy, Competitive advantage, Sustainability

ACKNOWLEDGEMENTS

The completion of this dissertation contributes to the success of my Ph.D. study. I would like to express my deepest gratitude to the following people and organizations, as their support is valuable for this accomplishment.

Firstly, this Ph.D. study would not have been possible without the support and guidance of my Ph.D. supervisor, Professor Van-Nam Huynh. His mentorship and encouragement are significantly valuable to the completion of my Ph.D. study. I also appreciate him for giving me the opportunity to be a member of Huynh lab, offering a supportive environment to conduct this Ph.D. study.

I would also like to express my gratitude to Professor Jose Arturo Garza-Reyes, Professor Vikas Kumar, and Associate Professor Sun Olapiriyakul for their expertise and input. Their constructive feedback significantly helps guide the direction of this study and reinforces the quality of this research.

I extend my gratitude to my parents, who fully love, support, and encourage me throughout this academic path. Furthermore, I would like to thank my parents for raising me and inspiring me to fulfill my dream.

I am also thankful for the scholarship awarded by Japan Advanced Institute of Science and Technology, Sirindhorn International Institute of Technology, and National Science and Technology Development Agency, which made this Ph.D. study possible.

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This dissertation was prepared according to the curriculum for the Collaborative Education Program organized by Japan Advanced Institute of Science and Technology and Sirindhorn International Institute of Technology, Thammasat University.

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LIST OF ABBREVIATIONS

Abbreviations	Terms
3Rs	Reduce, Reuse, and Recycle
AVE	Average Variance Extracted
CE	Circular Economy
CFA	Confirmatory Factor Analysis
CI	Confidence Interval
CVF	Competing Values Framework
EI	Eco-Innovation
EoL	End-of-Life
LCI	Lower Confidence Interval
NRBV	Natural-Resource-Based View
RBV	Resource-Based View
SDGs	Sustainable Development Goals
SEM	Structural Equation Modeling
SMEs	Small and Medium-Sized Enterprises
TOE	Technology-Organization-Environment
UCI	Upper Confidence Interval

CHAPTER 1
INTRODUCTION

This chapter emphasizes the importance of conducting this study. The chapter begins with a research background to provide the basis of this study. After that, the theoretical foundation is addressed, highlighting the theoretical perspectives that inspired this study. The research aim and objectives are then presented, guiding the direction of this study to address the gaps in existing research. The importance and contribution of this study are also highlighted. Lastly, the chapter presents the structure of this dissertation.

1.1 Research Background

The growing concern and attention toward global climate change and natural resource depletion are becoming increasingly apparent (Yang *et al.*, 2023). On top of that, global disruptions, e.g., the COVID-19 pandemic, cause substantial impacts across various sectors, especially the manufacturing sector. Despite the increasing demands for sustainability, manufacturing firms have to balance their sustainability improvement with the challenges raised by business disruptions. While the manufacturing sector significantly contributes to driving economic growth, the disruptions lead to a rapidly changing operating environment for manufacturing firms. More specifically, the pandemic has resulted in a demanding business climate, posing challenges for manufacturing firms to survive (Carracedo, Puertas and Marti, 2021) and requiring them to adapt and respond to these challenges (Ardolino, Bacchetti and Ivanov, 2022). Thus, these firms have to deal with sudden changes in market conditions. The COVID-19 pandemic has also disrupted the supply chain, requiring an improvement in supply

chain resilience and the adoption of technologies to improve information flow (van Hoek, 2020). Industry 4.0 technologies have been known to improve supply chain performance and enable supply chains to better handle disruptions (Frederico *et al.*, 2023). In order to secure competitiveness, manufacturing firms must seek improvement, which can be achieved by utilizing Industry 4.0 technologies. These technologies help manufacturing firms better respond to customer requirements, enhance manufacturing operations, and reduce costs (Bravi and Murmura, 2021). Industry 4.0 also has the potential to help firms advance toward CE and sustainable development (Awan, Sroufe and Shahbaz, 2021). Industry 4.0 technologies can support product design under the CE model, assisting firms in designing sustainable products (Pinheiro *et al.*, 2022). Moreover, firms should consider promoting the implementation of CE initiatives to improve their resource utilization and reduce waste for sustainable outcomes (Barros *et al.*, 2021). Therefore, the implementation of Industry 4.0 and the CE can be considered a promising solution, helping firms achieve sustainability performance.

Despite the strong potential of Industry 4.0 and the CE in promoting sustainable operations, embedding Industry 4.0 technologies with the CE is still challenging (Kumar, Singh and Kumar, 2021). While smart manufacturing achieved through Industry 4.0 technologies can offer sustainable production capability (Bag, Yadav, *et al.*, 2021) and aid firms in reaching sustainability goals (Kamble, Gunasekaran and Gawankar, 2018), firm intrinsic barriers play a significant role in impeding Industry 4.0 technologies adoption (Chauhan, Singh and Luthra, 2021). Since CE implementation demands conditions that facilitate technological integration (Bertassini *et al.*, 2021), overcoming firm intrinsic barriers to new technology integration can potentially result in effective CE implementation. Organizational culture is among the firm intrinsic factors that can influence the effective adoption of Industry 4.0 technologies (Bag, Yadav, *et al.*, 2021), and hence firms need to ensure that their cultural characteristics lead to successful Industry 4.0 adoption and have the potential to bring about CE capability.

1.2 Theoretical Foundation

Diverse theoretical aspects, comprising a Technology-Organization-Environment (TOE) framework, Socio-Technical Systems, a Resource-Based View (RBV), and a Natural-Resource-Based View (NRBV), inspire the foundation and development of this study, see Figure 1.1. These theoretical aspects provide initial insights into the connection between organizational culture, technology adoption within firms, the implementation of CE practices, and the enhancement of a firm's competitive edge.

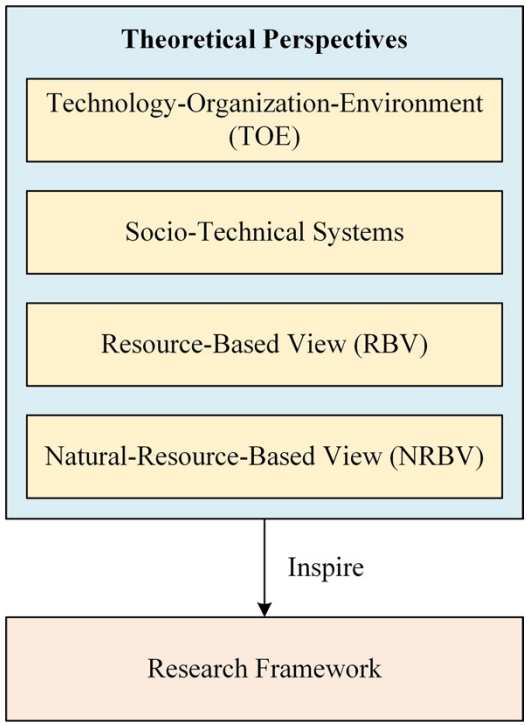

Figure 1.1 Theoretical Foundation

A growing body of literature demonstrates the association between organizational culture and firm capabilities. For example, the study of Lam *et al.* (2021) points out that organizational culture plays an important role in promoting firm knowledge management capability. Moreover, previous studies consider organizational culture's influence on other perspectives, such as the impact on performance (Karim and Qamruzzaman, 2020) and quality techniques (Gambi *et al.*, 2015). According to

the Competing Values Framework (CVF), organizational cultures can be categorized into four distinct profiles, namely group, developmental, hierarchical, and rational cultures (Cameron and Quinn, 2006). This framework is typically employed to determine organizational culture (Naor *et al.*, 2008; Gambi *et al.*, 2015).

The impact of culture on the successful implementation of technological initiatives has been brought to attention by previous studies, focusing on theoretical perspectives, including the TOE (Arcidiacono *et al.*, 2019) and Socio-Technical Systems (Sony and Naik, 2020). Organizational culture can lead to an environment that influences employees' openness to new technology adoption (Arcidiacono *et al.*, 2019). Industry 4.0 technologies adoption helps firms promote business model innovations and expansions, and continuous improvement is one of the supportive characteristics that firms need for successful adoption (Pozzi, Rossi and Secchi, 2023). Firms can expect flexibility improvement among the Industry 4.0 implementation benefits (Bianco *et al.*, 2023). Innovation, flexibility, and continuous improvement are part of key characteristics of developmental culture (Cameron and Quinn, 2006). Hence, this culture has the potential to support firms in the implementation of Industry 4.0.

To ensure their viability, organizations must carefully consider advancing their technology adoption in order to secure a competitive edge (Enyoghasi and Badurdeen, 2021). Based on the RBV, technology-leading firms are likely to have enhanced competitiveness (Wernerfelt, 1984). The study of Satyro *et al.* (2022) shows that firms implementing Industry 4.0 tend to expect an increase in competitiveness. Utilizing Industry 4.0 technologies can also help manufacturing firms attain sustainable production (Ching *et al.*, 2022) and bring about CE opportunities (Agrawal *et al.*, 2022).

Taking the RBV further, NRBV focuses on linking environmentally oriented capabilities with firm competitive advantage (Hart, 1995). The need to gain insight into how clean technology strategies yield capabilities, enabling firms to attain a competitive edge, is also suggested by a previous study (Hart and Dowell, 2011). The potential of Industry 4.0 to enhance companies' competitive edge has been pointed out in various areas (Weking *et al.*, 2020). Firms can also utilize digital technologies to promote a green competitive advantage (Rehman *et al.*, 2023). While the CE can possibly enhance a firm's competitive position, organizational changes are required to fully develop CE capability (Prieto-Sandoval *et al.*, 2019). Although firms seek to gain

benefits from Industry 4.0 and CE adoption, research demonstrating the impact of adoption on firms' competitive advantage in the Thai manufacturing context is still limited.

In brief, in order for firms to effectively implement Industry 4.0 technologies and CE practices, they must understand the factors that influence the implementation. Organizational culture is considered an important factor in developing CE strategies (Bertassini *et al.*, 2021), and in the same manner, Industry 4.0 adoption requires a supportive organizational culture (Arcidiacono *et al.*, 2019). Similarly, firms are still subject to existing intrinsic barriers when implementing Industry 4.0 and should seek a culture that supports digital implementation (Chauhan, Singh and Luthra, 2021). Thus, it is necessary to understand the influence of organizational culture on the adoption. Despite the potential of developmental culture to promote innovation (Prajogo and McDermott, 2011) and external focus (Cameron and Quinn, 2006), without further research, the understanding of the influence of developmental culture on Industry 4.0 and CE implementation remains insufficient due to limited empirical evidence. Therefore, there is a need for additional research to enhance this understanding, aiming to promote the competitive advantage of firms. The research aim and objectives are presented in the following section to help address the literature gaps.

1.3 Research Aim and Objectives

In order to understand the relationships between developmental culture, Industry 4.0, the CE, and firm competitive advantage, the following research aim is developed. This study examines the relationships in the Thai manufacturing sector.

Research Aim: This study aims to examine the influence of developmental culture on the implementation of Industry 4.0 and CE in manufacturing firms in Thailand, a developing country. The relationships between developmental culture, Industry 4.0, CE, and competitive advantage are quantitatively investigated. This enhances the understanding of developmental culture impacts and how manufacturing firms can promote competitive advantage through Industry 4.0 and CE initiatives.

The following three research objectives are set to guide this study in achieving the research aim.

Research Objective 1: To formulate hypotheses and develop a research framework to examine the relationships between developmental culture, Industry 4.0, CE, and competitive advantage. Existing theories are examined to understand the theoretical foundations to develop the research framework.

Research Objective 2: To conduct Structural Equation Modeling (SEM) to validate the developed research framework and test the formulated hypotheses. Primary data used for SEM is gathered from manufacturing companies in the Thai manufacturing sector.

Research Objective 3: To examine the results obtained from the SEM statistical tool, covering direct and indirect effect hypotheses within the proposed research framework. The analysis contributes to promote understanding of the influences of developmental culture in the Thai manufacturing sector, supporting manufacturing firms in implementing Industry 4.0 and CE to gain competitive advantage effectively.

This research mainly focuses on testing hypotheses based on the primary data collected from the Thai manufacturing sector. This study adopts SEM as the statistical tool for testing hypotheses; see Chapter 3 for more details regarding the hypotheses formulation. The following section highlights the importance and contribution of this study.

1.4 Importance and Contribution of This Research

The adoption of sustainability practices between developed and developing countries can vary due to differences in firms' operating environments (Ahmad *et al.*, 2021). More specifically, within the manufacturing industry, there is a notable contrast in the utilization of sustainability indicators, with developed countries showing more advanced usage compared to developing countries (Ahmad, Wong and Rajoo, 2019).

In the ASEAN economic community, incorporating digital technologies is necessary to develop smart regional integration, and Industry 4.0 is among the important factors for sustainability improvement, e.g., a low-carbon economy (ASEAN Secretariat, 2021). In the same manner, CE is also important for ASEAN in attaining low-carbon emissions (ASEAN Secretariat, 2023). In Thailand, an ASEAN member state, the manufacturing sector is vital to Thailand's development, and manufacturing firms need to consider improvements in various aspects such as information technology, efficiency, productivity, and innovation (World Bank, 2020). Currently, the full transition toward Industry 4.0 and CE in Thailand is still an ongoing process to be achieved in the long term. CE implementation is attracting more attention with high potential to support the reduction of greenhouse gases and promote efficient use of materials, and hence, it can contribute to economic growth with environmental impact consideration (World Bank Group, 2022). Industry 4.0 is considered the main global transition, and the Thai manufacturing sector is expected to progress to a high-technology environment for higher competitiveness (Office of the National Economic and Social Development Board, 2017). While Industry 4.0 and CE transition have the potential to offer various benefits to the Thai manufacturing sector, understanding the driving factors behind this transition can help the sector achieve an effective and successful transition. Accordingly, this study investigates the relationships between developmental culture, Industry 4.0, the CE, and competitive advantage in this sector. It is targeted that the outcomes of this study will help answer the following questions:

- How can Thai manufacturing firms effectively promote Industry 4.0 and CE implementation success?
- How does the implementation impact Thai manufacturing firms' competitive advantage?

This study will contribute to answering these questions through an enhanced understanding of the cultural influence on the implementation and the effect of the implementation on firms' competitive advantage.

In terms of the theoretical contribution, while organizational culture can potentially impact the transition to CE (Bertassini *et al.*, 2021) and Industry 4.0 (Ghobakhloo *et al.*, 2022), the influence of developmental culture on this transition and firms' competitive edge is still rarely explored, especially in the Thai manufacturing

context. This study contributes to demonstrating the connection between developmental culture, Industry 4.0, and the CE, and their impact on enhancing firms' competitive advantage. The findings, which illustrate the relationships between these elements, expand Industry 4.0 and the CE literature in the context of the Thai manufacturing industry.

With regard to practical contribution, the findings of this study provide inputs for manufacturing companies to understand the cultural attributes that beneficially impact Industry 4.0 and CE implementation. Since the Thai manufacturing sector is taking steps to advance Industry 4.0 and CE implementation, the outcomes demonstrating the positive implementation impact on firm competitive advantage can encourage manufacturing companies to advance toward Industry 4.0 and CE, providing benefits in terms of sustainable development.

1.5 Dissertation Structure

This dissertation consists of eight chapters, including an introduction, review of literature, hypotheses formulation, methodology, analysis and result, discussion, contributions, and conclusion chapters. The following paragraphs describe all chapters to enhance the understanding of the structure of this dissertation.

Chapter 1 Introduction

This chapter provides an introduction to this study. The chapter presents background knowledge in the research background section. The theoretical foundation section highlights theoretical perspectives that inspire this research. The research aim is then introduced, and research objectives are presented to guide this study to accomplish its aim. Furthermore, the importance and contribution of this research are summarized. Finally, the last section explains the structure of this dissertation.

Chapter 2 Review of Literature

The second chapter presents a literature review. This chapter provides details of the theoretical background, inspiring the development of this study. Theories, namely TOE, Socio-Technical Systems, RBV, and NRBV, are discussed. After that, the

concepts examined in this study, including the CE, Industry 4.0, developmental culture, and competitive advantage, are reviewed. In brief, the chapter examines the literature, providing an understanding of background concepts and fundamental inputs for the hypotheses formulation in Chapter 3.

Chapter 3 Hypotheses Formulation

This chapter is vital for this empirical study as it provides details regarding the formulation of the hypotheses necessary to satisfy the research aim. The chapter presents seven hypotheses comprising indirect and direct relationship hypotheses. Based on the literature review, there is still limited empirical evidence regarding the role of developmental culture in Industry 4.0 and the CE transition, as well as their influence on firms' competitive advantage in the Thai manufacturing sector. Therefore, the formulated hypotheses target to address these knowledge gaps. Last but not least, the research framework, demonstrating the formulated hypotheses, is presented in this chapter.

Chapter 4 Methodology

This chapter discusses the methodology of this study. It begins with a detailed explanation of the research objectives, followed by research design. Then, the chapter presents the method for data collection. After that, latent constructs and their measures, survey pilot-test and distribution, and data analysis methods are proposed.

Chapter 5 Analysis and Result

This chapter starts by explaining questionnaire respondent profiles using descriptive statistics, i.e., graphs. Confirmatory Factor Analysis (CFA) is then presented to assess the measurement model. The statistical approach, i.e., SEM, is used to test the hypotheses, and the results are reported, covering the mediation analysis and direct relationships.

Chapter 6 Discussion

The research findings are discussed in this chapter. To begin with, the chapter presents the key research processes in relation to research objectives. The findings are

then discussed with the existing literature. This chapter targets to contribute to expanding the body of Industry 4.0 and CE literature by promoting the understanding of the influence of developmental culture to gain a competitive advantage.

Chapter 7 Contributions

This chapter presents the contribution of this study. Firstly, the chapter provides an explanation of theoretical contribution. Then, the practical contribution is discussed. It is expected that the outcomes of this study will help Thai manufacturing companies understand the cultural attributes that drive Industry 4.0 and CE transition, contributing to enhancing their competitive advantage. Lastly, this research is presented from a perspective of knowledge science using the i-System.

Chapter 8 Conclusion

This closing chapter highlights the conclusion in relation to the research aim and objectives. The key outcomes are summarized and linked with the proposed research objectives. A concluding remark is then presented. The limitations of this study are addressed, and future research directions are suggested.

Figure 1.2 demonstrates the flow of this dissertation. The chapters are categorized into four main parts: an introduction, literature review and hypotheses formulation, empirical method and analysis, and contribution and conclusion.

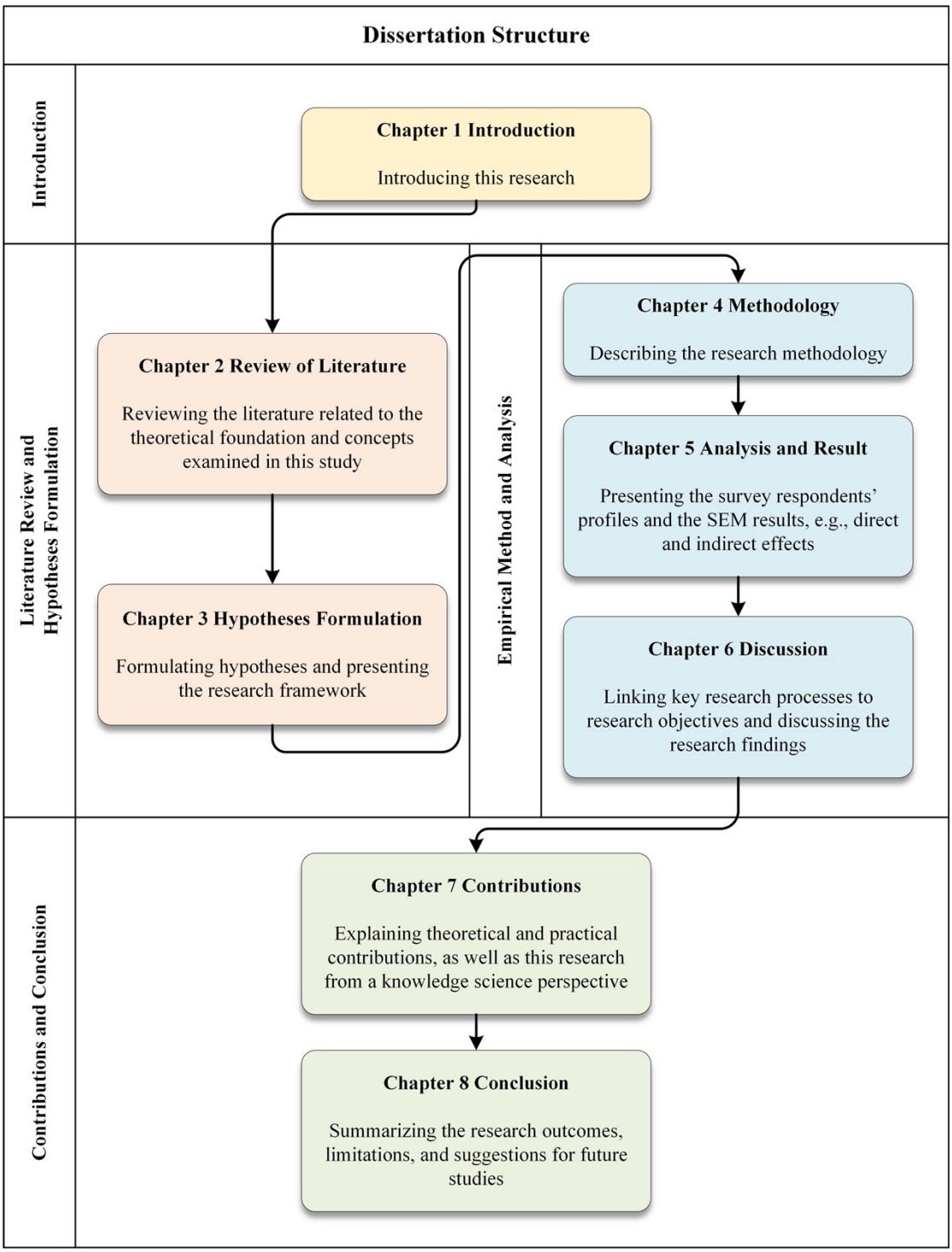

Figure 1.2 Overview of Dissertation Structure

CHAPTER 2
REVIEW OF LITERATURE

This chapter presents a review of the literature, providing knowledge and inputs for this study. The chapter begins with a theoretical background section. This section presents the theories that inspired the development of this study, and four theories are discussed, including TOE, Socio-Technical Systems, RBV, and NRBV. These theories provide the initial inputs for the development of a research framework consisting of developmental culture, Industry 4.0, the CE, and competitive advantage, which will be presented later in this dissertation. This chapter also reviews these concepts, providing essential background knowledge for the hypotheses formulation in Chapter 3.

2.1 Theoretical Background

2.1.1 Technology-Organization-Environment

The TOE framework comprises three main elements, i.e., external task environment, organization, and technology, that affect firm technological innovation (Tornatzky and Fleischer, 1990). The external task environment represents the firm's operating environment. The organizational dimension can be viewed as organizational factors that affect technological innovation adoption. The technology dimension represents the technology that firms use. The framework (see Figure 2.1) can be used as the basis for analyzing the relationship between these elements and promoting the understanding of how organizations adopt new technologies.

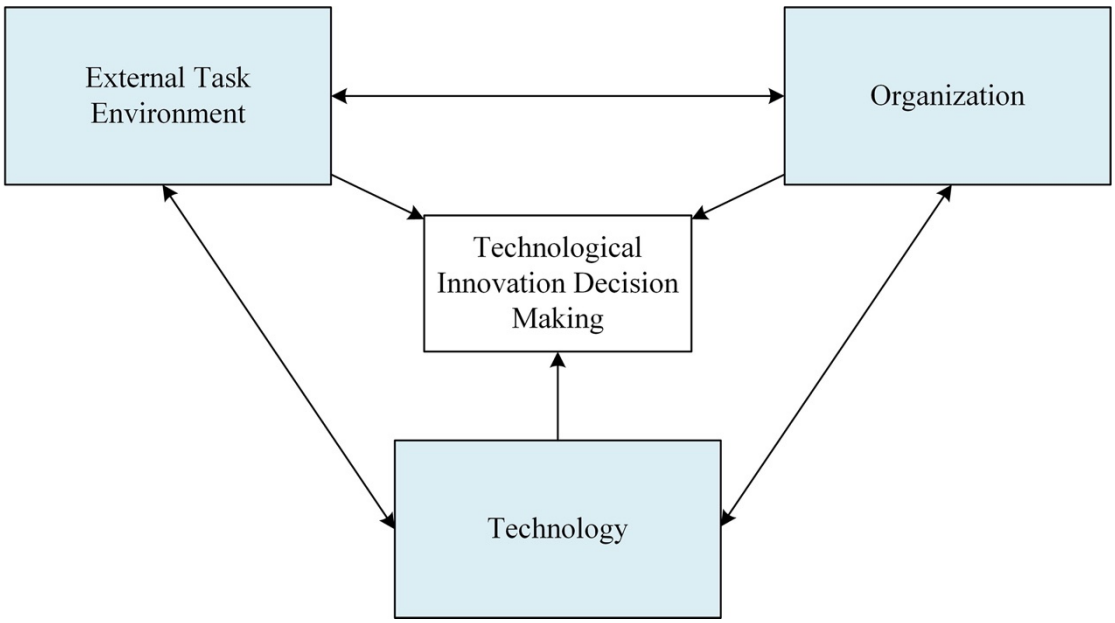

Figure 2.1 Technology-Organization-Environment Framework (Tornatzky and Fleischer, 1990)

While the primary focus of the TOE framework is to understand new technology implementation in organizations, it has a wide range of applications and can be used in various contexts. For example, previous studies have utilized this framework to examine green supply chain adoption (Hwang, Huang and Wu, 2016), customer relationship management (Cruz-Jesus, Pinheiro and Oliveira, 2019), and smart manufacturing systems (Shukla and Shankar, 2022). Therefore, the dimensions within the TOE framework, which encompass technological, organizational, and environmental dimensions, offer interesting perspectives for studying various contexts. The following paragraph demonstrates how the TOE framework inspires this study.

In terms of the external task environment, manufacturing companies have to actively address pressures from competitors and customers as well as comply with regulations and policies (Hwang, Huang and Wu, 2016). Thus, the external environment can put various challenges on firms, and in response to these challenges, competitiveness and sustainability performance enhancements are necessary improvements that firms need to consider. The study of Arcidiacono *et al.* (2019) adopts the TOE to promote the understanding of Industry 4.0 influencing factors in the SMEs

context. Their study highlights organizational culture as among the key organizational factors that impact Industry 4.0 adoption, and a supportive organizational culture is required to ensure a successful Industry 4.0 transition. Therefore, organizational culture can affect how effectively companies implement and utilize Industry 4.0 technologies.

2.1.2 Socio-Technical Systems

The Socio-Technical Systems theory addresses the social and technical aspects of the work, where these aspects should be linked and interacted together for successful outcomes (Appelbaum, 1997). The theory was developed to understand the connection between people and machines to ensure an efficient way of working (Ropohl, 1999). Organizations are viewed as complex systems and are subject to a dynamic environment (Hazy, 2006), and adapting to changes is essential for their survival. The Socio-Technical Systems theory also has the potential to support organizational development and technological advancement (Appelbaum, 1997). The study of Davis *et al.* (2014) presents the Socio-Technical Systems framework, which can represent the basis of work systems, including culture and technology, as well as other dimensions in the organizational system.

Digitalization has become increasingly important in creating new business opportunities, and organizations should prioritize socio-technical change when advancing to a digitalized business environment (Legner *et al.*, 2017). The Socio-Technical System shows robust potential for explaining digital usage in the work system. Münch *et al.* (2022) examine the linkage between Industry 4.0 and servitization, known as digital servitization. Their study utilized the Socio-Technical Systems to present the framework, demonstrating the required capabilities of digital servitization for smart product-service systems. From a cultural perspective, open innovation is highlighted as one of the essential preferable characteristics for advancing digital servitization. According to Yu, Xu and Ashton (2023), their study employs the Socio-Technical Systems to understand artificial intelligence adoption and highlights organizational culture as among the main organizational factors affecting the adoption. Sony and Naik (2020) emphasize the importance of considering the socio-technical elements when implementing Industry 4.0.

2.1.3 A Resource-Based View and A Natural-Resource-Based View

RBV focuses on firms' resources perspective that can help them attain competitive advantage (Barney, 1991; Barney, Wright and Ketchen Jr., 2001). Since resources can be in both tangible and intangible forms, firms should not overlook the importance of intangible resources. The study of Kamasak (2017) points out the significance of intangible resources on firm performance, and intangible resources comprise resources such as firm reputation and organizational culture. Organizational culture is perceived as a strategic resource, which is vital to support business strategy deployment (Klein, 2011). Thus, it is necessary for firms to understand the cultural elements that help them attain competitive advantage (Barney, 1986). Firms should consider improving their tangible and intangible resources to ensure advantages over their competitors. Firms can utilize technology to generate product and service uniqueness advantages (Sousa and da Silveira, 2020). In order to remain competitive in the long run, firms must develop technological capability (Wernerfelt, 1984). Therefore, an organizational culture that encourages new technology adoption is likely to contribute to strengthening competitive advantage.

NRBV, extended from the RBV, focuses on linking environmental performance improvement capabilities with sustained competitive advantage (Hart, 1995). Capabilities, such as sustainable development, pollution prevention, and product stewardship, can lead to competitive advantage. These capabilities also align with the emphasis on advancing CE (Masi *et al.*, 2018). Moreover, NRBV has been previously adopted in the study focusing on the CE as it can help promote the understanding of closed-loop supply chain practices (Jia *et al.*, 2020). A recent study by Yavuz *et al.* (2023) utilizes both TOE and NRBV as the basis to explore the relationship among Industry 4.0 technologies, sustainable operations practices, and sustainable performance. Their study shows the positive impact of Industry 4.0 technologies on sustainable operations practices.

Therefore, RBV and NRBV offer perspectives on resources and capabilities that can promote a firm competitive advantage. RBV emphasizes the potential of organizational culture and advanced technology as among resources that can drive a firm competitive advantage, and NRBV provides the input that connects environmental capabilities with a firm competitive advantage.

2.2 Circular Economy

CE has emerged as the solution to prolong and maintain resources within closed-loop systems (Morseletto, 2020). Under the traditional linear economic model, products are disposed when reaching their End-of-Life (EoL) stage, leading to natural resource depletion (Sawe *et al.*, 2021). This results in the growing concern about minimizing resource consumption, requiring the transition toward the CE (Whicher *et al.*, 2018). The CE model aims to close resource loops by promoting resource and material circularity, and hence, the traditional economic model is turned into a circular system (Merli, Preziosi and Acampora, 2018). Figure 2.2 shows the linear and CE model.

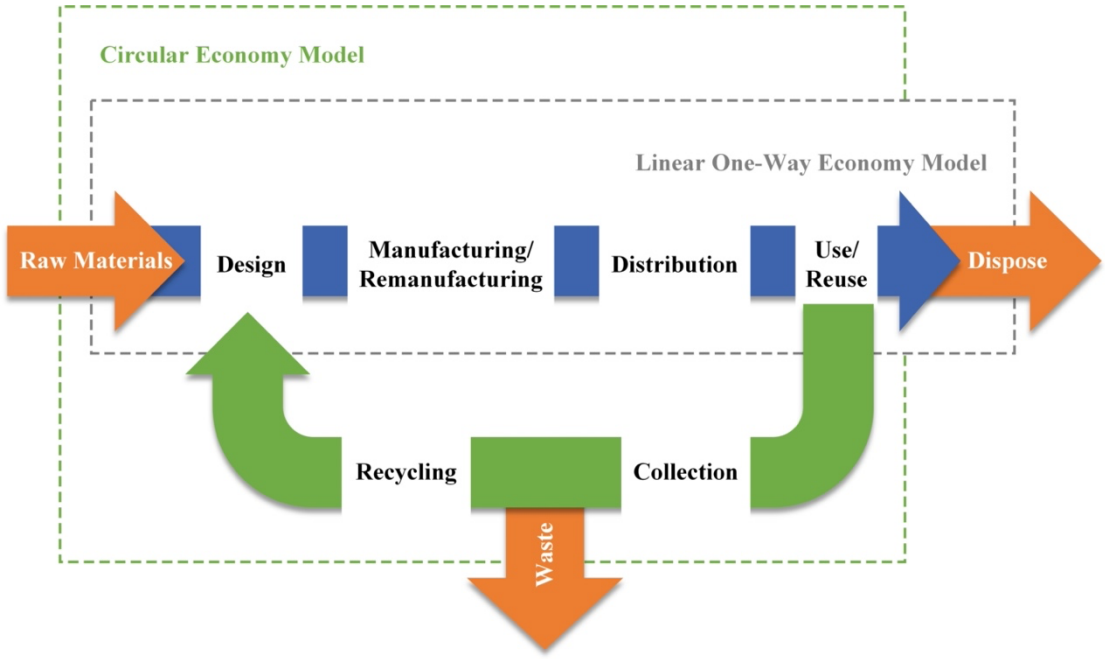

Figure 2.2 Linear and Circular Economy Model (Adapted from the study of Grafström and Aasma (2021))

Firms in the linear economy model gain economic benefits from using raw materials to manufacture products, which are then discarded at the EoL (Lieder and Rashid, 2016). On the other hand, the CE model takes into account the life cycle of products, slowing the rate of natural resource consumption and preparing for carbon

neutrality (Yang *et al.*, 2023). The study of Patwa *et al.* (2021) suggests that firms should exchange information to aid the CE transition, so participation from the related stakeholders is necessary for the transition. In this vein, Industry 4.0 technologies can enhance information sharing and decision-making, providing benefits in terms of waste management (Mastos *et al.*, 2020).

However, the progress of the transition toward the CE can be impacted by various existing challenges, e.g., lack of vision toward the CE, lack of financial support, and lack of skilled workforce (Sharma *et al.*, 2021). Technological and cultural barriers are also among the key barriers that impede CE adoption (Grafström and Aasma, 2021). More empirical studies surrounding the concepts of the CE and organizational culture are required (Bertassini *et al.*, 2021). To promote CE implementation, firms, especially those in emerging economies, should understand the long-term benefits achieved from the implementation (Patwa *et al.*, 2021). In this manner, further research examining the conditions that encourage the transition and the benefits of the transition is necessary. Therefore, this study examines developmental culture as the CE supportive factor and firm competitive advantage as the benefit gained from the CE transition.

2.3 Industry 4.0

The transition toward Industry 4.0 brings various benefits, e.g., resilience advantages, to manufacturing companies (Bianco *et al.*, 2023). Improvements in terms of efficiency, cost savings, productivity, flexibility, and agility can be expected as a result of implementing Industry 4.0 technologies (Ghobakhloo, 2020). The linkage between Industry 4.0 and sustainability has been emphasized by previous literature (Jamwal *et al.*, 2021). Industry 4.0 technologies can help firms attain sustainability opportunities, such as sustainable manufacturing (Ching *et al.*, 2022) and supply chain sustainability (Bag, Telukdarie, *et al.*, 2021; Akbari and Hopkins, 2022). Manufacturing companies can utilize Industry 4.0 technologies to promote sustainable production through remanufacturing activities (Kerin and Pham, 2019). While the adoption of Industry 4.0 technologies leads to sustainability improvements, a detailed examination of the potential of these technologies in supporting sustainable practices to meet sustainability requirements is crucial (Kumar, Singh and Kumar, 2021).

Despite numerous benefits from the Industry 4.0 transition, firms have to overcome Industry 4.0 implementation barriers to fully recognize Industry 4.0 potential. Although firms are subject to both Industry 4.0 internal and external barriers, Chauhan, Singh and Luthra (2021) recommend that internal challenges have greater influence than external barriers. Lack of proper understanding of the implementation benefits and resistance to change are among the main barriers limiting the implementation (Raj *et al.*, 2020). To facilitate the implementation, further examination of Industry 4.0 driving factors is necessary (Kamble, Gunasekaran and Gawankar, 2018; Cugno, Castagnoli and Büchi, 2021). Therefore, this study explores the intrinsic driving factor through the developmental culture perspective. The following section reviews the literature related to organizational culture, focusing on developmental culture.

2.4 Organizational Culture: A Developmental Culture Perspective

The CVF is the common framework utilized to explore organizational cultural profiles, providing an enhanced understanding of organizational core values and effectiveness (Cameron and Quinn, 2006). The framework has been previously adopted to explore the influence of organizational culture in the manufacturing industry, such as the influence on lean production (Hardcopf, Liu and Shah, 2021) and supply chain integration (Cao *et al.*, 2015). Manufacturing firms benefit significantly from understanding their organizational culture, as it provides insights into their behavior, aiding the achievement of organizational targets. The CVF consists of four quadrants, representing cultural profiles, i.e., group, developmental, hierarchical, and rational cultures (see Figure 2.3). The framework has vertical and horizontal axes.

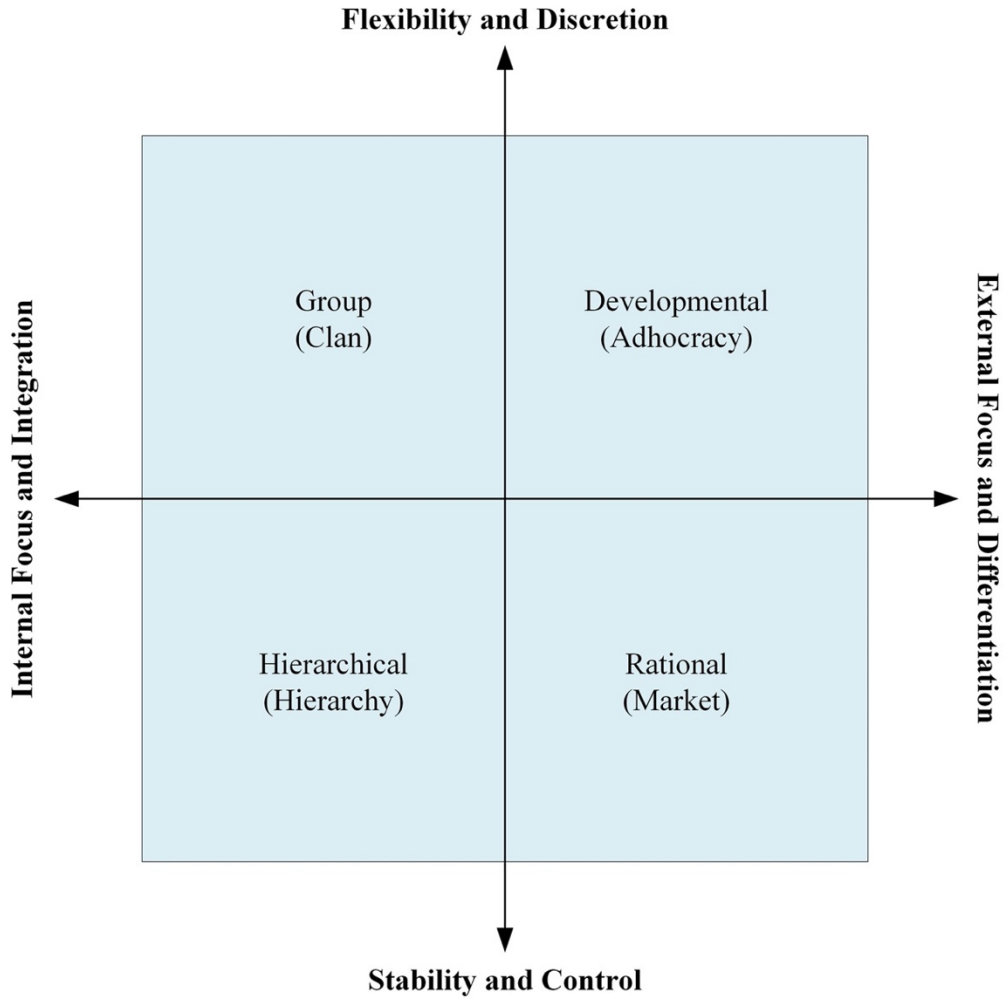

Figure 2.3 The Competing Values Framework (Cameron and Quinn, 2006)

According to the CVF framework, the vertical axis is oriented with flexibility at the top and stability at the bottom, and the horizontal axis displays external focus on the right and internal focus on the left. Developmental culture prioritizes key characteristics such as flexibility and external orientation. This cultural profile is also grounded in adaptation, innovation, dynamism, risk-oriented, continuous improvement, and having new products, services, and resources (Cameron and Quinn, 2006). With these characteristics, a developmental culture could enable manufacturing companies to explore the potential of new technologies, for instance, the adoption of Industry 4.0, and develop innovative strategies to enhance sustainability performance through CE practices.

The transition toward the CE requires stakeholder engagement (Hartley, van Santen and Kirchherr, 2020) and flexibility (De Angelis, Howard and Miemczyk, 2018). In terms of the Industry 4.0 transition, prioritizing aspects such as flexibility and continuous improvement can lead to an effective transition, and this transition can enable business model innovation (Pozzi, Rossi and Secchi, 2023). Developmental culture with key characteristics such as flexibility, external focus, and continuous improvement has a strong potential to promote Industry 4.0 and CE transition. Nevertheless, the current understanding of how developmental culture impacts Industry 4.0 and CE transition is still limited, especially in the context of the Thai manufacturing sector, requiring more empirical studies to further advance the understanding.

2.5 Competitive Advantage

The manufacturing sector in Thailand contributes significantly to the country's economy. World Bank (2020) suggests that enhancing manufacturing companies' productivity and efficiency should be given priority. Moreover, firms should engage with the global economy, expand economic openness, promote innovation, and improve technological capability. The importance of innovation on firms' competitive advantage, especially those in emerging economies, has been identified in the literature (Anning-Dorson, 2018). Firm innovation can be impacted by organizational culture, and firms that seek to advance innovation must develop a supportive environment (Naranjo-Valencia, Jiménez-Jiménez and Sanz-Valle, 2011). Business model innovation is vital for firms transitioning to Industry 4.0 to improve competitive advantages (Marcon, Le Dain and Frank, 2022). As pointed out in section 2.4, developmental culture has a strong potential to help advance firm innovation. Therefore, it is interesting to further examine the linkage between this cultural profile and firm competitive advantage.

Previous studies have attempted to determine the connection between environmental performance and competitive advantage. The study of Mishra and Yadav (2021) shows that proactive environmental strategies can contribute to competitive advantage. According to Do and Nguyen (2020), to deal with environmental issues, a proactive environmental approach is preferable to a reactive

environmental approach. Their study shows that proactive environmental strategies bring about a competitive advantage in terms of cost dominance and differentiation. They also suggest that the strategies should focus on emphasizing product innovativeness. Green product innovation can also help manufacturing companies improve their competitive advantage (Chang, 2011). While firms implementing CE show strong environmental performance (Prieto-Sandoval *et al.*, 2019), prior research examining CE influence on firm competitive advantage in the Thai manufacturing sector remains limited. This study targets to enhance the understanding of competitive advantage improvement in Thai manufacturing companies by examining the impact of developmental culture and the implementation of Industry 4.0 and CE.

2.6 Conclusion

This chapter provides essential knowledge and inputs for the development of this study. This study mainly focuses on the concepts of developmental culture, Industry 4.0, the CE, and competitive advantage. To begin with, the theoretical background inspiring this study is provided in section 2.1. The connection between organizational culture and the adoption of technology is pointed out by theories, i.e., TOE and Socio-Technical Systems. The developmental culture has been previously known to influence innovation (Prajogo and McDermott, 2011), which can potentially aid the Industry 4.0 transition. The advancement of technology and organizational culture can be perceived as the firms' resources that push competitive advantage, as indicated by the RBV. In the same manner, based on the NRBV, firms prioritizing environmental performance improvement could also gain a competitive advantage. Therefore, inputs from these theories inspire the development of the research framework and the formulation of the hypotheses presented in Chapter 3, targeting to further expand the knowledge in the relevant field and address the following research gaps:

- Despite the potential of developmental culture to promote innovation and flexibility, empirical research on its influence on Industry 4.0 and CE implementation in the manufacturing sector in Thailand, a developing country, is not mature.
- The literature focusing on Industry 4.0 and the CE in the Thai manufacturing context is still in its early stages. More specifically, research examining the impact of Industry 4.0 and CE implementation on firm competitive advantage from the perspective of developmental culture is still lacking.

CHAPTER 3
HYPOTHESES FORMULATION

The hypotheses are formulated in this chapter with the purpose to promote the understanding of the relationship between the concepts, i.e., developmental culture, Industry 4.0, the CE, and competitive advantage, in the context of the Thai manufacturing sector. The formulated hypotheses cover both indirect and direct effects. The indirect effect aims to test the serial mediation effect of Industry 4.0 and the CE between developmental culture and competitive advantage, while the direct effects focus on the direct influence of these concepts. The research framework is also presented later in this chapter.

3.1 Indirect Effect

3.1.1 Serial mediation effect of Industry 4.0 and Circular Economy in the relationship between developmental culture and competitive advantage

Organizational culture can have a positive impact on firms when it aligns with the business environment, and firms with developmental culture tend to demonstrate a supportive environment for technology adoption (Cameron and Quinn, 2006; Pakdil and Leonard, 2015). Sustainability performance enhancement and operational efficiency improvement are among the Industry 4.0 implementation benefits for firms in the manufacturing industry (Ghobakhloo, 2020; Enyoghasi and Badurdeen, 2021; Jamwal *et al.*, 2021). Industry 4.0 technologies promote efficient information exchange and contribute to enhancing the ability of manufacturing companies to advance green products and processes (Ghobakhloo *et al.*, 2021). The potential of digital technologies

to help attain CE capabilities is gaining more attention in the literature (Kristoffersen *et al.*, 2020). The enhanced information sharing achieved through the implementation of Industry 4.0 technologies can result in the capability for the CE (Rossi, Bianchini and Guarnieri, 2020). Technological advancement is essential for the transition toward the CE, and the transition can potentially help firms obtain a competitive advantage (Sharma *et al.*, 2021). Thus far, the influence of developmental culture in promoting innovation (Prajogo and McDermott, 2011) and supporting innovative organizations (Büschgens, Bausch and Balkin, 2013) is perceivable. Nevertheless, research, focusing on driving the competitive advantage of manufacturing companies by leveraging Industry 4.0 and the CE with the existence of developmental culture, is still lacking. Thus, this study further examines how Industry 4.0 and CE act as mediators between developmental culture and competitive advantage. In this regard, the following hypothesis is formulated.

H1: *Industry 4.0 and the CE mediate the relationship between a developmental culture and a company's competitive advantage.*

3.2 Direct Effects

3.2.1 Influence of developmental culture on Industry 4.0

Organizational culture can be considered a vital factor that influences firm performance (Prajogo and McDermott, 2011). Firms must ensure that their organizational culture can contribute to attaining organizational targets (Sadri and Lees, 2001). Implementing Industry 4.0 technologies requires openness and employee training to acquire the necessary knowledge and skills (Ghobakhloo *et al.*, 2022). Developing human resources is significant for firms aiming to achieve Industry 4.0, particularly those focused on enhancing sustainability (Ghobakhloo, 2020). Developmental culture leads to an environment that not only promotes employee training and development but also supports technological progress (Cameron and Quinn, 2006; Pakdil and Leonard, 2015). However, even with the potential of this culture, the understanding of its influence on the transition to Industry 4.0 is still

limited, especially in the Thai manufacturing sector, requiring further examination. Therefore, the following hypothesis is developed to enhance this understanding.

> ***H2a:*** *A developmental culture has a positive influence on the adoption of Industry 4.0*

3.2.2 Influence of developmental culture on the Circular Economy

Examining the relationship between organizational culture and the implementation of CE is an interesting research area (Barros *et al.*, 2021). While organizational culture can be the driving factor in the CE transition (Sawe *et al.*, 2021), an unsupportive culture could negatively impact the transition (Kevin van Langen *et al.*, 2021). Firms with a hesitant culture may resist CE transition as they might hesitate to invest in the transition (Kirchherr *et al.*, 2018). Therefore, to ensure an effective CE transition, it is necessary to understand the organizational culture that supports the transition. Implementing CE requires active participation (Whicher *et al.*, 2018; Patwa *et al.*, 2021) and engagement between CE stakeholders (Vanhamäki *et al.*, 2020). Developmental culture facilitates firms to adapt effectively to their external surroundings and maintain a long-term perspective (Cameron and Quinn, 2006). This culture can support firms in interacting with their stakeholders, e.g., suppliers and customers, to promote innovative ideas for enhancing sustainability (Osei *et al.*, 2023). Hence, developmental culture can potentially aid manufacturing companies in realizing the long-term benefits of the CE, which could contribute to promoting the CE transition. Despite the potential of developmental culture on CE transition success, the empirical evidence linking this cultural profile to the CE transition is still limited. Therefore, more empirical evidence is needed to improve the understanding of the influence of developmental culture on CE implementation, and hence, the following H2b is proposed.

> ***H2b:*** *A developmental culture has a positive influence on the adoption of CE.*

3.2.3 Influence of developmental culture on competitive advantage

Organizational culture can be the supporting factor in shaping firms' improvements, for instance, advancing innovation (Zeb *et al.*, 2021) and sustainability initiatives (Isensee *et al.*, 2020). Firms should understand the organizational culture that contributes to attaining competitiveness. Under a volatile business environment, improving flexibility and responsiveness and reacting promptly to changes are vital (Roh, Hong and Min, 2014). Innovation and changes are significant in promoting sustainable development, so it is recommended that firms be open to embracing innovation and incorporating changes. (Silvestre and Ţîrcă, 2019). Firms with a well-established developmental culture often demonstrate characteristics such as external adaptation, innovation, readiness, and flexibility, which are necessary for effectively implementing lean practices contributing to manufacturing performance improvement (Hardcopf, Liu and Shah, 2021). In the same manner, developmental culture drives firms to embed innovation into their operations, which brings about enhanced performance in various dimensions (Prajogo and McDermott, 2011). Improvement in innovation can contribute to competitive advantage enhancement (Anning-Dorson, 2018). Similarly, technological innovation has been known to support sustainable competitive advantage (Feng *et al.*, 2020). However, empirical studies linking this cultural profile with competitive advantage are still lacking. Therefore, the following hypothesis is formulated, allowing this research to examine the influence of developmental culture on firm competitive advantage in the Thai manufacturing sector.

> ***H2c:*** *A developmental culture has a positive influence on a company's competitive advantage.*

3.2.4 Influence of Industry 4.0 on the Circular Economy

A recent study shows that digitalization can aid firms in promoting sustainability performance (Broccardo, Truant and Dana, 2023). Industry 4.0 technologies have the potential to advance sustainable manufacturing by contributing to aspects such as integrating supply chain processes and enhancing resource efficiency (Ching *et al.*, 2022). In order for firms to effectively implement CE practices, they must

establish an environment facilitating the implementation of new technologies (Bertassini *et al.*, 2021). Adopting digital technologies creates the potential for the CE as these technologies enable firms to track and promote product recovery (Kurniawan *et al.*, 2022). Industry 4.0 technologies can also help supply chains with real-time information-sharing capabilities, connecting supply chain members and contributing to promoting material circularity (Dev, Shankar and Qaiser, 2020).

The linkage between Industry 4.0 and the CE has been studied previously in various contexts, e.g., the manufacturing industry in India (Kumar, Singh and Kumar, 2021) and South Africa (Bag, Yadav, *et al.*, 2021). Although Industry 4.0 technologies have strong potential to aid the CE transition (de Sousa Jabbour *et al.*, 2018; Lu, Zhao and Liu, 2024), challenges, such as high capital investment and technological barriers, pose limitations on linking Industry 4.0 with the CE (Zhang *et al.*, 2019). Thus, the presence of these challenges could limit manufacturing companies from fully promoting CE capability using these technologies. The influence of Industry 4.0 on the CE has not been completely explored in the Thai manufacturing sector. Therefore, H3a is proposed to expand the knowledge in this particular context.

H3a: *Industry 4.0 contributes positively to the adoption of CE.*

3.2.5 Influence of Industry 4.0 on competitive advantage

The transition toward Industry 4.0 brings a wide range of benefits to manufacturing companies. For example, the transition leads to improvements across dimensions such as sustainable innovation (Ghobakhloo *et al.*, 2021), sustainable development (Ching *et al.*, 2022), and operational resilience (Bianco *et al.*, 2023). The opportunities achieved from the Industry 4.0 transition, including sustainability advancements, can potentially enhance manufacturing companies' competitive advantage (Bai *et al.*, 2020). Industry 4.0 also contributes to business model improvements (Ghobakhloo, 2020; Massaro *et al.*, 2021), and the business model with cloud manufacturing can lead to a competitive advantage in the long run (Charro and Schaefer, 2018). While enhancing firms' competitive edge is one of the drivers for

adopting Industry 4.0 technologies (Bravi and Murmura, 2021; Pozzi, Rossi and Secchi, 2023), complete adoption is still subject to various barriers, such as challenging organizational changes, compatibility concerns, and substantial investment (Majumdar, Garg and Jain, 2021). Since this study focuses on the manufacturing sector in a developing country, i.e., Thailand, manufacturing companies may experience challenges due to limited resource availability, preventing the full adoption of Industry 4.0 technologies. Therefore, the following hypothesis is formulated to test the influence of Industry 4.0 on competitive advantage in the Thai manufacturing sector.

H3b: *Industry 4.0 contributes positively to a company's competitive advantage.*

3.2.6 Influence of the Circular Economy on competitive advantage

With the increase in demand for sustainability, pushing the need to improve sustainability performance, the role of CE in helping promote closed-loop systems has received significant attention (Ghisellini, Cialani and Ulgiati, 2016). Firms can maintain their competitive edge through circular business model innovation (Pieroni, McAloone and Pigosso, 2019). Moreover, manufacturing firms can potentially promote their competitiveness by implementing CE practices (Sharma *et al.*, 2021) to strengthen their brand image (Nudurupati *et al.*, 2022).

However, implementing the CE is subject to challenges such as financial barriers, absence of environmental incentives, and cultural barriers (Kumar *et al.*, 2019). These barriers may limit firms to fully transitioning to the CE. The transition toward the CE in Thai manufacturing is still in progress. The following hypothesis is proposed to examine the linkage between CE and competitive advantage in this particular context.

H4: *CE contributes positively to a company's competitive advantage.*

In summary, one indirect effect and six direct effect hypotheses are formulated in this section. Figure 3.1 provides an overall picture of the formulated hypotheses.

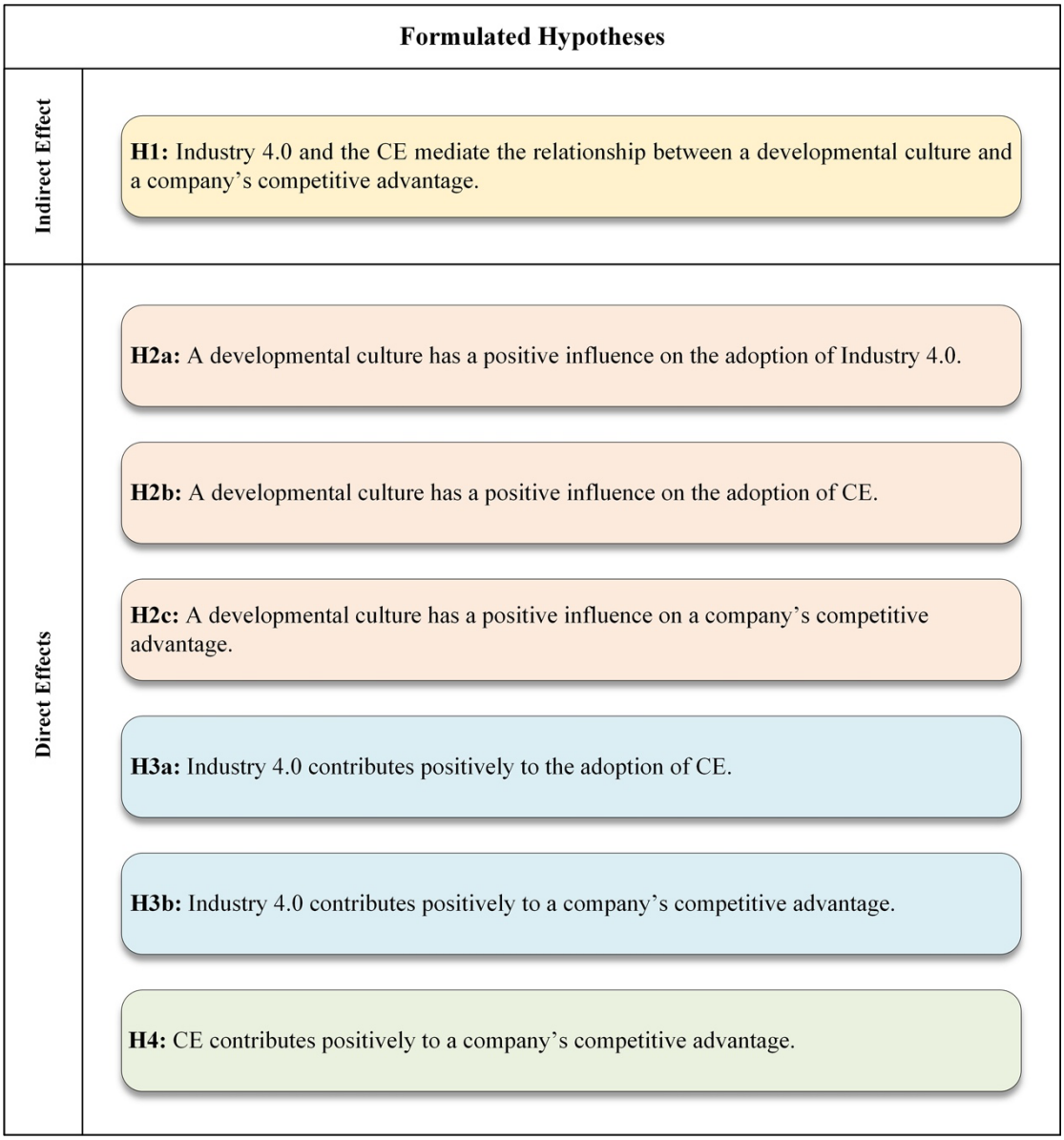

Figure 3.1 Summary of the Formulated Hypotheses

3.3 Research Framework

This section presents the research framework (see Figure 3.2). The framework consists of four main constructs namely developmental culture, Industry 4.0, the CE, and competitive advantage. The formulated hypotheses are also presented in the framework. The proposed hypotheses include both indirect and direct relationships. The dotted line shows the indirect relationship, representing the H1. The indirect relationship is examined, involving Industry 4.0 and the CE as mediators connecting developmental culture and competitive advantage. The solid lines illustrate the direct effects. The direct impacts of developmental culture on Industry 4.0 adoption (H2a) and CE implementation (H2b) are investigated. Additionally, the effect of developmental culture on a firm's competitive advantage (H2c) is explored. The impacts of Industry 4.0 on the implementation of CE (H3a) and a firm's competitive advantage (H3b) are also examined. Last but not least, the effect of CE implementation on a firm's competitive advantage is determined using H4. Therefore, the formulated hypotheses allow this study to determine the relationships between these constructs. They also help extend the knowledge to promote the understanding of Industry 4.0 and CE adoption in the context of the Thai manufacturing sector.

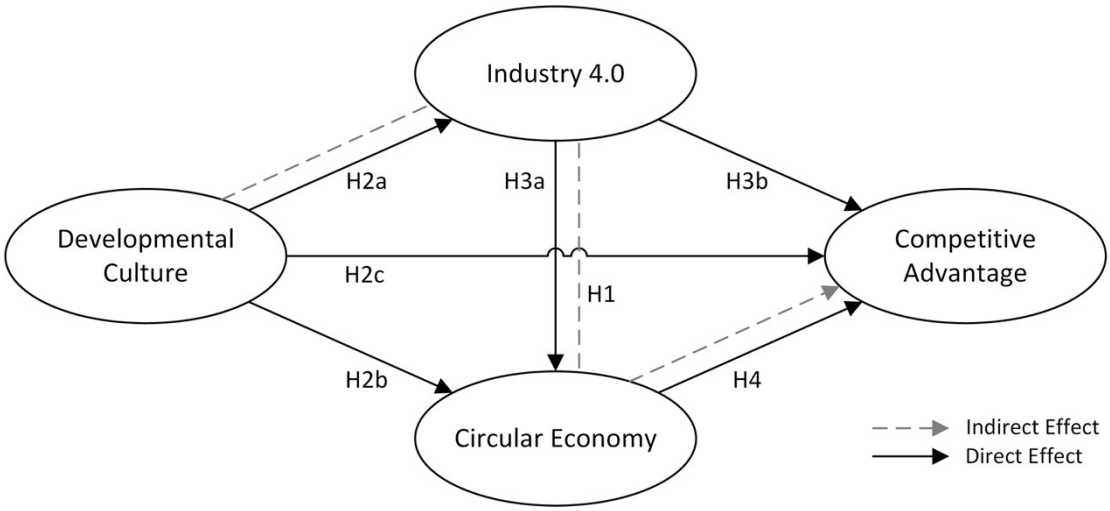

Figure 3.2 Research Framework

3.4 Conclusion

Indirect and direct relationship hypotheses are formulated based on inputs from the literature. In total, seven hypotheses are formulated, consisting of one serial mediation effect and six direct effect hypotheses. The serial mediation effect has Industry 4.0 and the CE as the mediators between developmental culture and firm competitive advantage. Moreover, the six direct effect hypotheses focus on the direct relationships between constructs, as shown in Figure 3.2. The following chapter presents the methodology of this study.

CHAPTER 4
METHODOLOGY

This chapter outlines the research methodology employed to conduct this study. The chapter starts with the research objectives. Then, the research design is presented. After that, the data collection method is discussed. This chapter also covers the constructs and their measures, as well as the survey pilot test and distribution. Finally, the chapter provides details related to data analysis.

4.1 Research Objectives

Research Objective 1: To formulate hypotheses and develop a research framework to examine the relationships between developmental culture, Industry 4.0, CE, and competitive advantage. Existing theories are examined to understand the theoretical foundations to develop the research framework.

Research Objective 2: To conduct Structural Equation Modeling (SEM) to validate the developed research framework and test the formulated hypotheses. Primary data used for SEM is gathered from manufacturing companies in the Thai manufacturing sector.

Research Objective 3: To examine the results obtained from the SEM statistical tool, covering direct and indirect effect hypotheses within the proposed research framework. The analysis contributes to promote understanding of the influences of developmental culture in the Thai manufacturing sector, supporting manufacturing firms in implementing Industry 4.0 and CE to gain competitive advantage effectively.

To begin with, three research objectives have been set to guide this study in attaining its aims. This section provides explanations for these three research objectives. The primary goal of the first research objective is to formulate hypotheses and develop a research framework, enabling this study to advance the understanding of how developmental culture influences the competitive advantage of firms and Industry 4.0 and CE implementation, especially in the context of the Thai manufacturing sector. The formulated hypotheses also help improve the understanding of the potential of Industry 4.0 in enhancing effective CE transition and the influence of the implementation of Industry 4.0 and CE on a firm's competitive advantage. The Thai manufacturing sector is experiencing the transition toward both Industry 4.0 and the CE. Hence, it is necessary for manufacturing firms in Thailand to understand the impact of the transition on their competitive advantage. Most importantly, analyzing the serial mediation influence of Industry 4.0 and the CE in linking developmental culture with a firm's competitive advantage brings about the novelty of this work.

The second research objective is formulated to guide this study in conducting SEM to test the formulated hypotheses and validate the research framework. Collecting primary data from Thai manufacturing companies is vital for conducting the SEM. While the transition toward Industry 4.0 and the CE has strong potential for enhancing manufacturing sustainability (Kumar, Singh and Kumar, 2021), different operating environments may affect Industry 4.0 (Raj *et al.*, 2020) and CE (Patwa *et al.*, 2021) transition. Thus, the outcomes of the transition may vary across different manufacturing contexts, and conducting the study in the Thai manufacturing context could provide additional insights.

Despite the growing awareness of benefits from the transition to both Industry 4.0 and the CE (Dantas *et al.*, 2021; Lu, Zhao and Liu, 2024), research in this domain, particularly incorporating the perspective of developmental culture within the context of Thai manufacturing, is still not mature. The third research objective is developed to guide this study in analyzing the findings obtained from SEM to broaden the knowledge in Industry 4.0 and CE literature. The findings could provide essential insights for manufacturing companies, helping them understand the cultural influences affecting the transition and improve their competitive edge. The following section describes the design of this study.

4.2 Research Design

This section explains the research design, covering the research paradigm and reasoning approach. According to Collis and Hussey (2021), there are two main research paradigms namely positivism and interpretivism. This study tends to align with positivism as it targets to collect large sample data from Thai manufacturing firms. Moreover, this study also uses quantitative data to test the formulated hypotheses, promoting the understanding of the influence between constructs, as demonstrated in the research framework (Figure 3.2).

Based on the work of Saunders, Lewis and Thornhill (2023), there are three methods of reasoning, including deductive, inductive, and abductive approaches. This study begins with an examination of existing theories and literature, which are used as inputs for hypotheses formulation and research framework development. Afterward, data collection is carried out within the Thai manufacturing sector to obtain primary data for hypotheses testing. Therefore, this study is in line with the deductive reasoning approach.

4.3 Data Collection Method

Although there are various existing data collection techniques, such as questionnaires and interviews (Collis and Hussey, 2021), it is necessary to select the appropriate data collection method to achieve the desirable research outcomes. To begin with, the theoretical background and literature review covering concepts, i.e., developmental culture, Industry 4.0, the CE, and competitive advantage, are presented in Chapter 2. Nevertheless, there are still some existing knowledge gaps, as pointed out in Chapter 2. More specifically, in the context of the Thai manufacturing sector, empirical evidence demonstrating the connection between these concepts is still limited, especially the effects of developmental culture. To address these gaps, the hypotheses are formulated in Chapter 3, and data gathering is necessary before conducting hypothesis testing. This study adopts a quantitative method, i.e., a survey questionnaire, as the primary data collection tool. A self-completed questionnaire was adopted. The questionnaire used in this study is an online-based questionnaire that can

be accessed through an online platform, i.e., Google Form, enabling this study to collect data from participants in the Thai manufacturing sector. In addition, a suitable time frame for conducting the study needs to be considered to control the research timeline. A cross-sectional study is an appropriate research design when there is a limited time constraint (Saunders, Lewis and Thornhill, 2023), making it suitable for this study. In summary, the purpose of the data collection is to obtain the primary data used for testing hypotheses, targeting to fill the gaps in the literature and contribute to the body of knowledge by examining the relationships between the concepts being studied. The following section presents the key constructs and measures employed in this study.

4.4 Constructs and Measures

This section presents the constructs and their measures used in this study. A construct or latent variable is a conceptual factor that is unable to be measured directly, and hence, observed variables or measured variables are used as indicators representing the construct (Hair *et al.*, 2014). This study adopted or adapted the measures of the latent constructs from the previous studies. For the developmental culture construct, the measures are adapted from various works, including the work of Cameron and Quinn (2006), Prajogo and McDermott (2011) and Gambi *et al.* (2015). The measures for the Industry 4.0 construct are mainly based on or modified from the work of the Brazilian National Confederation of Industry (2016) and Tortorella and Fettermann (2018). In terms of the CE construct, the measures are adapted from the study of Masi *et al.* (2018). Lastly, for the competitive advantage construct, the measures are modified from the study of Chang (2011) and Mishra and Yadav (2021). Table 4.1 presents latent constructs and their measures.

Table 4.1 Constructs and Measures

Constructs	Items	References
Developmental Culture	DC1: Our organization strives to assess the capability of innovations, new technologies, new manufacturing methods, and changes. DC2: Our organization prioritizes seeking new opportunities, creative problem-solving processes, and new challenges. DC3: Achievements are based on innovation, advancement, expansion, growth, and having cutting-edge products. DC4: Our management approach emphasizes flexibility, freedom, decentralization, innovation, distinctiveness, and personal risk-taking.	(Cameron and Quinn, 2006; Prajogo and McDermott, 2011; Gambi *et al.*, 2015)
Industry 4.0	I1: Sensorless digital automation I2: Sensor-enhanced process control I3: Remote monitoring and control I4: Digital automation with sensor-based system for monitoring product status and operating conditions, flexible manufacturing/assembly lines I5: Use of integrated engineering systems for the development and manufacturing of products I6: Adoption of additive manufacturing and rapid prototyping, or 3D printing I7: Implementation of simulation and virtual model analysis I8: Big data I9: Product-based cloud services I10: Integration of digital services such as Internet of Things (IoT) and online product service systems into products	(Brazilian National Confederation of Industry, 2016; Tortorella and Fettermann, 2018)
Circular Economy	CE1: Pollution Prevention CE2: Product Stewardship CE3: Waste reduction 3Rs (Reduce, Reuse, Recycle) CE4: Life Cycle Analysis CE5: Eco-design CE6: Internal Environmental Management (IEM) CE7: Green Purchasing CE8: Cooperation with the customer (Environmental requirements) CE9: Refurbish/ Remanufacturing CE10: Investment Recovery	(Masi *et al.*, 2018)

Competitive Advantage	CA1: Company's image improvement CA2: Superior managerial capabilities over the competitors CA3: Profitability increases from cost reduction CA4: Superior R&D capabilities over the competitors CA5: Quality of products and services better than competitors' CA6: Attracting new customers while promoting the loyalty of current customers CA7: High difficulty in seeking competitive advantage by competitors	(Chang, 2011; Mishra and Yadav, 2021)

4.5 Questionnaire Pilot Test

It is necessary to ensure that the data collection tool can achieve its intended data collection purpose, which is to collect data for hypothesis testing. As pointed out in the previous section, the observed variables for all constructs are based on or modified from the existing literature. The observed variables, presented in Table 4.1, are measured using a five-point Likert scale. A small-scale pilot test was performed to ensure the validity of the questionnaire survey. The questionnaire was validated by six experts, including three academic experts in the relevant research field and three experts in the Thai manufacturing sector. Their inputs were used to improve questionnaire clarity and readability, promoting the understanding of the questions.

4.6 Questionnaire Distribution

A questionnaire can be distributed in various ways, e.g., by postal mail and online (Saunders, Lewis and Thornhill, 2023). This study intends to test the proposed hypotheses, so it is vital to obtain a large number of responses. To achieve this, an online questionnaire survey is preferable for this study since respondents can access the survey anywhere with an internet connection. The online questionnaire survey also enables respondents to participate in the survey not only from their computers but also from their mobile devices, enhancing accessibility to the survey. This study encompasses respondents from Thai manufacturing companies across all hierarchical positions, covering levels from top management to frontline employees. The

questionnaire was mainly distributed using channels such as email and Line application to respondents from a wide range of industries in the Thai manufacturing sector. Participation in the survey was voluntary. Overall, this study obtained 354 usable responses that were utilized for statistical analysis. The next section presents data analysis methods.

4.7 Data Analysis Methods

This research is a quantitative study, and the primary data was collected using the questionnaire survey. Both descriptive and SEM statistical methods were adopted to analyze the collected data.

4.7.1 Descriptive Statistics

Descriptive statistics can be used to describe the characteristics of the participants taking part in the survey. Graphing data is adopted to help visualize and summarize the collected data (Bordens and Abbott, 2018), allowing this study to clearly present the survey participants' characteristics. The characteristics of the sample, such as firm size, types of manufacturing industries, the geographical distribution of respondents' manufacturing sites across different regions of Thailand, and respondents' positions, are presented using graphs that show percentages; see Section 5.1 in the following chapter.

4.7.2 Structural Equation Modeling (SEM)

For the hypotheses testing, a statistical tool, i.e., SEM, is used to analyze the collected data. SEM has been broadly employed in prior studies that examine the influence of organizational culture across various contexts (Prajogo and McDermott, 2011; Cao *et al.*, 2015; Gambi *et al.*, 2015). SEM is considered an appropriate statistical approach for this study to test the proposed hypotheses since it allows the determination of relationships between latent constructs, such as testing for direct and mediation effects. While SEM is typically known to require a large sample size (Kline, 2005), the number of usable responses, i.e., 354 responses, satisfies the requirements for conducting SEM (Hair *et al.*, 2014).

In terms of the statistical software, this study adopts IBM® SPSS® Amos™ 28.0.0 software to perform SEM, enabling the examination of the connection between the concepts being studied. Previous studies have widely utilized this software to conduct SEM in the relevant research domains (Chauhan, Singh and Luthra, 2021; Rajbhandari *et al.*, 2022; Rodríguez-Espíndola *et al.*, 2022), allowing them to test the hypotheses and understand the relationships between constructs in their studying context.

4.7.3 Measurement Model

To begin with, for the measurement model, the CFA is employed to assess whether observed variables can well represent latent constructs. Hence, the CFA helps ensure the reliability and validity of constructs. In terms of convergent validity, Hair *et al.* (2014) recommend using criteria, e.g., factor loadings and Average Variance Extracted (AVE). They point out the following equation 4.1 to compute the AVE:

$$AVE = \frac{\sum_{i=1}^{n} L_i^2}{n} \tag{4.1}$$

From the above equation, the standardized factor loading for item i is represented by L_i, and n represents the number of items. The standardized factor loadings are obtained from the Amos software. The AVE is determined through the summation of the squared standardized factor loadings and then divided by the number of items. For reliability, this study uses the coefficient omega (Viladrich, Angulo-Brunet and Doval, 2017), and the approach from the study of Hayes and Coutts (2020) is utilized to determine the coefficient omega. In terms of discriminant validity, as suggested by Fornell and Larcker (1981), the square root of AVE is computed to ensure the discriminant validity. They recommend that the square root of each construct's AVE should be higher than the correlations with other constructs. The model fit is assessed using indicators, i.e., CMIN/df≤3, RMSEA<0.07, SRMR≤0.08, CFI>0.9, and TLI>0.9 (Hair *et al.*, 2014).

4.7.4 Structural Model

The structural model is constructed mainly to determine the connection between latent constructs, covering mediating and direct relationships. Components such as four latent constructs and firm size are included in the model. The structural model is utilized for the hypotheses testing purpose. The seven formulated hypotheses comprise six direct effects and one indirect effect, as presented in Chapter 3. Bootstrap with Bias-corrected confidence interval is used. It is performed with a 95% confidence level and 5,000 bootstrap samples. The bootstrap confidence intervals are examined to assess the statistical significance of the relationships in the structural model (Amrutha and Geetha, 2021). A user-defined estimand function in the Amos software is a common method used to test the particular indirect effect (Thyroff and Kilbourne, 2018; Guan *et al.*, 2023), and hence it is suitable to test the serial mediation effect. The serial mediation examined in this study involves Industry 4.0 and CE constructs as the mediators in the relationship between developmental culture and competitive advantage constructs; see Section 5.3.2 in the following chapter.

4.8 Conclusion

This chapter provides an explanation of the research objectives. In terms of the research design, this study tends to align with positivism and deductive approach. A survey questionnaire is adopted as the data collection tool for this empirical study. The measures of constructs are adopted or adapted from the previous studies. A small-scale pilot test with six experts was performed to ensure the clarity and validity of the questions. The online survey method was chosen to promote survey accessibility, making it convenient for the respondents to participate in this study. In terms of the data analysis methods, this study uses both descriptive and SEM statistical methods. For the descriptive statistics, pie and bar charts are adopted to visualize the overview of respondent profiles. SEM is used to analyze relationships between latent constructs, enabling this study to test the formulated hypotheses. The following chapter provides an explanation of the respondent profiles and the CFA. It also examines both direct and indirect relationships within the structural model.

CHAPTER 5
ANALYSIS AND RESULT

This chapter presents the findings of this research based on the primary data collected from participants in the Thai manufacturing sector. The chapter begins with the respondent profiles. Following that, analyses related to the measurement model and structural model are discussed. The testing results of the hypotheses are also presented in this chapter.

This chapter includes both descriptive and SEM statistical analysis. The respondent profiles are presented using descriptive statistics, i.e., pie and bar charts, while hypotheses testing is performed using SEM to test both indirect and direct relationships.

5.1 Questionnaire Respondent Profiles

This section describes respondent profiles, such as company size, manufacturing industry, and manufacturing site. Respondents' positions are also presented. Both pie and bar charts are used to illustrate the respondent profiles. This promotes an understanding of the characteristics of participants who participated in this study as well as the characteristics of the manufacturing companies represented by these respondents.

5.1.1 Company size

The company sizes are classified based on the number of employees, i.e., small-size (less than or equal to 50 employees), medium-size (more than 50 and up to 200 employees), and large-size (over 200 employees). Figure 5.1 demonstrates the respondents' company sizes in percentages.

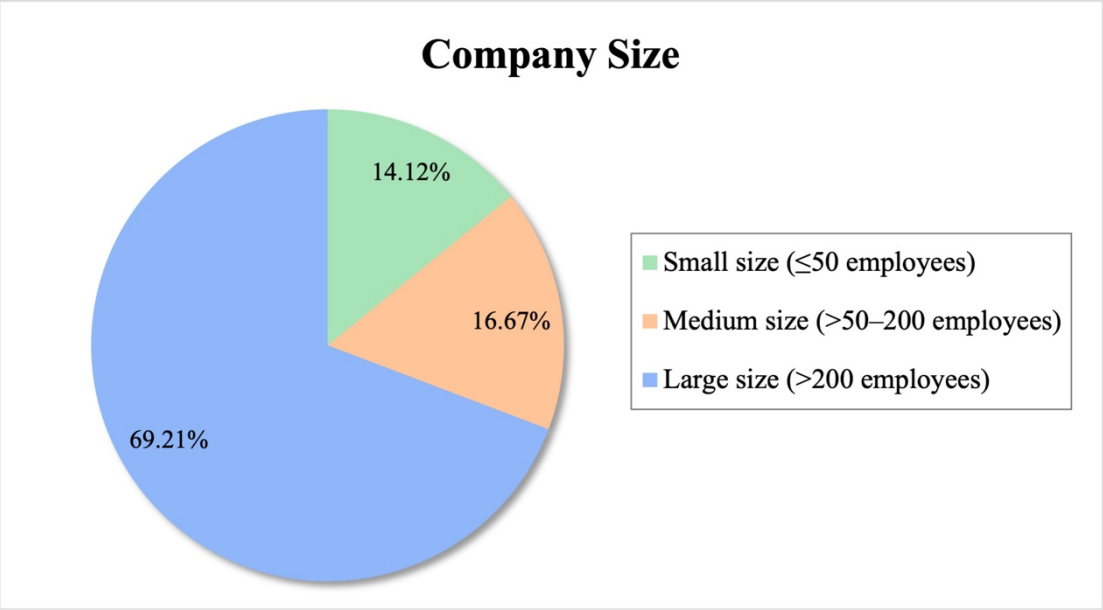

Figure 5.1 Company Size

As shown in Figure 5.1, the majority of the respondents' companies are large manufacturing companies, comprising 69.21%. The percentages of small- and medium-size companies are 14.12% and 16.67%, respectively.

5.1.2 Manufacturing industry

The questionnaire survey was distributed to respondents across various industries within the Thai manufacturing sector. Hence, it is also interesting to understand the characteristics of the industries represented by the participants involved in this study. Figure 5.2 shows the manufacturing industries of the participants' companies in percentages. The electronics industry is ranked first (17.23%), followed by the automotive industry (14.12%), and then the building material industry (13.84%).

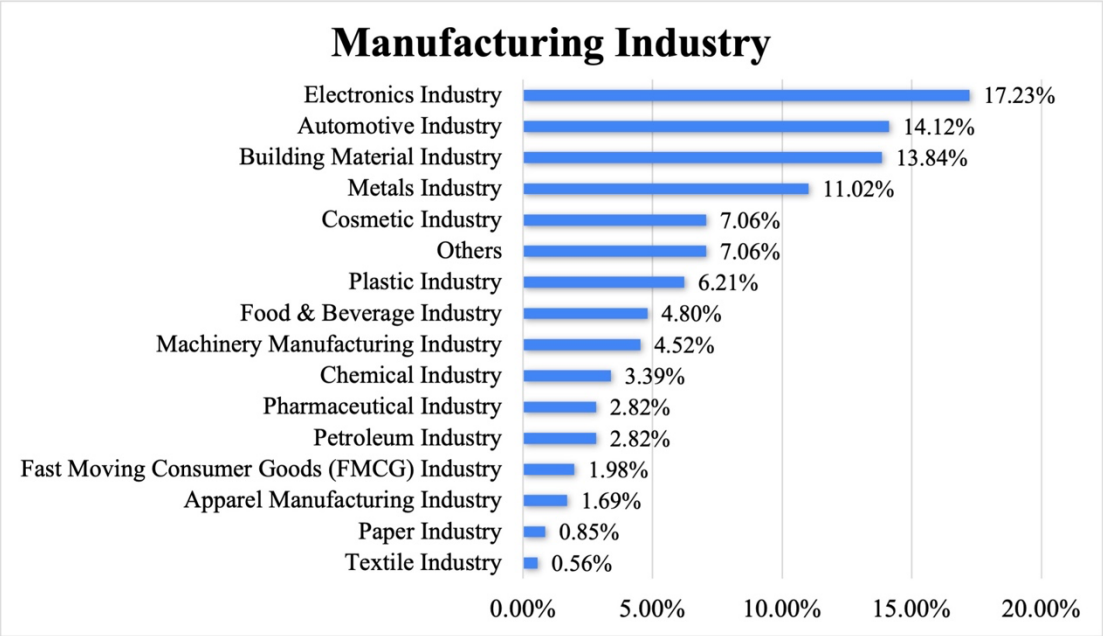

Figure 5.2 Manufacturing Industry

5.1.3 Manufacturing site

This section presents the characteristics of the manufacturing sites of respondents' companies. These participants were asked whether their manufacturing sites are located in industrial estates (see Figure 5.3).

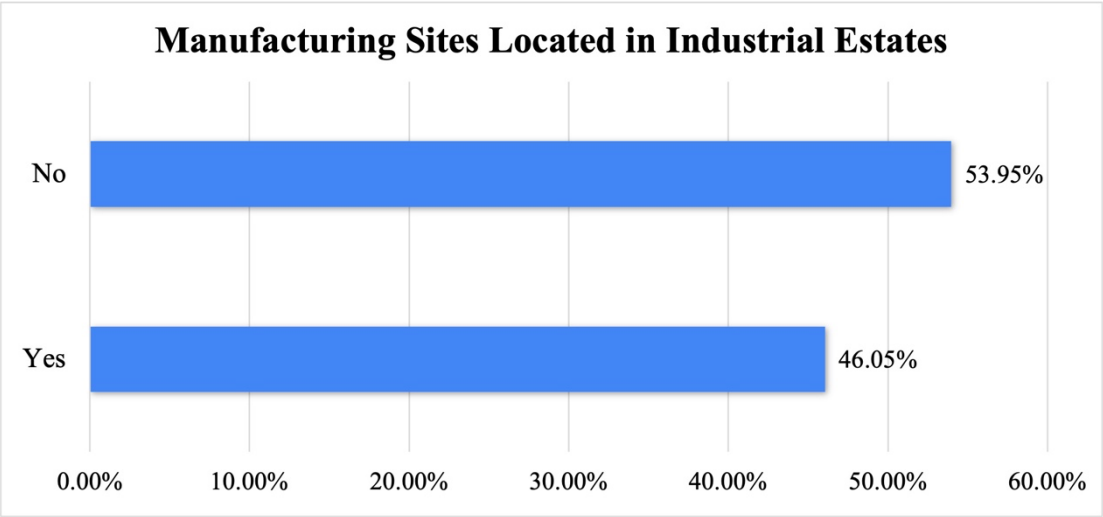

Figure 5.3 Manufacturing Site – Industrial Estates

From Figure 5.3, 53.95% of respondents' manufacturing sites are not situated in any industrial estate. On the other hand, another 46.05% of the respondents have manufacturing sites in industrial estates.

The regions of the respondents' manufacturing sites in Thailand were also collected from the survey; see details in Figure 5.4. It is not surprising that most of the respondents' manufacturing sites are located in the Central (67.51%) and Eastern (25.42%) regions of Thailand, as these regions consist of major industrial zones in many provinces such as Samut Prakan, Phra Nakhon Si Ayutthaya, Chon Buri, and Rayong provinces.

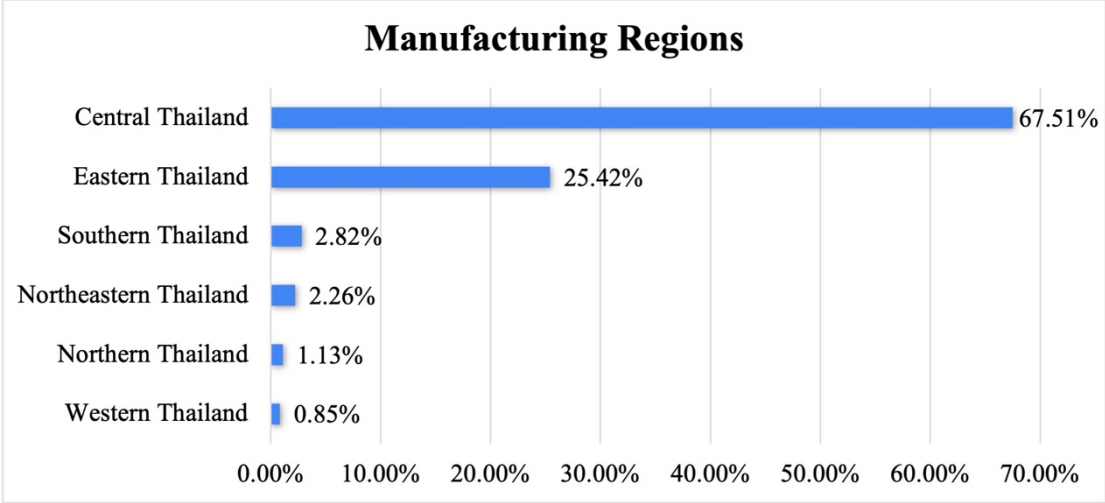

Figure 5.4 Manufacturing Site – Manufacturing Regions

5.1.4 Respondent position

To promote the understanding of the participants' profiles, it is also vital to understand their positions in manufacturing companies (see Figure 5.5). The percentages of respondents who work in first-line management and team leader positions are 26.55% and 25.42%, respectively. Respondents working at the operational level comprise 16.10% of the participants. Moreover, respondents holding management positions such as top-level management (14.12%), e.g., C-level and managing director, and middle-level management (17.80%), e.g., director, participated in this study.

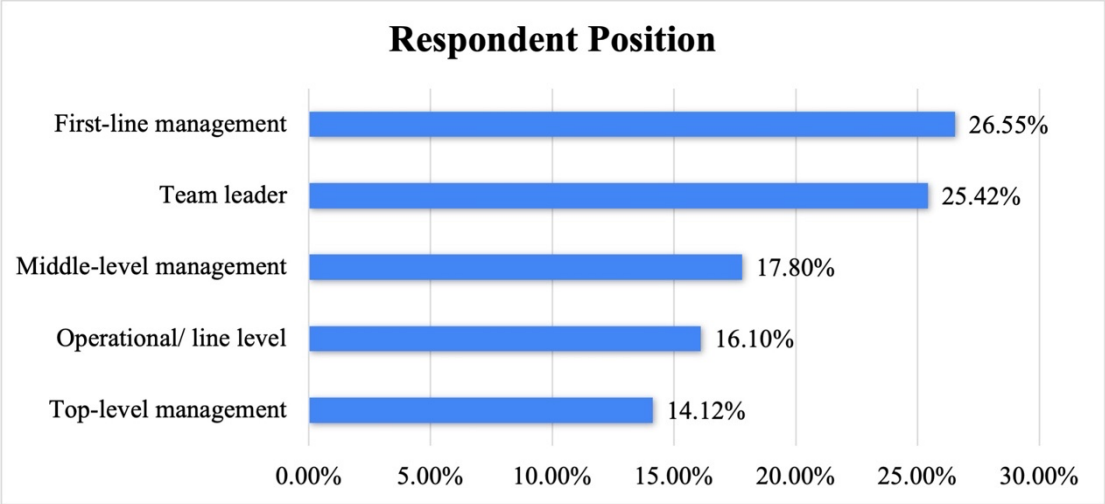

Figure 5.5 Respondent Position

This study adopts SEM to examine the relationships between the latent constructs in order to test the formulated hypotheses, as shown in Chapter 3. The following sections, i.e., Sections 5.2 and 5.3, demonstrate the analysis of the measurement model and structural model, respectively.

5.2 Confirmatory Factor Analysis – Measurement Model

There are four latent constructs examined in this study, i.e., developmental culture, Industry 4.0, the CE, and competitive advantage constructs. The purpose of this section is to assess the measurement model to ensure the constructs' reliability and validity.

5.2.1 Measurement model assessment

The measurement model comprises key elements, including latent constructs, namely developmental culture, Industry 4.0, the CE, and competitive advantages, along with their respective measures (see Appendix A). Table 5.1 shows the factor loadings, coefficient omega, and AVEs for assessing both the reliability and validity of the measurement model.

Table 5.1 Measurement Model Assessment: Constructs Reliability and Validity

Constructs	Measures	Factor Loading	Coefficient Omega (ω)	AVE
Developmental Culture	DC1	0.837	0.876	0.654
	DC2	0.871		
	DC3	0.819		
	DC4	0.697		
Industry 4.0	I2	0.628	0.872	0.513
	I3	0.681		
	I4	0.767		
	I5	0.821		
	I6	0.593		
	I7	0.708		
	I8	0.757		
	I9	0.704		
	I10	0.757		
Circular Economy	CE1	0.698	0.912	0.539
	CE2	0.653		
	CE3	0.698		
	CE4	0.829		
	CE5	0.799		
	CE6	0.794		
	CE7	0.831		
	CE8	0.776		
	CE9	0.613		
	CE10	0.601		
Competitive Advantage	CA1	0.739	0.914	0.604
	CA2	0.811		
	CA3	0.683		
	CA4	0.794		
	CA5	0.810		
	CA6	0.796		
	CA7	0.797		

Note: Measure I1 is removed due to low factor loading.

Hair *et al.* (2014) suggest considering criteria such as factor loadings and AVE to evaluate convergent validity. They indicate that factor loading should be at least 0.5 or above, with a value of 0.7 or higher considered ideal. They also recommend a value

of 0.5 or higher for AVE. According to Table 5.1, many factor loadings exceed 0.7, with the minimum factor loading above 0.5. All the AVE values are above the suggested minimum value of 0.5. Therefore, the convergent validity is considered adequate. To assess reliability, Viladrich, Angulo-Brunet and Doval (2017) suggest using the coefficient omega owing to correlated errors. A value of 0.7 or above is a desirable value for reliability. The approach from the study of Hayes and Coutts (2020) is employed to find the coefficient omega. From Table 5.1, all latent constructs in the CFA model have coefficient omega values above 0.7, indicating that they satisfy the reliability requirement. Table 5.2 demonstrates the correlation between latent constructs, and the diagonal values show the square root of AVEs.

Table 5.2 Correlation Between Latent Constructs

	1	**2**	**3**	**4**
1. Developmental Culture	0.809	0.570	0.565	0.733
2. Industry 4.0	0.570	0.716	0.688	0.632
3. Circular Economy	0.565	0.688	0.734	0.657
4. Competitive Advantage	0.733	0.632	0.657	0.777

Note: Diagonal values represent the square root of AVEs

Discriminant validity is assessed using the square root of AVE for each construct, and it is considered satisfactory when this square root value exceeds the correlations with other constructs (Fornell and Larcker, 1981). From Table 5.2, it can be clearly seen that each construct's square root of AVE surpasses the correlations with other constructs. Thus, discriminant validity meets the recommended criteria.

For the model fit, the fit indices with the following recommended threshold values: CMIN/df≤3, RMSEA<0.07, SRMR≤0.08, CFI>0.9, and TLI>0.9 (Hair *et al.*, 2014) are utilized in this study. The CFA model shows a satisfactory model fit (χ^2= 960.787, CMIN/df= 2.439, CFI= 0.921, TLI= 0.913, RMSEA= 0.064, and SRMR= 0.056).

5.3 Structural Equation Modeling – Structural Model

The structural model consists of components such as latent constructs, observed variables, and firm size (see Appendix B). A previous study points out that firm size can impact sustainability performance and digitalization (Broccardo, Truant and Dana, 2023). Therefore, this study incorporates firm size as the control variable in the structural model. A three-point Likert scale is used to measure firm size, with 1 for small-size (less than or equal to 50 employees), 2 for medium-size (more than 50 and up to 200 employees), and 3 for large-size (over 200 employees). The fit indices of the structural model are as follows: χ^2= 1009.532, CMIN/df= 2.404, CFI= 0.918, TLI= 0.910, RMSEA= 0.063, and SRMR= 0.056. The main purpose of the structural model is to test the formulated hypotheses.

The hypotheses testing results are presented in the following sections. More specifically, the following two sections demonstrate both direct and indirect effects. SEM is utilized as the statistical tool to test these effects. The hypotheses testing results were obtained from the Amos software. To test the hypotheses, bootstrap with Bias-corrected confidence intervals is adopted, using 5,000 bootstrap samples and a 95% confidence level, to compute Lower Confidence Interval (LCI) and Upper Confidence Interval (UCI); see details in the following two sections.

5.3.1 Hypotheses testing – Direct effects

The results of hypotheses related to direct effects are presented before addressing the indirect effect to promote the understanding of relationships between latent constructs. The presentation of findings of direct effect hypotheses is in the following order: the direct effects of developmental culture (H2a, H2b, and H2c), the direct effects of Industry 4.0 (H3a and H3b), and the direct effect of CE (H4). Figure 5.6 demonstrates the direct effects examined in this study. The figure presents only the latent variables, firm size, and standardized estimates, highlighting the key elements.

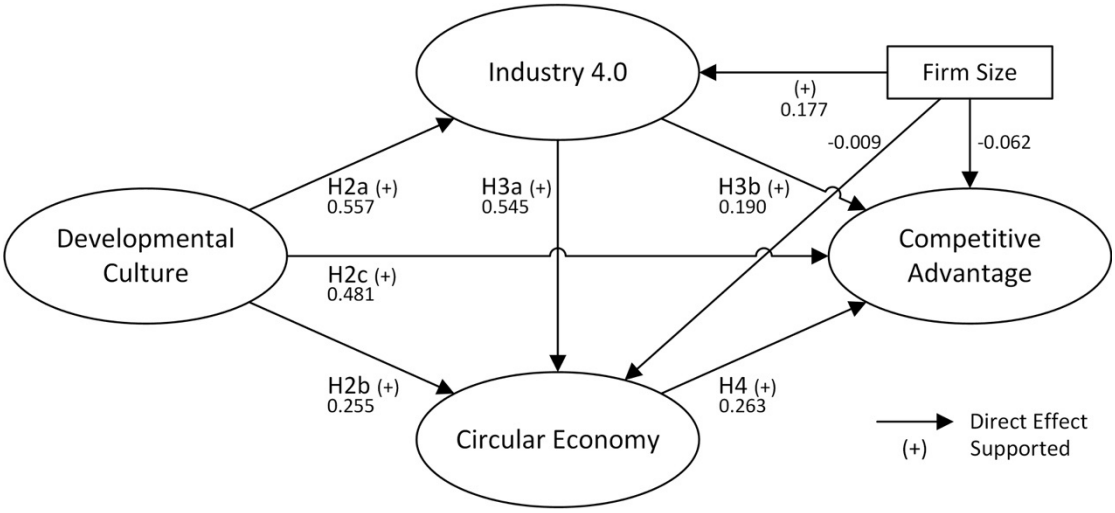

Figure 5.6 Direct Effects

Table 5.3 provides details related to direct effects, including structural path, estimate, Bias-corrected confidence interval, p-value, and result.

Table 5.3 Direct Effects – Hypotheses Testing Results

Hypothesis	Structural path	Standardized				Unstandardized				Result
		Estimate	Bias-corrected confidence interval		p-value	Estimate	Bias-corrected confidence interval		p-value	
			LCI	UCI			LCI	UCI		
H2a	Developmental Culture → Industry 4.0	0.557	0.465	0.638	0.001	0.536	0.416	0.691	0.000	Supported
H2b	Developmental Culture → Circular Economy	0.255	0.112	0.396	0.001	0.212	0.089	0.358	0.001	Supported
H2c	Developmental Culture → Competitive Advantage	0.481	0.351	0.608	0.000	0.407	0.285	0.532	0.000	Supported
H3a	Industry 4.0 → Circular Economy	0.545	0.418	0.673	0.000	0.472	0.355	0.616	0.000	Supported
H3b	Industry 4.0 → Competitive Advantage	0.190	0.048	0.324	0.013	0.167	0.042	0.294	0.012	Supported
H4	Circular Economy → Competitive Advantage	0.263	0.115	0.422	0.001	0.267	0.112	0.456	0.001	Supported
	Firm Size → Industry 4.0	0.177	0.063	0.291	0.002	0.168	0.058	0.300	0.002	Supported
	Firm Size → Circular Economy	-0.009	-0.099	0.081	0.848 (ns)	-0.007	-0.080	0.068	0.845 (ns)	Not Supported
	Firm Size → Competitive Advantage	-0.062	-0.137	0.010	0.093 (ns)	-0.052	-0.114	0.007	0.086 (ns)	Not Supported

Note: ns denotes not significant.

The results of direct effects, as shown in Table 5.3, are explained in the paragraphs below. To begin with, the following paragraph provides an explanation related to H2a, H2b, and H2c, demonstrating the direct effects of developmental culture.

H2a: *A developmental culture has a positive influence on the adoption of Industry 4.0.*

H2b: *A developmental culture has a positive influence on the adoption of CE.*

H2c: *A developmental culture has a positive influence on a company's competitive advantage.*

H2a was set to determine the relationship between developmental culture and the adoption of Industry 4.0. The result indicates that H2a is accepted (Estimate: 0.557, CI: 0.465 to 0.638), meaning that this culture positively supports Thai manufacturing firms in implementing Industry 4.0. To explore the connection between developmental culture and CE adoption, H2b was formulated. The hypothesis testing shows that H2b is confirmed (Estimate: 0.255, CI: 0.112 to 0.396). The result reveals that this culture contributes positively to the successful CE adoption. This study also investigates the effect of developmental culture on a firm competitive advantage through H2c, and the outcome presents a significant positive impact (Estimate: 0.481, CI: 0.351 to 0.608). The following paragraph demonstrates the direct effects of Industry 4.0, covering H3a and H3b.

H3a: *Industry 4.0 contributes positively to the adoption of CE.*

H3b: *Industry 4.0 contributes positively to a company's competitive advantage.*

To enhance understanding of the impact of Industry 4.0 adoption within the Thai manufacturing industry, H3a and H3b were formulated. The result of H3a indicates a positive effect of Industry 4.0 implementation on the adoption of CE

(Estimate: 0.545, CI: 0.418 to 0.673). This suggests that companies implementing Industry 4.0 technologies tend to have advanced capabilities in CE. In terms of H3b, the acceptance of this hypothesis (Estimate: 0.190, CI: 0.048 to 0.324) indicates that Industry 4.0 adoption leads to the enhancement of a firm competitive edge. Additionally, this study examines the direct effect of CE, and the result is presented in the following paragraph.

H4: *CE contributes positively to a company's competitive advantage.*

H4 was constructed to examine the effect of CE implementation on a firm's competitive advantage. The examination of this hypothesis improves the understanding of the impact of the implementation on a firm's competitive edge in the Thai manufacturing sector, where there is an ongoing effort to encourage the implementation. The testing result of H4 confirms the positive impact of CE implementation on a firm's competitive advantage (Estimate: 0.263, CI: 0.115 to 0.422). The next paragraph discusses the direct effects of firm size.

Table 5.3 also presents the direct effects of firm size. Even though the findings indicate the insignificant influence of firm size on both CE implementation and firm competitive advantage, firm size has a positive influence on Industry 4.0 adoption. These findings suggest that regardless of firm size in the Thai manufacturing sector, there is no significant advantage in terms of CE implementation and competitive advantage. However, large firms are more likely to implement Industry 4.0 technologies effectively than smaller firms. Smaller firms could be subject to Industry 4.0 implementation challenges, such as inadequate financial resources and infrastructure deficiency (Raj *et al.*, 2020; Cugno, Castagnoli and Büchi, 2021), limiting the broad adoption of Industry 4.0 technologies.

5.3.2 Hypothesis testing – Indirect effect

This section focuses on the indirect effect, i.e., the mediation effect (H1), which examines the serial mediation in the relationship between developmental culture and firm competitive advantage, with Industry 4.0 and the CE as mediators. The understanding of this indirect relationship is still limited, so the outcome of H1 can contribute to expanding the knowledge in the literature. Thus, this mediation test enhances the uniqueness of this study. The finding of this hypothesis is presented later in this section.

> ***H1:*** *Industry 4.0 and the CE mediate the relationship between a developmental culture and a company's competitive advantage.*

In order to test H1, a user-defined estimand function in the Amos software is employed to assess the mediation effect, i.e., a specific indirect effect. The paths, including Path_A, Path_B, and Path_C, were specifically named to test a specific indirect effect, see Figure 5.7. While the structural model consists of various components, the figure includes only the latent constructs and firm size for ease of understanding.

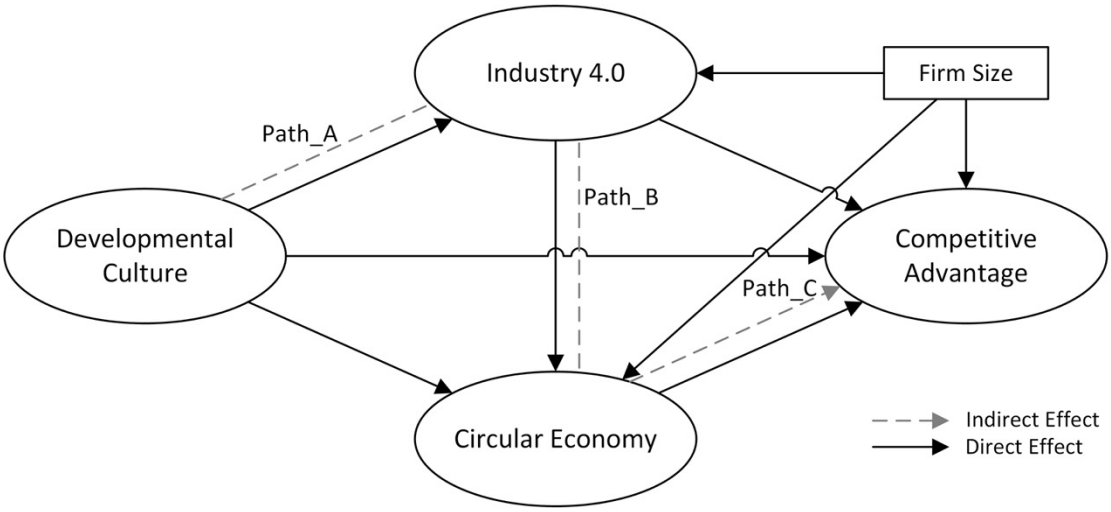

Figure 5.7 Paths for the Indirect Effect

These three paths, i.e., Path_A, Path_B, and Path_C, reflect the specific indirect effect, i.e., serial mediation pathway, between developmental culture and competitive advantage. Industry 4.0 and the CE are mediators in the indirect effect. Firstly, Path_A is the path from the developmental culture construct to the Industry 4.0 construct. Then, Path_B connects the Industry 4.0 construct to the CE construct. Lastly, Path_C links the CE construct to the competitive advantage construct.

The indirect effect, i.e., serial mediation effect, can be derived by the product of the regression weights of Path_A, Path_B, and Path_C (Hayes, 2022). Therefore, the indirect effect, i.e., Indirect_Effect=Path_A*Path_B*Path_C, was defined in the user-defined estimand function to compute the serial mediation effect. The outcome of the indirect effect is presented in Table 5.4. The unstandardized estimate is reported for the specific indirect effect based on the output from the user-defined estimand function. The finding indicates that Industry 4.0 and the CE act as mediators between developmental culture and firm competitive advantage, and hence, H1 is confirmed (Estimate 0.067, CI: 0.028 to 0.127). However, with the presence of the direct effect between developmental culture and competitive advantage constructs, as shown in section 5.3.1, the identified indirect effect is considered partial mediation.

Table 5.4 Indirect Effect – Hypothesis Testing Result

Hypothesis	**Structural Path**	**Estimate**	**Bias-corrected confidence interval**		**p-value**	**Result**
			LCI	**UCI**		
H1	Developmental Culture → Industry 4.0 → Circular Economy → Competitive Advantage	0.067	0.028	0.127	0.000	Supported (Partial mediation)

Note: This table presents an unstandardized estimate of the specific indirect effect.

5.4 Conclusion

This chapter presents the respondent profiles using descriptive statistics, i.e., graphs, and also includes the CFA and structural model analyses. The findings reveal the acceptance of all hypotheses, covering six direct effects and one indirect effect. The results highlight the significant influences of developmental culture in helping Thai manufacturing firms advance their competitive advantage and implement both CE and Industry 4.0. The positive role of Industry 4.0 in supporting these firms in implementing CE has also been determined. The finding also shows that large firms tend to be more effective in terms of Industry 4.0 implementation. The following chapter discusses the key research processes and findings.

CHAPTER 6
DISCUSSION

This chapter provides a discussion of the research results based on the analysis presented in the previous chapter. The chapter begins with explanations of the key research processes linked to the research objectives, highlighting how each research objective is achieved. The research outcomes are then discussed with the literature to broaden the knowledge and fill the literature gaps. This chapter aims to extend the current knowledge in the CE and Industry 4.0 literature, especially in the context of the Thai manufacturing sector. It provides insights into the impact of organizational culture on Industry 4.0 and CE implementation in Thai manufacturing, particularly the effect of developmental culture. The influences of this culture and the implementation on manufacturing firms' competitive advantage are also discussed.

6.1 Key Research Processes in Relation to Research Objectives

This section explains the linkage between the key research processes and the research objectives. To begin with, three research objectives were formulated, as described in Chapter 4. These objectives guide the development of this study to accomplish the research aim, promoting the understanding of the developmental culture influences on Industry 4.0 adoption, CE implementation, and competitive advantage in Thai manufacturing firms. Figure 6.1 presents key research processes in relation to the research objectives, and detailed explanations are provided in the following paragraphs.

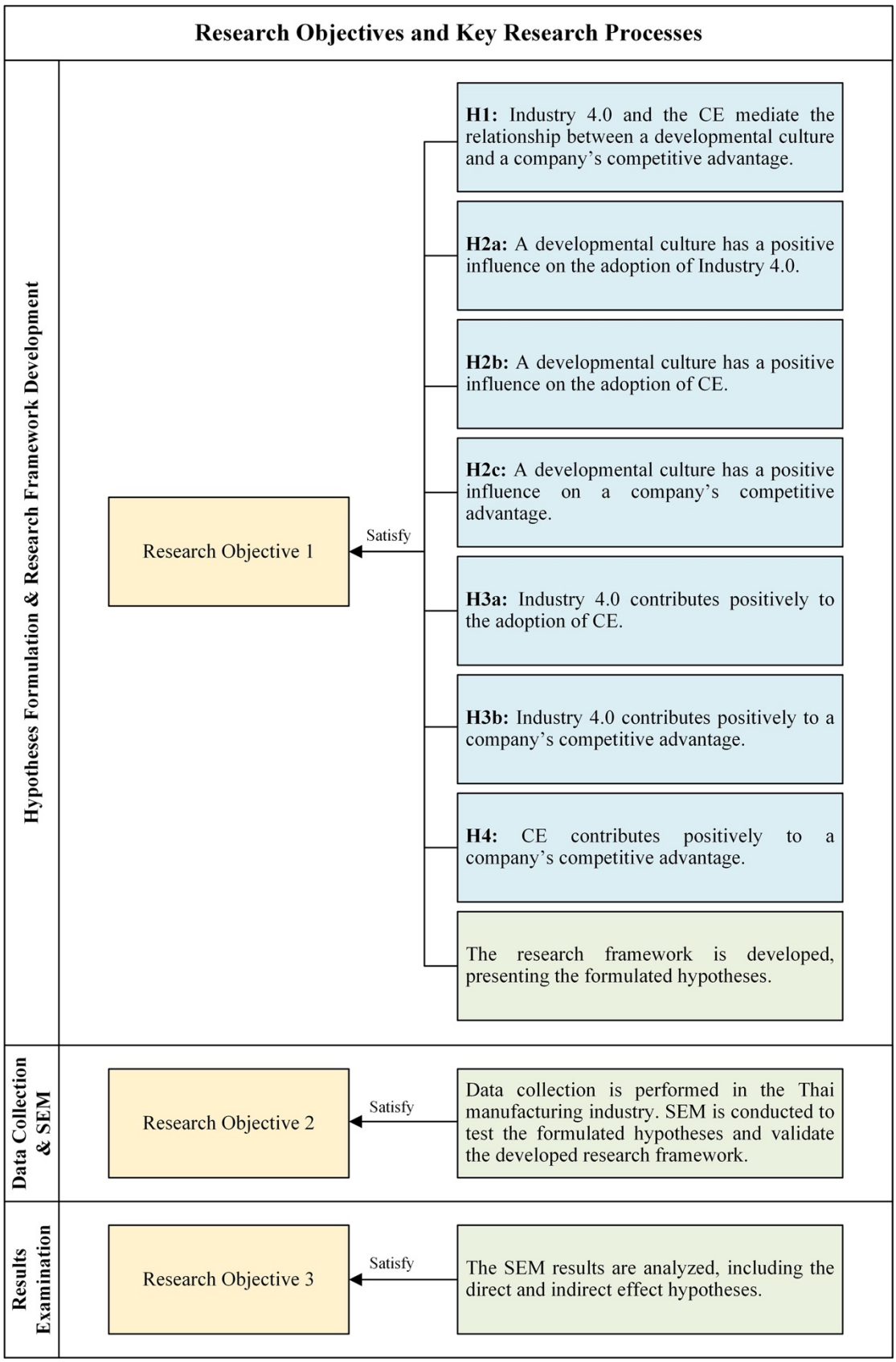

Figure 6.1 Key Research Processes in Relation to Research Objectives

To begin with, the first research objective is achieved via the formulation of hypotheses and the development of the research framework. This study formulates seven hypotheses, which are summarized below:

- The influences of developmental culture on the implementation of both Industry 4.0 and CE are examined through H2a and H2b, respectively.
- The relationship between Industry 4.0 and CE implementation is examined using H3a.
- The influences of developmental culture and the implementation of Industry 4.0 and CE on firm competitive advantage are tested through H2c, H3b, and H4, respectively.
- Lastly, to determine the indirect effect between developmental culture and firm competitive advantage, having Industry 4.0 and the CE as mediators, H1 is formulated.

To examine these hypotheses within the context of the Thai manufacturing industry, it is essential to gather primary data from Thai manufacturing companies and perform SEM to test the hypotheses. Hence, the second research objective was developed. Conducting SEM as the statistical tool to test these hypotheses, based on the collected 354 usable survey responses, fulfills this research objective. The third research objective was set to understand the relationships covering direct effects and indirect effect based on the formulated hypotheses. To satisfy this research objective, the outcomes from SEM are examined, which reveal the acceptance of all seven hypotheses. The following section discusses the outcomes of hypotheses testing with relevant literature.

6.2 Discussion of the Findings

This section discusses the findings of this research. Figure 6.2 provides an overview of the outcomes derived from the SEM.

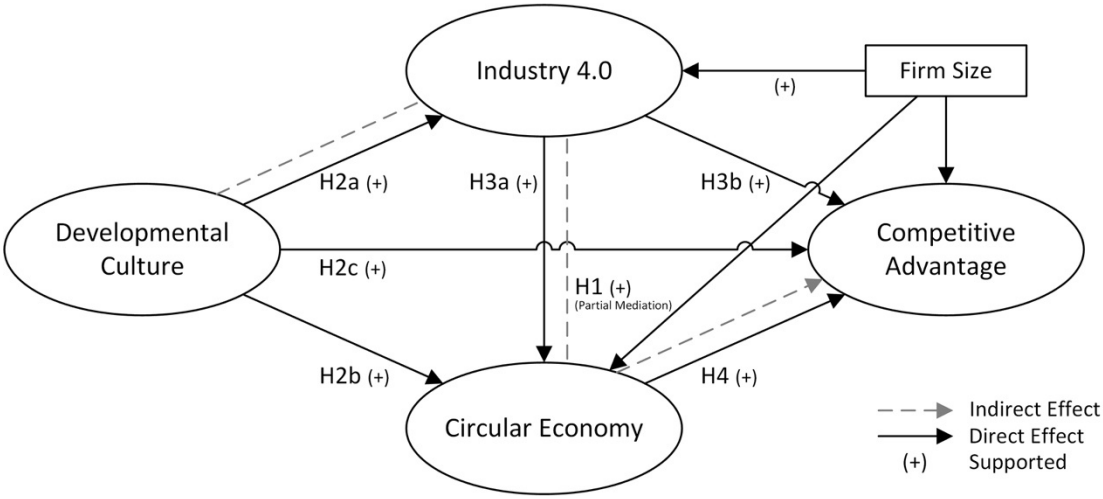

Figure 6.2 Overview of Hypotheses Testing Results

The association between digitalization and sustainability is increasingly receiving attention in the current literature, and firms that achieved a high level of digitalization tend to have an increased sustainability performance (Broccardo, Truant and Dana, 2023). According to Sadri and Lees (2001), firms should have an organizational culture that brings about positive impacts. They also point out that top management of firms must understand the organizational culture in order to develop an environment that leads to preferred firm achievements. Manufacturing firms have to actively engage with the environment in which they operate. They must respond to business disruptions from pandemics (Bianco et al., 2023) and react to the demands within their operating environment (Hwang, Huang and Wu, 2016). For example, stakeholders can put pressure on firms to employ sustainable production practices, so firms should consider leveraging this for a competitive advantage (Baah *et al.*, 2021). Thus, understanding the impact of Industry 4.0 and CE transition on firms' competitive advantage can potentially help them perceive the benefits and promote the transition, which could help them better respond to these requirements. Apart from this understanding, firms should also understand the organizational culture that facilitates the effective implementation of digital technologies for sustainability and competitiveness improvement.

This study focuses on developmental culture to promote the understanding of how this cultural profile impacts a firm's competitive advantage as well as the transition

toward Industry 4.0 and the CE. Furthermore, the findings also contribute to providing empirical evidence demonstrating the connection between TOE elements based on the context of the Thai manufacturing industry. The identified relationship between developmental culture and Industry 4.0 adoption reflects the linkage between technology and organizational dimensions of the TOE, and this relationship also demonstrates the linkage between social and technical aspects, as highlighted in Socio-Technical Systems. Since the competitive environment is among the TOE environmental factors influencing Industry 4.0 adoption (Arcidiacono *et al.*, 2019), the recognized positive impact of Industry 4.0 adoption on firm competitive advantage demonstrates the potential of digital technologies in helping firms react to competitive pressures from their external environment. The findings, suggesting that the adoption of Industry 4.0 and CE positively contribute to improving firm competitive advantage, also align with RBV and NRBV, respectively. Moreover, this study also recognizes a positive relationship between developmental culture and CE adoption.

The emphasis of this study is on the manufacturing sector in Thailand, an emerging economy, where companies in this sector are transitioning toward Industry 4.0. A study shows that the implementation of Industry 4.0 is more impacted by intrinsic barriers within a firm than external challenges (Chauhan, Singh and Luthra, 2021). Intrinsic barriers, such as employee reluctance to change (Raj *et al.*, 2020) and a lack of top management commitment (Majumdar, Garg and Jain, 2021) can impede the successful Industry 4.0 implementation. To overcome these intrinsic barriers, firms must ensure that their organizational culture supports an effective transition to Industry 4.0 (Ghobakhloo *et al.*, 2022). A study also indicates that digitalization can be affected by organizational culture (Isensee *et al.*, 2020). Therefore, examining the influence of organizational culture on Industry 4.0 adoption is important. A developmental culture has attributes such as emphasizing innovation and change (Cameron and Quinn, 2006; Hardcopf, Liu and Shah, 2021), which are essential aspects for the Industry 4.0 transition (Santos and Martinho, 2020; Ghobakhloo *et al.*, 2022). However, research on the influence of developmental culture on the transition, especially in the context of the Thai manufacturing industry, remains limited, so this study addresses this by testing H2a. The finding reveals that developmental culture can aid the adoption of Industry 4.0 technologies, highlighting the positive influence of a particular culture on the

Industry 4.0 transition. Moreover, the connection between developmental culture and a firm competitive advantage is also investigated using H2c. A previous study made an effort to examine the linkage between organizational culture and competitive advantage (Anning-Dorson, 2021). The finding of H2c offers a specific perspective on the influence of developmental culture in enhancing competitive advantage in the Thai manufacturing industry, suggesting that companies with a strong presence of developmental culture tend to demonstrate an enhanced competitive advantage. This finding can be explained by the characteristics of developmental culture, for instance, innovation, external focus, creative problem solving, risk-taking, and flexibility (Cameron and Quinn, 2006). These characteristics contribute to helping firms better respond to changes in customer needs and improving firms' performance in aspects such as innovation and quality (Prajogo and McDermott, 2011).

Since a reluctant organizational culture can hamper an effective CE transition (Kirchherr *et al.*, 2018), firms should recognize the organizational culture that can aid the transition. According to Singh *et al.* (2020), it is recommended that a developmental culture is a culture preferred to support firms' green human resource management to improve green innovation capability, helping firms achieve their environmental targets. While eco-innovation (EI) has been identified as a fundamental element facilitating firms in implementing CE initiatives (de Jesus *et al.*, 2018), embedding EI necessitates a supportive organizational culture (Suchek *et al.*, 2021) characterized by attributes such as risk-taking and embracing change (Kiefer, González and Carrillo-Hermosilla, 2019). Thus, it is very promising that developmental culture can aid firms in improving their sustainability performance and closing their resource loop, leading to CE capability. The testing result of H2b confirms the beneficial impact of developmental culture on CE adoption. Thus, a developmental culture can help Thai manufacturing firms implement CE.

This research also targets to understand the connection between Industry 4.0 and the CE in the Thai manufacturing sector. Industry 4.0 transition brings about the potential to enhance manufacturing decision-making and real-time data visibility and contributes to promoting sustainability (de Oliveira Neto, da Conceição Silva and Filho, 2023). Innovative technologies, combined with circular manufacturing, can help firms address Sustainable Development Goals (SDGs) (Dantas *et al.*, 2021). Digital

technologies also have the potential to support the development of CE business model innovation (Ranta, Aarikka-Stenroos and Väisänen, 2021). While firms should consider implementing Industry 4.0 technologies along with CE initiatives to improve business sustainability, they must deal with various challenges (Kumar, Singh and Kumar, 2021). The CE transition, together with Industry 4.0, usually requires expertise and substantial capital investment (Abdul-Hamid *et al.*, 2020; Laskurain-Iturbe *et al.*, 2021). In emerging economies, firms are confronting challenges, such as resource constraints and a lack of competencies, that could impede the integration of technological innovations to support CE initiatives (Cezarino *et al.*, 2021). Therefore, it is beneficial to examine the relationship between Industry 4.0 and the CE in the context of the manufacturing sector in Thailand, where research in this area is still not mature. The result of hypothesis testing (H3a) indicates that Industry 4.0 contributes significantly to CE implementation, showing that the adoption of Industry 4.0 technologies can help Thai manufacturing companies effectively implement CE initiatives.

Developing business model innovation under Industry 4.0 can help firms capture new opportunities (Weking *et al.*, 2020). Enhancing manufacturing competitiveness is among the speculated Industry 4.0 implementation benefits (Jamwal *et al.*, 2021). However, the empirical research examining the impact of Industry 4.0 implementation on the competitive edge of firms in the Thai manufacturing industry is inadequately studied, demanding additional investigation within this specific context. This is addressed through the examination of H3b. The finding suggests that Industry 4.0 technologies contribute to the advancement of a firm's competitive advantage. This finding aligns with the intended Industry 4.0 motivation to improve firm competitiveness (Bravi and Murmura, 2021). Hence, Thai manufacturing companies can anticipate an enhancement in competitive advantage by implementing Industry 4.0 technologies. In brief, the outcomes of this study contribute to enhancing the understanding of the benefits resulting from the implementation of Industry 4.0 technologies in the Thai manufacturing sector. More specifically, the adoption of Industry 4.0 technologies can enhance a firm's competitive advantage and contribute to effective CE implementation.

The transition toward the CE can lead to green product development and improvements in environmental performance (Kumar *et al.*, 2019). It can also help firms differentiate their products by highlighting eco-concern (Mura, Longo and Zanni, 2020). Firms can expect an enhanced brand image from the transition (Nudurupati *et al.*, 2022). Moreover, recycling and waste treatment can help firms promote brand reputation (Mazzucchelli *et al.*, 2022). CE practices such as remanufacturing and recycling could also help them attain price competitiveness (Bag, Gupta and Kumar, 2021). This helps explain the result of H4 as the implementation of CE leads to firm competitive advantage improvement. What's more, this study highlights the serial mediation effect between developmental culture and firm competitive advantage, in which Industry 4.0 and the CE act as mediators, bringing a unique aspect to this study. Due to the significant direct relationship between developmental culture and competitive advantage, the outcome of H1 reveals that Industry 4.0 and the CE partially mediate this relationship. All in all, these findings contribute to extending the current literature, especially in the context of the manufacturing sector in Thailand.

6.3 Conclusion

This chapter provides a discussion of the research outcomes as well as the rationales supporting the testing results of the hypotheses. Since research focusing on linking developmental culture, Industry 4.0, the CE, and firm competitive advantage in a combined manner is still limited, the outcomes contribute to filling literature gaps, particularly in the Thai manufacturing context. The findings are discussed with the literature and fulfill the research aim. The following chapter presents the contributions of this study in terms of theoretical contribution and practical contribution, and this research from a perspective of knowledge science is also provided.

CHAPTER 7
CONTRIBUTIONS

This chapter presents the contributions of this study. The chapter begins with a discussion on theoretical contribution, advancing the understanding of the connection between developmental culture, Industry 4.0, the CE, and firm competitive advantage. Next, practical contribution is presented, providing the practical implications of the findings. Lastly, this research is discussed from a perspective of knowledge science.

7.1 Theoretical Contribution

Various theoretical perspectives inspire and contribute to the development of the research framework, including TOE, Socio-Technical Systems, RBV, and NRBV. The RBV offers the perspective linking the adoption of leading technology with firm competitive advantage (Wernerfelt, 1984). Organizational culture as an intangible resource is also vital for firms to effectively implement the strategy required to promote organizational performance (Klein, 2011). The NRBV demonstrates the standpoint highlighting the connection between environmental capabilities and firm competitive advantage (Hart, 1995). The linkage between technology adoption and organizational culture has been previously acknowledged through theoretical perspectives, including the TOE and Socio-Technical Systems. For example, in terms of Socio-Technical Systems, it has been applied to promote the understanding of the impact of workplace culture on the adoption of technology (Davis *et al.*, 2014). Furthermore, according to Arcidiacono *et al.* (2019), organizational culture is perceived as one of the important factors within the organizational dimension of the TOE framework, influencing

technology adoption. These theoretical viewpoints provide the basis for the development of this study. This study provides theoretical contributions by demonstrating the relationships between the constructs within the research framework. This study examines these relationships in the Thai manufacturing sector.

Developmental culture demonstrates considerable potential in driving innovation forward (Prajogo and McDermott, 2011). Innovation ecosystems play a vital role in helping firms co-create value under Industry 4.0 (Benitez, Ayala and Frank, 2020). The transition toward the CE requires business model development, and integrating innovation with sustainability consideration, referred to as EI, can potentially support this transition (de Jesus *et al.*, 2018). Even though developmental culture can potentially push innovation, its influence on implementing Industry 4.0 and CE in Thai manufacturing is rarely studied. Therefore, this study contributes to filling this gap, demonstrating the positive influences of this culture on Industry 4.0 and CE implementation in Thai manufacturing companies.

A previous study summarizes the potential of Industry 4.0 technologies to advance sustainable production (Enyoghasi and Badurdeen, 2021). In the same manner, the sustainability benefits achieved through Industry 4.0 are previously highlighted in the literature (Ghobakhloo, 2020). Firms can utilize digital technologies to innovate their business models, providing benefits in resource efficiency (Ranta, Aarikka-Stenroos and Väisänen, 2021). However, firms in emerging economies may face persistent challenges as they strive to transition toward CE with the support of these technologies (Cezarino *et al.*, 2021). On top of that, developing and developed economies are dissimilar in terms of sustainability involvement (Wang *et al.*, 2019). Therefore, it is interesting to examine the connection between Industry 4.0 and the CE in the context of the manufacturing sector in Thailand. The finding of this study contributes by showing that Industry 4.0 positively impacts CE adoption in this manufacturing sector. Implementing digital technologies along with CE practices has the potential to drive business competitiveness (Chaudhuri, Subramanian and Dora, 2022). Therefore, this study also examines the impacts of both Industry 4.0 and CE implementation on the competitive advantage of Thai manufacturing companies, and the results indicate that both have supportive effects.

To facilitate Industry 4.0 implementation, firms should have a supportive organizational culture (Arcidiacono *et al.*, 2019). The movement toward Industry 4.0 helps firms with the ability to streamline their manufacturing operations and promote sustainability performance (Bai *et al.*, 2020). Industry 4.0 technologies could assist firms in embedding sustainability into innovation (Ghobakhloo *et al.*, 2021). Firms must consider improving their business model innovation to capture value from the CE transition (Suchek et al., 2021), and this transition can help them gain competitive advantage (Sharma *et al.*, 2021). Furthermore, Rehman *et al.* (2023) point out that technological innovation supports firms in enhancing green competitive advantage. The findings of these studies help explain the outcome of the examined serial mediation, which is that Industry 4.0 and the CE act as mediators between developmental culture and firm competitive advantage. The result indicates a partial mediation effect. This serial mediation test adds novelty to this study.

In brief, the findings show that developmental culture contributes to providing a supportive environment for firms to adopt Industry 4.0 technologies and CE. These technologies also aid firms in adopting CE practices. Moreover, developmental culture, the implementation of Industry 4.0, and the adoption of CE lead to improvement in a firm's competitive advantage. All in all, this study extends the literature by demonstrating these relationships in the Thai manufacturing industry, highlighting the importance of development culture in promoting Industry 4.0 and the CE transition success, as well as contributing to improving firm competitive edge.

7.2 Practical Contribution

Sustainable economic development is gaining more attention in the ASEAN region (ASEAN Secretariat, 2023). The CE has a strong potential to help reduce carbon footprint and promote sustainable development. The manufacturing sector is important to strengthening Thailand’s economy. Thus, enhancing the competitive advantage of Thai manufacturing companies is required to reinforce the economy. To advance this sector, technological enhancements are among the key elements that need to be considered.

The findings of this study provide valuable input for Thai manufacturing companies to understand the benefits of Industry 4.0 and CE implementation on their competitive advantage. As a result, this can motivate these companies to advance to Industry 4.0 and the CE, aiming to enhance competitive advantage and also improve sustainability performance. With the successful transition to the CE, manufacturing companies can contribute to mitigating resource depletion by transforming from the linear to the CE model.

To effectively transition toward Industry 4.0 and CE, firms must understand the supporting factors. Organizational culture can be the influencing factor, and understanding the cultural attributes that lead to a supportive environment for the transition is vital. This study provides a perspective on the influence of developmental culture on this transition in Thai manufacturing. This study reveals the positive influences of this culture in facilitating the implementation of Industry 4.0 and CE, and hence, manufacturing companies can synchronize their cultural characteristics with developmental culture to encourage both digital technologies and CE adoption.

On top of that, this study also highlights the positive influence of Industry 4.0 on the implementation of CE. Therefore, Thai manufacturing companies can utilize Industry 4.0 technologies to enhance the success of CE implementation. The results of this study offer insights for policymakers and industrialists to better understand the connection between developmental culture, Industry 4.0, and the CE in order to aid Thai manufacturing companies in improving their competitive advantage. These findings could also be applied to other emerging nations in the ASEAN region under comparable economic conditions.

7.3 This Research from a Knowledge Science Perspective

According to Nakamori (2003) and Nakamori, Wierzbicki and Zhu (2011), a knowledge creating system, so-called i-System, consists of five key dimensions, including *Intelligence*, *Imagination*, *Involvement*, *Integration*, and *Intervention* (see Figure 7.1). This study utilizes the i-System to help explain the knowledge created through this study. Firstly, in *Intervention*, the problem begins with the following questions (as discussed in Chapter 1):

- How can Thai manufacturing firms effectively promote Industry 4.0 and CE implementation success?
- How does the implementation impact Thai manufacturing firms' competitive advantage?

In *Intelligence*, this study examines the literature and diverse theoretical perspectives such as TOE, Socio-Technical Systems, RBV, and NRBV, to understand the fundamental knowledge and theoretical foundation. In *Imagination*, this study is inspired by these theoretical perspectives, and the hypotheses are formulated based on inputs from the literature. In *Involvement*, this study collected primary data from participants in the Thai manufacturing sector. Lastly, in *Integration,* this study draws conclusions based on the findings from SEM statistical analysis, enabling an understanding of the relationships examined.

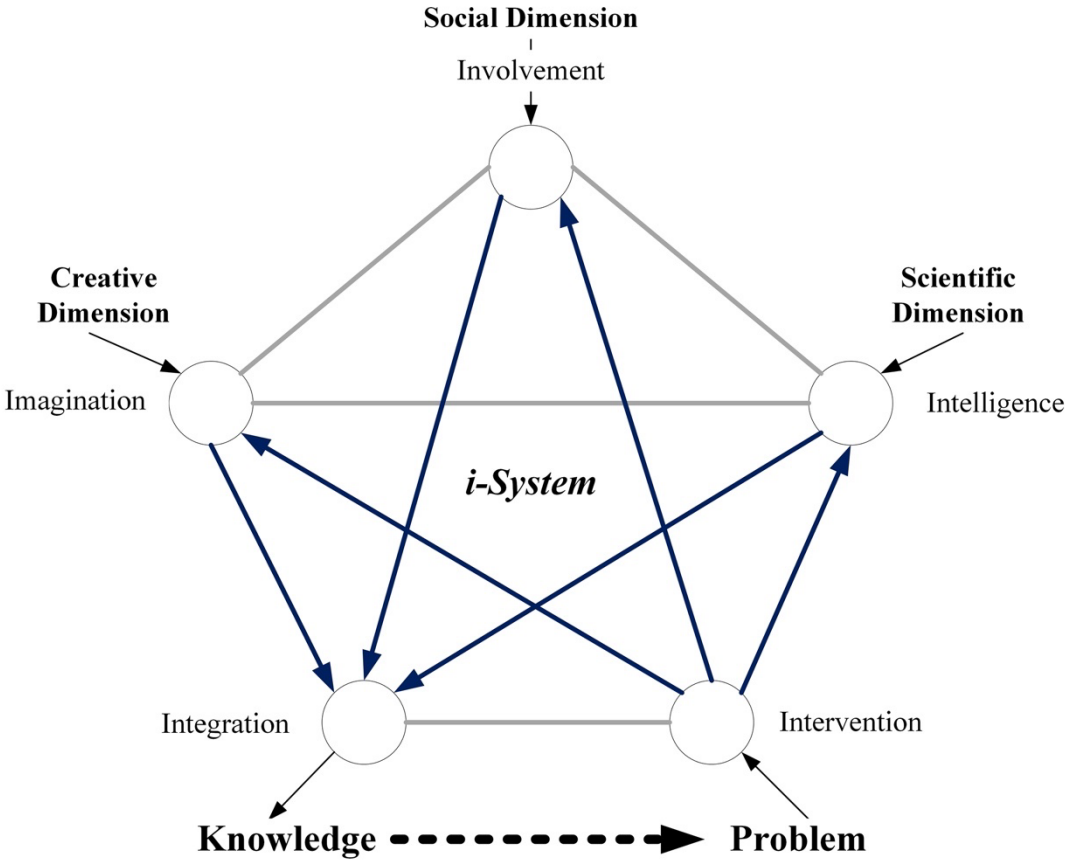

Figure 7.1 A Knowledge Creating System (Nakamori, 2003; Nakamori, Wierzbicki and Zhu, 2011)

In summary, the research outcomes contribute to expanding the knowledge related to the influences of developmental culture on the transition toward Industry 4.0 and the CE, helping Thai manufacturing companies understand the cultural characteristics that support the transition, as well as the transition impacts on firm competitive advantage. Last but not least, this study also demonstrates the application of the i-System using the context of this study.

7.4 Conclusion

This chapter provides details related to the contributions of this study, including theoretical contribution and practical contribution, as well as the knowledge science perspective of this research. In terms of theoretical contribution, the research findings contribute to expanding knowledge in Industry 4.0 and CE literature by examining relationships as shown in the research framework.

For practical contribution, the identified positive influences of developmental culture on both Industry 4.0 and CE adoption help manufacturing companies gain a better understanding of the cultural characteristics that lead to effective adoption. Moreover, this study also points out the positive impacts of both adoption on a firm's competitive advantage. Realizing these positive impacts can encourage manufacturing companies to advance toward Industry 4.0 and CE. The findings benefit scholars and businesses, demonstrating that they should not disregard the impacts of organizational culture on implementing Industry 4.0 and the CE.

Finally, for this research from a knowledge science perspective, the i-System is adopted to help explain the knowledge created through this study. This study also contributes to demonstrating the application of the i-System.

CHAPTER 8
CONCLUSION

To begin with, this research is inspired by various theoretical viewpoints, including TOE, Socio-Technical Systems, RBV, and NRBV. The inputs from the literature and these viewpoints lead to the development of the research framework consisting of four constructs, namely developmental culture, Industry 4.0, the CE, and competitive advantage. However, research focusing on the linkage between the constructs within the research framework is still limited, especially in the context of the Thai manufacturing industry. This calls for further study in this particular context. This study adopts a quantitative approach, i.e., SEM, to advance the understanding of the relationships between the constructs and fill the literature gaps, as addressed in Chapter 2. In total, seven hypotheses, consisting of one indirect effect and six direct effects, are formulated to broaden the knowledge in Industry 4.0 and CE literature, see Chapter 3.

This closing chapter summarizes the research findings, based on the SEM outcomes, in relation to the research aim and objectives. This chapter also presents concluding remarks, limitations, and future studies. The limitations and future studies section elaborates on the theoretical perspective and studying context.

8.1 Conclusion in Relation to the Research Aim and Objectives

This section summarizes this research in relation to the research aim and objectives. While the transition to Industry 4.0 and CE is receiving more attention, research focusing on the transition impact on firm competitive advantage through a developmental culture perspective in the context of Thai manufacturing remains

lacking. This study, therefore, contributes to extending Industry 4.0 and CE literature in this aspect. The outcomes are also vital to help Thai manufacturing firms promote effective transition and understand the impact of the transition on their competitive advantage. The following research aim was proposed as the primary goal of this study.

Research Aim: This study aims to examine the influence of developmental culture on the implementation of Industry 4.0 and CE in manufacturing firms in Thailand, a developing country. The relationships between developmental culture, Industry 4.0, CE, and competitive advantage are quantitatively investigated. This enhances the understanding of developmental culture impacts and how manufacturing firms can promote competitive advantage through Industry 4.0 and CE initiatives.

To accomplish the proposed research aim, three research objectives were developed to guide this study, see details in Section 4.1. Table 8.1 shows the key research outcomes in relation to research objectives.

Table 8.1 Key Outcomes in Relation to Research Objectives

Research Objectives	Key Outcomes
Research Objective 1	• This research objective is achieved via the development of the research framework and formulation of hypotheses. The formulated hypotheses include direct effect hypotheses, i.e., H2a, H2b, H2c, H3a, H3b, and H4, as well as an indirect effect hypothesis, i.e., H1. • H2a and H2b are formulated to understand the impacts of developmental culture on Industry 4.0 and CE implementation, respectively. • H3a is developed to examine the impact of Industry 4.0 adoption on CE implementation. • H2c, H3b, and H4 are proposed to identify the influences of developmental culture, Industry 4.0, and CE on firm competitive advantage, respectively.

	• H1 is formulated to understand the indirect relationship, i.e., serial mediation effect, between developmental culture and firm competitive advantage, with Industry 4.0 and CE as mediators in this relationship.
Research Objective 2	• This research objective is accomplished by collecting primary data from the participants in the Thai manufacturing sector and conducting SEM. In total, 354 usable responses were collected and used for the SEM analysis. • SEM is performed to test the hypotheses and validate the research framework.
Research Objective 3	• The findings of H2a and H2b reveal the acceptance of these hypotheses. The findings suggest that Thai manufacturing companies can align their organizational culture with developmental culture to develop an environment that supports Industry 4.0 and CE transition. • The outcome confirms H3a. It suggests that Thai manufacturing companies can utilize Industry 4.0 technologies to promote CE adoption. • The findings support H2c, H3b, and H4. It can be implied from the findings that developmental culture, Industry 4.0, and the CE can help Thai manufacturing companies attain a competitive advantage. • The result of H1, which examined the serial mediation effect, demonstrates a partial mediation effect in the relationship between developmental culture and firm competitive advantage, having Industry 4.0 and the CE as mediators. • Overall, by aligning organizational culture with developmental culture, Thai manufacturing companies can expect to effectively utilize Industry 4.0 technologies and CE practices to gain a competitive edge.

8.2 Concluding Remarks

Manufacturing companies in a developing country can experience challenges such as highly volatile market conditions and resource scarcity. This may limit their ability to maintain a competitive edge. In the Thai manufacturing sector, Industry 4.0 and the CE are receiving more awareness regarding their potential in facilitating long-term sustainable development. While Industry 4.0 and CE transition is an evolving process in the Thai manufacturing sector, companies need to understand the impact of the transition, especially on their competitive advantage. Recognizing the positive impacts of the transition on competitive advantage could encourage this transition, leading to long-term advantages in sustainable development.

Organizational culture can be one of the factors that influence firms to improve their operations, making it necessary for them to properly understand the supportive cultural conditions. This study promotes the understanding of the organizational culture that aids firms in the effective implementation of Industry 4.0 and CE, helping companies attain a competitive advantage. Hence, this study broadens the Industry 4.0 and CE literature by considering various aspects:

- Emphasizing the context of the manufacturing industry in Thailand, a developing country in ASEAN
- Highlighting the influences of developmental culture on the implementation of Industry 4.0 and CE
- Identifying the impacts of developmental culture and the implementation of Industry 4.0 and the CE on firm competitive advantage
- Examining the serial mediation influence of Industry 4.0 and the CE on the linkage between developmental culture and firm competitive advantage

All in all, the findings of this study provide inputs helping Thai manufacturing firms promote their competitive advantage and effectively implement Industry 4.0 and CE from the organizational standpoint, specifically from a developmental culture perspective.

8.3 Limitations and Future Studies

This section highlights the limitations of this study and areas for future studies. The section consists of two subsections covering theoretical perspective and studying context.

Theoretical perspective

- Even though this study is inspired by multiple theoretical perspectives, the study does not tie to any distinct theoretical perspective. Therefore, it is possible for future studies to examine Industry 4.0 and CE adoption while focusing on specific theoretical perspectives.
- While this study emphasizes the developmental culture perspective and identifies the positive influence of this culture on Industry 4.0 and CE adoption, it is still interesting to examine the impact of other cultural profiles on the adoption to promote a broad perspective of organizational culture influence.
- Apart from focusing on the influence of organizational culture on the adoption, future studies can also consider examining the influence of other intrinsic and extrinsic factors, providing a wider viewpoint supporting the successful adoption of Industry 4.0 and CE.

Studying context

- In this work, the Thai manufacturing sector was selected to examine the impact of the culture on Industry 4.0 and CE implementation, offering a perspective on the ongoing Industry 4.0 and CE transition. It is also interesting to conduct the study in different countries, providing more insights into the impact of the organizational culture in different manufacturing contexts, e.g., other manufacturing sectors in various developing and developed countries. This will allow the comparison of the results from different contexts and add further perspectives to the existing literature.

- Examining the manufacturing sector in a particular country can help minimize the bias from the culture at the country level. However, the manufacturing sectors in different countries are subject to different operating environments. Hence, exploring cultural influence at a macro level on the transition can provide additional insightful knowledge.
- Future research could also study the role of developmental culture in driving competitive advantage in the service sector in Thailand and other developing countries. This will enlarge the scope of the study to a broader range of sectors.

PUBLICATIONS

Journal Papers

Piyathanavong, V., Olapiriyakul, S., Garza-Reyes, J.A., Kumar, V., Huynh, V.-N. and Karnjana, J. (2024) 'Implementing Industry 4.0 and circular economy through the developmental culture perspective—Driving a competitive advantage in the manufacturing industry', *Business Strategy and the Environment*. Available at: https://doi.org/10.1002/bse.3967.

Piyathanavong, V., Huynh, V.-N., Karnjana, J. and Olapiriyakul, S. (2024) 'Role of project management on Sustainable Supply Chain development through Industry 4.0 technologies and Circular Economy during the COVID-19 pandemic: A multiple case study of Thai metals industry', *Operations Management Research,* 17, pp. 13–37. Available at: https://doi.org/10.1007/s12063-022-00283-7.

Conference

Piyathanavong, V., Huynh, V.-N., Karnjana, J. and Olapiriyakul, S. (2023) 'Sustainability Synergies and Trade-offs of a Thai Metal Manufacturing Company', in *Proceedings of the 4th Asia Pacific Conference on Industrial Engineering and Operations Management*. Available at: https://doi.org/10.46254/AP04.20230184.

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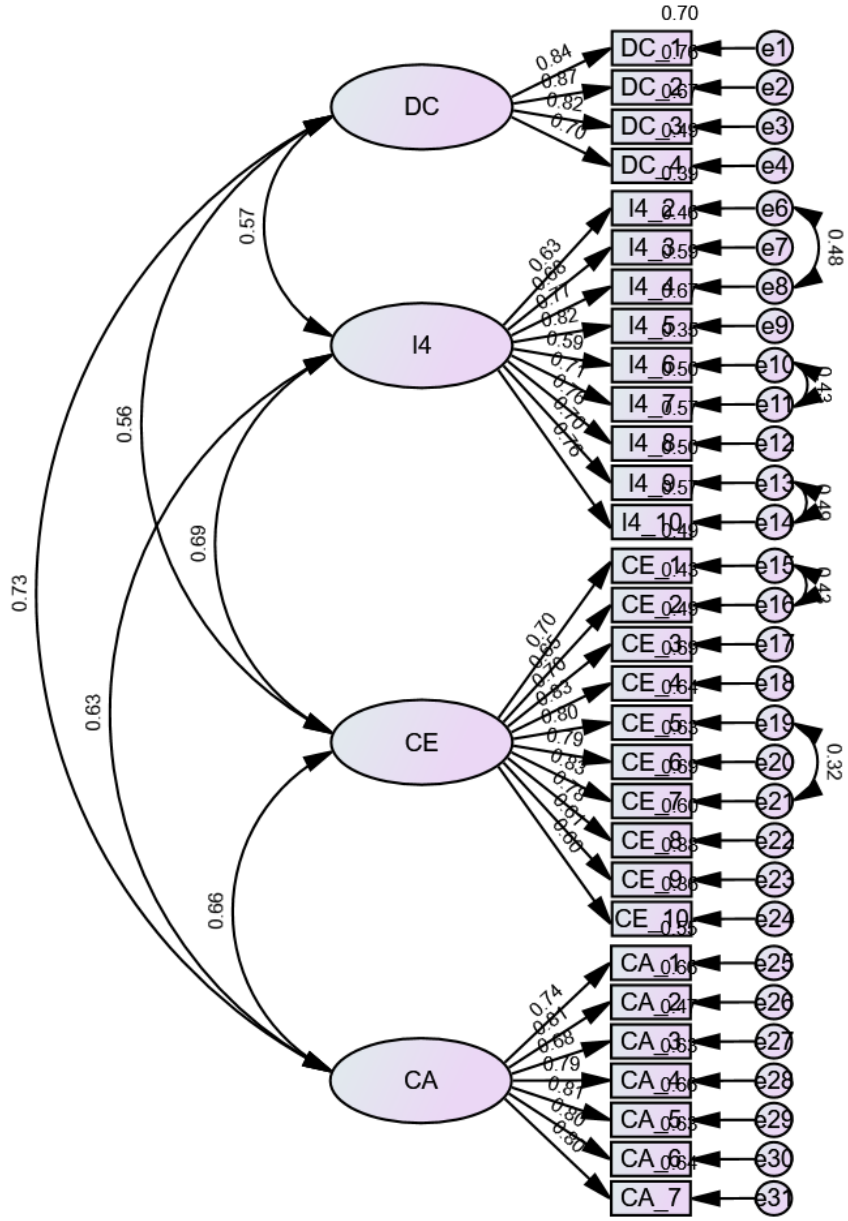
APPENDIX A
CONFIRMATORY FACTOR ANALYSIS: MEASUREMENT MODEL

The CFA model below consists of four latent constructs, i.e., developmental culture (DC), Industry 4.0 (I4), the CE (CE), and competitive advantage (CA), and their measures.



APPENDIX B
STRUCTURAL MODEL

The structural model incorporates elements such as developmental culture (DC), Industry 4.0 (I4), CE (CE), and competitive advantage (CA) constructs, their measures, and firm size. Standardized estimates are presented in the model.