CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

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ปัจจัยความสำเร็จที่สำคัญสำหรับการเปลี่ยนผ่านสู่ดิจิทัลในอุตสาหกรรมก่อสร้าง : แนวทาง Integrated Fuzzy Cognitive Map และ Ranking Analysis

นายทาน ถาน ทราง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต
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Thesis Title	CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH
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ทาน ถาน ทราง : ปัจจัยความสำเร็จที่สำคัญสำหรับการเปลี่ยนผ่านสู่ดิจิทัลในอุตสาหกรรมก่อสร้าง : แนวทาง Integrated Fuzzy Cognitive Map และ Ranking Analysis. (CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH) อ.ที่ปรึกษาหลัก : วีระศักดิ์ ลิขิตเรืองศิลป์, อ.ที่ปรึกษาร่วม : โนบุโยชิ ยาบุกิ

กระบวนการของการเปลี่ยนผ่านสู่ดิจิทัล (DX) เกี่ยวข้องกับการบูรณาการเทคโนโลยีดิจิทัล กระบวนการ และทักษะอย่างเป็นระบบในทุกระดับและหน้าที่ภายในองค์กร อุตสาหกรรม หรือระบบนิเวศ การเกิดขึ้นและการแพร่กระจายอย่างรวดเร็วของไวรัสโคโรนาได้เร่ง DX ในทุกอุตสาหกรรม รวมถึงอุตสาหกรรมการก่อสร้าง บริษัทก่อสร้างกำลังจะเปลี่ยนแปลงครั้งสำคัญ โดยถูกขับเคลื่อนด้วยความก้าวหน้าและการรับเทคโนโลยีดิจิทัลมาใช้ อย่างไรก็ตามความรู้และสารสนเทศเกี่ยวกับการนำ DX ไปใช้อย่างมีประสิทธิภาพในบริษัทก่อสร้างนั้นมีลักษณะกระจัดกระจายและมีอยู่จำกัด สิ่งเหล่านี้นำไปสู่ความล้มเหลวของการเปลี่ยนผ่านสู่ดิจิทัลของบริษัทก่อสร้างส่วนใหญ่ งานวิจัยนี้พัฒนาแผนที่ยุทธศาสตร์ของ DX รวมถึงสำรวจปัจจัยความสำเร็จที่สำคัญ (CSF) สำหรับการนำ DX ไปใช้ในมุมมองของผู้รับจ้างก่อสร้าง เทคนิค Fuzzy Cognitive Map (FCM) และการวิเคราะห์การจัดอันดับถูกนำมาใช้เพื่อวิเคราะห์ความสัมพันธ์ระหว่างปัจจัยเหล่านี้และจัดอันดับความสำคัญของพวกมัน ในบรรดาปัจจัยที่ได้รับการตรวจสอบและวิเคราะห์การจัดอันดับทั้งหมด 30 รายการ เราพบว่าความเป็นผู้นำที่มีประสิทธิภาพ ความปลอดภัยของข้อมูล และความสามารถในการเปลี่ยนข้อมูลเป็นสินทรัพย์เป็นปัจจัยที่สำคัญที่สุดสำหรับการนำ DX ไปใช้สำหรับผู้รับจ้างก่อสร้างให้ประสบความสำเร็จ ผลลัพธ์ที่ได้จากการวิเคราะห์ FCM บ่งชี้ปัจจัยที่มีอิทธิพลมากที่สุดสามประการได้แก่ ความเป็นผู้นำที่มีประสิทธิภาพ ประโยชน์ที่รับรู้ได้ของ DX และการพัฒนากลยุทธ์ดิจิทัลและขอบเขตการเปลี่ยนแปลง ในขณะที่ปัจจัยสามประการที่ได้รับอิทธิพลจากตัวแปรอื่น ๆ มากที่สุด ได้แก่ ความสามารถในการวิจัยและพัฒนาขององค์กร ความยืดหยุ่นและความสามารถขององค์กรในการปรับตัวให้เข้ากับตลาด และความสามารถในการเปลี่ยนข้อมูลให้เป็นทรัพย์สินที่มีค่า ผลการวิจัยนี้มีส่วนช่วยในการพัฒนาความพยายามในการเปลี่ยนผ่านสู่ดิจิทัลในอุตสาหกรรมการก่อสร้าง และส่งเสริมผลลัพธ์ทางธุรกิจที่ดีขึ้นสำหรับผู้รับจ้างในภูมิทัศน์ดิจิทัลที่มีการพัฒนาอย่างรวดเร็ว

สาขาวิชา วิศวกรรมโยธา ลายมือชื่อนิสิต .....

ปีการศึกษา 2565 ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

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KEYWORD: Digital transformation, roadmap, ranking analysis, critical success factors, fuzzy cognitive map, construction industry, contractors, COVID-19

Tan Thanh Trang : CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH. Advisor: Assoc. Prof. VEERASAK LIKHITRUANGSILP, Ph.D. Co-advisor: Prof. Nobuyoshi Yabuki, Ph.D.

The process of digital transformation (DX) involves the systematic integration of digital technologies, processes, and skills at all levels and functions within an organization, industry, or ecosystem. The emergence and rapid spread of the coronavirus are accelerating DX in all industies and the construction industry is not an exception. Construction companies are on the verge of significant transformation driven by advancements and the adoption of digital technologies. However, knowledge and information about how to implement DX efficiently in construction firms are fragmented and limited. This leads to the failure of DX journey of the majority of construction firms. This research develops a DX implementation roadmap and investigates the Critical Success Factors (CSFs) for DX adoption in the contractors' perspective. Fuzzy cognitive map (FCM) technique and ranking analysis are applied to analyze the relationship between these factors and rank their importance. Among the 30 CSFs identified through ranking analysis, we found that effective leadership, data security, and the ability to turn data into assets be the most crucial factors for the successful implementation of DX in construction contractors. The results from FCM analysis highlighted that the three most influential factors were effective leadership, the perceived benefits of DX, and the development of a digital strategy and transformation areas. Meanwhile, the three factors that were most influenced by other variables were the research and development capabilities of the organization, the organizational flexibility and adaptability to the market, and the ability to turn data into valuable assets. These research findings contribute to advancing the digital transformation efforts in the construction industry and promoting enhanced business outcomes for contractors in the rapidly evolving digital landscape.

Field of Study:	Civil Engineering	Student's Signature .....
Academic Year:	2022	Advisor's Signature .....
		Co-advisor's Signature .....

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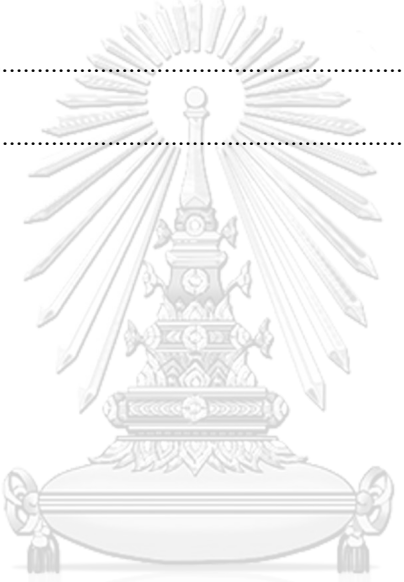

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Chapter 1

INTRODUCTION

1.1 Background

Digital transformation (DX) involves the incorporation of digital technology to revolutionize services or businesses, either by substituting non-digital or manual procedures with digital processes or upgrading older digital technology with more advanced alternatives. In addition, DX refers to the systematic and strategic integration of digital technologies, processes, and capabilities across all levels and functions of an organization, industry, or ecosystem. It encompasses cultural, organizational, and operational changes that are implemented in a staged and strategic manner (i-SCOOP, 2021b). The Enterprisers Project (2016) defined DX as the incorporation of digital technology into every aspect of a business leads to significant transformations in its operations and value delivery methods to customers.

The construction sphere is standing at the threshold of a comprehensive and extensive transformation driven by innovations and digital technologies (Koscheyev et al., 2019). In order to position construction firms for profitable growth in a fiercely competitive industry and address workforce challenges, it is essential to implement process changes and adopt new resources that leverage the potential of data. This enables improved communication, efficiency, productivity, and safety (Shapiro et al., 2019). Nowadays, the construction industry in general and contractors, in particular, adopt different digital technologies into their firms in an attempt to save time and cost, improve work efficiency, enable efficient and direct coordination and monitoring processes between project participants. Some digital technologies used in the construction industry can be listed as follows: Building Information Modeling (BIM), Drone, Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT), 3D printing and laser scanning, etc.

DX strategy is related not only to technologies but also to other components of the construction contractors. Bhanda (2021) pointed out seven key components of DX strategy, namely, communication and culture change, strategy and leadership, data curation, optimizing processes, technologies, team structure and results or measure transformation success. A DX strategy can be compared to a customized roadmap that drives significant transformations in business operations. Implementing such a strategy demands substantial financial investment, time commitment, and specialized technical knowledge (Bhanda, 2021).

In order to implement DX successfully, construction contractors need to employ DX as a thorough strategy. A good DX implementation roadmap and appropriate critical success factors (CSFs) significantly help contractors in doing so. A roadmap serves as a visual representation of a strategic plan, outlining a specific goal or desired outcome and illustrating the key steps or milestones required to achieve it (Aha! Labs Inc., 2022; ProductPlan, 2022). Center for Management & Organization Effectiveness (2021) defined CSFs as the specific elements or areas of action that a business, team, or department must prioritize and effectively implement in order to achieve its strategic objectives. Determining a great DX implementation roadmap and right CSFs will help construction contractors deploy business strategies effectively in terms of DX adoption. It also helps construction contractors by reducing cost and time for DX implementation and keeping them away from DX adoption failures.

1.2 Problem statement

DX is an emerging concept in the construction industry, particularly in developing countries such as Vietnam. However, there is currently a lack of comprehensive knowledge and information regarding efficient DX implementation in construction firms. This fragmented and limited understanding necessitates the creation of a centralized knowledge source that provides guidance on effective DX adoption. Such a resource would enable construction contractors to reference best

practices and strategies to successfully integrate DX into their business operations. By establishing a unified knowledge base, the industry can enhance its collective understanding and support the widespread implementation of DX in a manner that is more streamlined and productive.

The construction sector has been relatively slow to embrace DX compared to other industries, according to the McKinsey Global Institute (2017). However, contractors worldwide have recognized the potential of digital technologies such as Building Information Modeling (BIM), Augmented Reality (AR), Virtual Reality (VR), drones, and laser scanning to enhance collaboration and improve efficiency in the construction industry. To fully capitalize on these technologies and reap their benefits, contractors must overcome several challenges. One notable challenge is reorganizing their organizational structure to effectively incorporate BIM adoption, as highlighted by Ahn et al. (2016). This indicates the need for contractors to have a well-defined DX implementation roadmap and identify the CSFs associated with DX adoption to align it with their business strategy.

The successful implementation of DX requires careful planning and consideration of various factors. Contractors must navigate the complexities of incorporating digital technologies into their existing processes and workflows. A comprehensive DX implementation roadmap provides a structured and systematic approach for contractors to follow, outlining the essential measures and significant milestones to proficiently incorporate digital technologies into their operations.

In addition to the roadmap, identifying the correct CSFs for DX adoption is crucial. These CSFs act as guiding principles that help contractors prioritize their efforts and resources in implementing DX. By understanding the factors that contribute to successful DX adoption, contractors can align their strategies, resources, and organizational structure accordingly. This alignment ensures that DX initiatives are integrated into the broader business strategy, maximizing the benefits and minimizing potential challenges.

The implementation of DX initiatives in the construction industry often faces challenges, leading to a significant number of these initiatives falling short of expectations. One key reason behind this is the tendency of companies to prioritize specific technologies without considering the broader alignment with their overall business strategy (Tabrizi et al., 2019). As a result, many construction companies only partially leverage digital technologies, failing to fully capitalize on their potential advantages (Koscheyev et al., 2019). In addition, digital businesses that are less mature often concentrate on addressing isolated business issues by employing individual digital technologies, rather than adopting a comprehensive business strategy (Kane et al., 2015). To address these issues, it is recommended that construction contractors adopt a holistic perspective when approaching DX. This entails considering the integration of digital technologies within the broader context of their business operations and strategy. By taking a comprehensive approach to DX, construction contractors can ensure that digital initiatives are aligned with their overall business objectives, enabling them to unlock the full potential of digital technologies and achieve meaningful transformation throughout their organization.

In conclusion, the construction industry is currently in the initial phases of embracing DX initiatives., particularly in developing countries like Vietnam. There is a lack of comprehensive knowledge and resources for efficient DX implementation in construction firms. To overcome this, a centralized knowledge source is needed to provide guidance and best practices for successful DX adoption. It is crucial for construction contractors to have a well-defined DX implementation roadmap and identify CSFs as well as define the interrelationship of CSFs to align DX initiatives with their business strategies. By taking a holistic approach and integrating digital technologies into their operations, contractors can maximize the benefits of DX and overcome potential challenges. Future research and collaboration are necessary to further advance DX implementation in the construction industry.

1.3 Objectives of research

The main objectives of this research are:

(1) To develop DX implementation roadmap for construction contractors.

(2) To finalize CSFs and link the CSFs with steps of DX roadmap for DX implementation of construction contractors.

(3) To rank the importance of CSFs for DX implementation in the construction industry.

(4) To analyze the interrelationship among CSFs to assist contractors in terms of exploring the interrelation and interconnection between CSFs regarding DX adoption.

1.4 Scope of the research

The scope of this research is as follows:

(1) This research focuses on DX implementation at the organizational level in the construction industry. More specifically, contractors are targeted to be explored in this research.

(2) This research targets medium-sized and large enterprises.

(3) The respondents in this research are a group consisting of top or middle staff from contractors, highly experienced experts in construction digital technologies, and representatives from other types of construction firms in Vietnam.

(4) Vietnam is the targeted country to explore the DX adoption in this research.

(5) In term of DX technologies, the following technologies belong to the scope of this research: Building Information Modelling (BIM), Internet of Things (IoT), Virtual/Augmented Reality (VR; AR), 3D Laser Scanner, Unmanned Aerial Vehicles (Drone), Cloud Computing.

1.5 Research methodology

The research framework is illustrated in Figure 1-1 as follows:

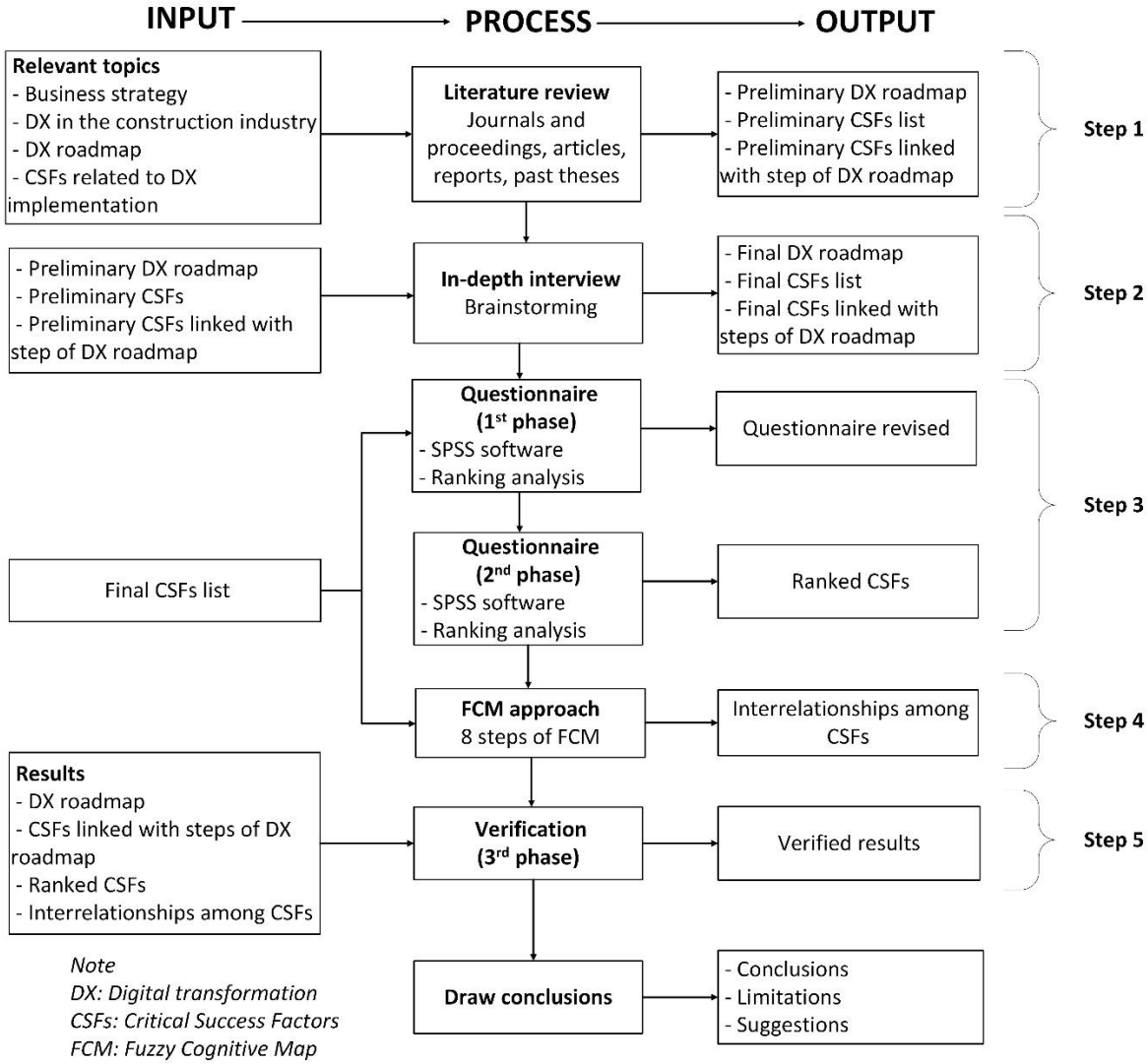

Figure 1-1. Proposed research framework

(1) Step 1: Literature review

(a) *Input:* relevant topics consist of business strategy, DX in the construction industry, DX roadmap and CSFs related to DX implementation.

(b) *Process:* literature review from journal, proceedings, articles, reports and past theses.

(c) *Output:* the outputs of this step are preliminary DX roadmap, preliminary CSF list, and preliminary CSFs linked with step of DX roadmap.

(2) Step 2: Defining final CSFs and DX roadmap

(a) *Input:* Results from step 1 are used as input for this step.

(b) *Process:* in-depth interviews with experts are organized.

(c) *Output:* the output of this step is the final DX roadmap, the final CSF list and the final CSFs linked with each step of DX roadmap.

(3) Step 3: Ranking the CSFs

(a) *Input:* the final CSF list from step 2 is used as input for the third step.

(b) *Process:* reliability test analysis and ranking analysis are applied to check internal consistency and rank the final CSF list.

(c) *Output:* the output of step 3 is ranked CSFs.

(4) Step 4: Analyzing interrelationship among CSFs

(a) *Input:* the final CSF list from step 2 is used as input for this step.

(b) *Process:* 8 steps of Fuzzy Cognitive Map (FCM) approach are deployed to explore the relationship among the CSFs.

(c) *Output:* FCM which contains the relationship among factors is the output of this step.

(5) Step 5: Verifying the results

(a) *Input:* results from step 2, step 3 and step 4 are the input of the final step.

(b) *Process:* in-depth interview with experts is processed to verify the research results.

(c) *Output:* verified results from step 2, step 3 and step 4 are the output of this step.

1.6 Research results

DX implementation roadmap for construction contractors, CSFs linked with steps of DX roadmap, the ranked CSFs related to DX adoption of the contractors and FCM which present the interrelationship among the factors are the results of the study. A detailed DX implementation roadmap is developed. A list of CSFs regarding DX implementation in the construction industry is defined and CSFs are linked with

each step of DX roadmap. FCM includes the relationship weights among the factors and the interdependence is visualized via a map diagram. Ranked graph indices between the factors are also represented in FCM.

1.7 Research contributions

This research provides construction contractors with a strategy map to implement DX successfully. Besides, this research can assist the contractors in terms of identifying the CSFs linked with DX roadmap when they plan to implement DX into their business. Moreover, the relationship analysis among the factors can help contractors to have a thorough knowledge and detailed view regarding the success factors of the DX process. This helps contractors to distribute their limited resources wisely and reduce time and cost when applying DX. By defining the right and reasonable DX roadmap and CSFs, it can help contractors to keep going on the right track and reduce the chance of failure in their business transformation.

Chapter 2

LITERATURE REVIEW

This chapter reviews the basic knowledge, former studies and theories related to this research. It is divided into six sections. The first section provides the fundamental concept of business strategy. The next section discusses basic knowledge about digital transformation (DX) and DX roadmap. The definition of Critical Success Factors (CSFs) affecting the implementation of DX in the construction industry is examined in the third unit. The ranking analysis technique is presented in the fourth section and the Fuzzy Cognitive Map (FCM) is explained in the fifth section. Finally, the research gap is composed in the sixth section.

2.1 Business strategy

2.1.1 Definition of business strategy

Business Strategy is a strategic roadmap or a series of deliberate choices made by entrepreneurs to attain specific business objectives. It serves as a comprehensive plan implemented by a company's management to establish a competitive position in the market, sustain operations, satisfy customers, and accomplish the desired goals of the business (Business Jargons, 2021). International Institute for Management Development (2021) defined Business Strategy as a well-defined framework consisting of plans, actions, and goals that delineate how a business intends to compete within a specific market or markets, offering a product or range of products or services. A strategy encompasses an organization's overarching objectives and outlines the means by which it aims to accomplish them. It serves as a roadmap that guides the organization towards realizing its defined vision (Heubel, 2021).

Business Strategy is a meticulously crafted and adaptable blueprint intended to achieve the goal of (1) achieving effectiveness; (2) perceiving and utilizing opportunities; (3) mobilizing resources; (4) securing an advantageous position; (5)

meeting challenges and threats; (6) directing efforts and behavior and (7) gaining command over the situation (Business Jargons, 2021). Different definitions of Business Strategy are summarized in Table 2-1.

Table 2-1. Definitions of Business Strategy

Definitions of Business Strategy	Sources
Business strategy can be defined as the deliberate actions and decisions undertaken by entrepreneurs to attain specific business objectives.	Business Jargons (2021)
A business strategy is a well-defined framework consisting of a set of plans, actions, and goals that delineate how a business intends to establish its competitive position in a specific market or markets, offering a particular product or range of products and services.	International Institute for Management Development (2021)
A business strategy delineates the strategic plan aimed at accomplishing the vision and predetermined objectives of an organization. It serves as a guiding force for decision-making processes, enabling the company to enhance its financial stability within a competitive market environment.	Heubel (2021)

2.1.2 Levels of business strategy

Strategies are commonly employed at three distinct levels: (1) the corporate level; (2) the business level and (3) the functional level (Business Jargons, 2021; Heubel, 2021). Figure 2-1 illustrates the level of Business Strategy.

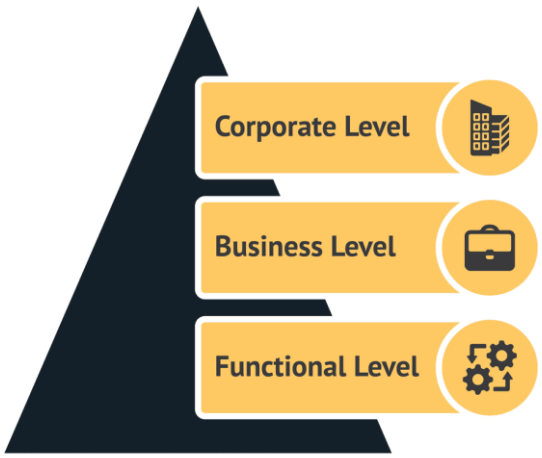

Figure 2-1. Levels of Business Strategy (Heubel, 2021)

All three levels collectively constitute the strategic framework of an organization are presented in detail below (Business Jargons, 2021; Heubel, 2021):

(1) Corporate level: Corporate level strategies refer to the strategic plans devised by top management in an organization. These strategies have a profound impact on the long-term performance of the company and shape the mission and vision statements.

(2) Business level: Business level strategies focus on a specific business. It is developed by the general managers. At this level, the objectives and vision are translated into tangible strategies that dictate how a business will position itself and compete within the market.

(3) Functional level: Functional level strategies are crafted by first-line managers or supervisors within an organization. These strategies entail decision-making at the operational level, specifically in functional areas such as marketing, production, human resources, research and development, finance, and more.

2.1.3 Steps to develop a business strategy

To implement Business Strategy successfully, it is crucial to create a comprehensive plan. MacDonald (2022) outlined straightforward procedures to assist organizations in implementing a successful business strategy:

(1) Gather the facts: organizations should assess past performance or the current situation by conducting a thorough review. An effective tool for this process is the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. Internally, organizations should focus on identifying their strengths and weaknesses, while externally, they should examine opportunities and threats posed by external factors.

(2) Develop a vision statement: this stage involves outlining the future trajectory of the business and its medium to long-term goals.

(3) Develop a mission statement: this focuses on short-term mission to realize the long-term vision. It also outlines its primary objectives.

(4) Identify strategic objectives: this step is geared towards establishing a comprehensive set of objectives that encompass all aspects of the business. It highlights the priorities and the plans to make sure the organization's vision and mission are delivered successfully.

(5) Tactical plans: in this stage, the strategic objectives are broken down into more specific and actionable plans. These plans encompass the actions to be taken by various departments and functions within the organization.

(6) Performance management: regularly reviewing objectives and action plans is crucial to ensure that organizations remain on track towards achieving their overarching goals. Managing and monitoring an entire strategy is a challenging and intricate undertaking. It requires organizations to capture the relevant information, plan, prioritize, etc.

A business strategy holds significant importance as it bridges the gap between the mission statement's idealism and the practical decision-making processes in day-

to-day operations. To develop an effective business strategy, it is essential to have a comprehensive understanding of the business, its products, the market, and the objectives. Regardless of size or stage of operation, every successful business requires a well-defined business strategy to concentrate its efforts and allocate resources efficiently (MasterClass staff, 2021).

2.2 Digital transformation

2.2.1 Definition of digital transformation

According to The Enterprisers Project (2016), Digital Transformation (DX) entails incorporating digital technology into every aspect of a business, leading to fundamental shifts in operational methods and value delivery to customers. DX involves a fundamental reevaluation of how an organization utilizes technology, people, and processes to explore new business models and generate additional revenue streams. It is motivated by shifts in customer expectations regarding products and services (Boulton, 2021). According to Salesforce (2021), DX can be defined as the utilization of digital technologies to establish novel or adapt existing business processes, culture, and customer experiences in order to address evolving business and market demands. Meanwhile, i-SCOOP (2021b) described DX more comprehensively. They said DX involves a strategic and phased integration of digital technologies, processes, and competencies across all levels and functions within an organization, industry, or ecosystem. This integration drives cultural, organizational, and operational changes to facilitate a smarter and more effective approach to digital transformation. Different definitions of DX are presented in Table 2-2.

Table 2-2. Definitions of DX

Definitions of DX	Source
DX entails incorporating digital technology into every aspect of a business, leading to fundamental shifts in operational methods and value delivery to customers.	(The Enterprisers Project, 2016)

Definitions of DX	Source
DX involves a fundamental reevaluation of how an organization utilizes technology, people, and processes to explore new business models and generate additional revenue streams. It is motivated by shifts in customer expectations regarding products and services.	(Boulton, 2021)
DX is the utilization of digital technologies to establish novel or adapt existing business processes, culture, and customer experiences in order to address evolving business and market demands.	(Salesforce, 2021)
DX involves a strategic and phased integration of digital technologies, processes, and competencies across all levels and functions within an organization, industry, or ecosystem.	(i-SCOOP, 2021b)

A conceptual exploration of how technology affects our society is carried out by Stolterman & Fors in 2004. The authors of the paper undertake an exploration and present a research standpoint that challenges uncritical acceptance of information technology. Their position is founded on an empirical and theoretical comprehension of the evolving technology, referred to as digital transformation. They emphasize the significance of embracing aesthetic experience as a central methodological concept within this context (Stolterman & Fors, 2004).

DX goes beyond technology and encompasses strategic thinking and innovative mindsets. It necessitates businesses to enhance their strategic mindset more significantly than their Information Technology (IT) infrastructure (D. Rogers, 2016). Companies worldwide are undertaking digital transformation initiatives as they face the imperative to enhance business processes, cultivate new capabilities, and establish innovative business models (i-SCOOP, 2021a). The contemporary digital transformation landscape for businesses can be categorized into five domains, those

are (1) customers, (2) competition, (3) data, (4) innovation and (5) value (D. Rogers, 2016). Figure 2-2 shows five domains of DX. The details of the five domains of DX are presented below (D. Rogers, 2016):

(1) Customers: digital technologies have revolutionized the way we connect with customers and generate value. Customers now wield greater influence through their communications and reviews, and their active participation has emerged as a pivotal driver of business success.

(2) Competition: digital technologies reshape our perspective on competition. It is no longer limited to rival companies within our industry; we now contend with organizations outside our industry that attract customers through their innovative digital offerings.

(3) Data: digital technologies have revolutionized our perception of data. In the past, data acquisition was costly and storage was complex. However, in today's landscape, data is being generated at an unprecedented pace, not only by companies but by individuals as well. Additionally, cloud-based storage systems have become affordable, easily accessible, and user-friendly. The major challenge now lies in transforming the vast amount of data into valuable insights and information.

(4) Innovation: digital technologies are also revolutionizing the approach to business innovation. Previously, innovation was a costly and high-risk endeavor. Testing new ideas was challenging and came with substantial expenses. However, with the advent of digital technologies, continuous testing and experimentation have become feasible, allowing businesses to explore new concepts in ways that were previously unimaginable.

(5) Value: digital technologies enable us to adopt a fresh perspective on understanding and generating value for customers. The evolving preferences of customers necessitate agile responses, as our competitors are continually identifying new opportunities that our customers may

value. It is crucial to consistently push the boundaries in order to discover the next source of customer value.

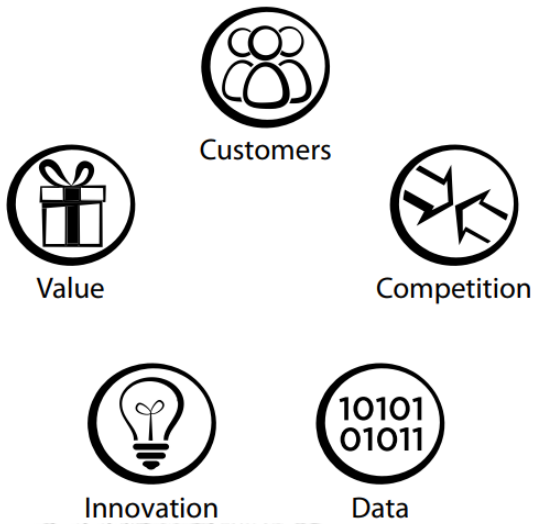

Figure 2-2. Five domains of DX (D. Rogers, 2016)

Due to the COVID-19 pandemic, remote work and reduced in-person interactions have made digital solutions indispensable for customer outreach and support. Angevine et al. (2021) ut forward six fundamental components that can assist industrial companies in formulating a robust digital strategy and extracting maximum value from digitization. Figure 2-3 illustrates these building blocks.

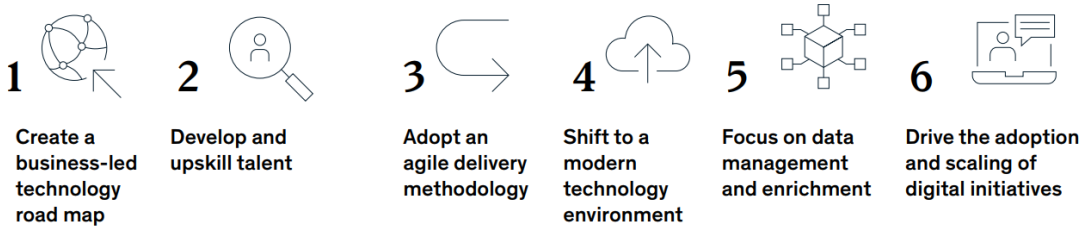

Figure 2-3. Building blocks of digital transformation (Angevine et al., 2021)

The details of the above six building blocks are presented below:

(1) Creating a business-led technology road map: formulating and aligning a digital vision for the organization while consistently considering the ramifications for distributors.

(2) Developing and upskilling talent: identifying strategies and talent requirements to address any existing gaps: developing new organizational structures to facilitate the integration of digital talent and harnessing digital learning programs, technology, and external resources to nurture talent.

(3) Adopting an agile delivery methodology: conducting swift digital campaign testing and implementing revisions based on field-derived insights.

(4) Shifting to a modern technology environment: developing innovative technology solutions that encompass various areas, such as front-end interfaces, commerce backbone services, and integration architecture.

(5) Focusing on data management and enrichment: taking data-related considerations into account when formulating strategic roadmaps, including assessing architecture requirements and identifying specific use cases that can leverage analytics for maximum benefit.

(6) Driving the adoption and scaling of digital initiatives: scale is changed across the organization, with a focus on product, service, commercial strategy and execution; and customer service and transactions.

In order to gain insights into the challenges and prospects related to the utilization of social and digital business, Kane et al. (2015) conducted a survey involving over 4,800 business executives, managers, and analysts from organizations across the globe. The findings indicated that mature digital businesses prioritize the integration of digital technologies to transform their operations. On the other hand, less mature digital businesses primarily concentrate on addressing specific business issues through the application of individual digital technologies. Below are highlights of their findings:

(1) The level of digital maturity is propelled by the implementation of an effective digital strategy.
(2) The potency of a digital transformation (DX) strategy is determined by its breadth and targeted goals.
(3) Evolving digital organizations cultivate the necessary skills to actualize their strategic objectives.
(4) Employees exhibit a strong inclination to work for organizations recognized as digital frontrunners.
(5) Embracing risk-taking has become an ingrained cultural norm.
(6) The digital agenda is steered by top-level leadership within the organization.

There are several research works related to DX strategy and DX of business. Matt et al. (2015) suggested four key dimensions of DX strategy, those are (1) use of technologies, (2) changes in value creation, (3) structural changes and (4) financial aspects. The relationship between these four key dimensions is illustrated in Figure 2-4. A case research of twenty large companies in North America and Europe across different industries is conducted by Andal-Ancion et al. (2003) to explore the impact of emerging information technologies on industry and value chains and their potential for transformation. The researchers proposed ten key drivers to assist companies in identifying the most suitable strategy for their specific context. These ten drivers are divided into three categories and is presented in Figure 2-5.

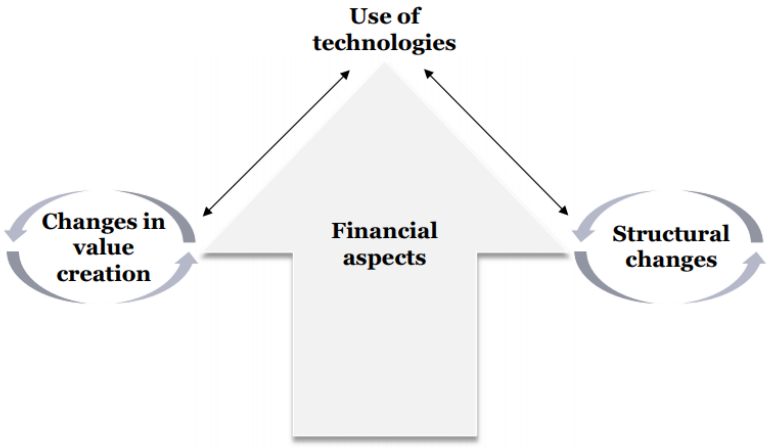

Figure 2-4. Balancing four transformational dimensions (Matt et al., 2015)

The 10 Drivers of New Information Technologies (NIT)

Type of Driver	Driver
Inherent characteristics of product or service	1. Information intensity
	2. Customizability
	3. Electronic deliverability
	4. Aggregation effects
Interactions between company and its customers	5. Search costs
	6. Real-time interface
	7. Contracting risk
Interactions between company and its partners and competitors	8. Network effects
	9. Standardization benefits
	10. Missing competencies

Figure 2-5. Ten drivers of new Information Technologies (Andal-Ancion et al., 2003)

Schwertner (2017) discussed the potential opportunities for DX in businesses, highlighting the various changes that arise from the implementation of digital technology across all aspects of the organization. They discussed some technical aspects of digital business transformation, such as mobile technology, cloud computing, Data Analysis, Big Data, The Internet of things, etc. To help managers in shaping and executing their organizations' DX strategies., Ismail et al. (2017) synthesized and analyzed previous studies regarding business-level DX. They provided fresh perspectives on the positioning of DX and shed light on the defining

attributes that differentiate DX from earlier technology-driven transformations. Figure 2-6 displays the literature synthesis framework used by Ismail et al. (2017) to discover DX strategy for business.

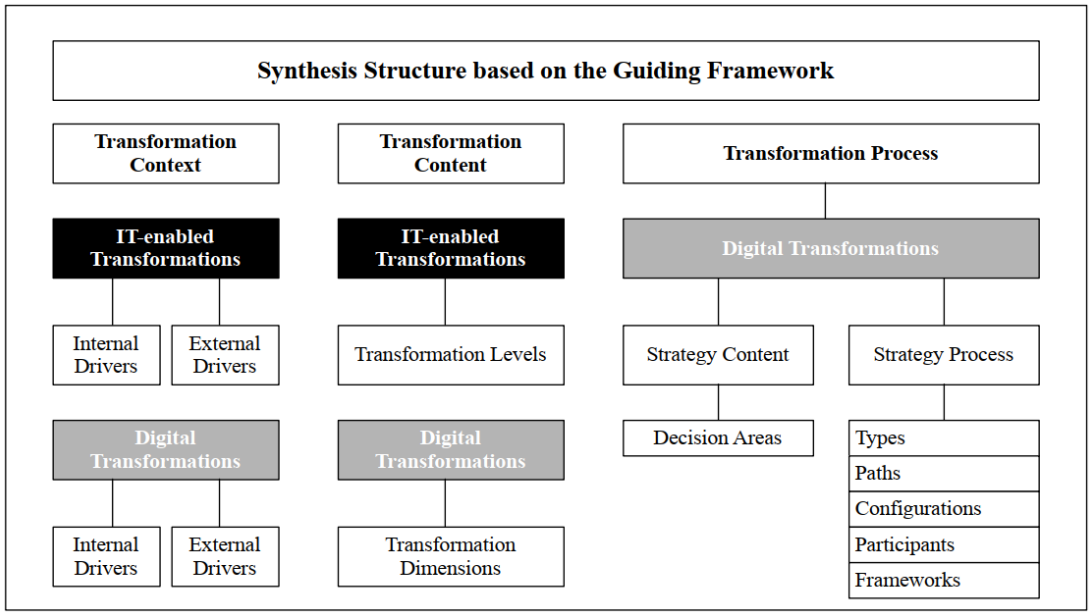

Figure 2-6. Literature synthesis framework (Ismail et al., 2017)

2.2.2 DX in the construction industry

The construction industry is one of the world's largest industrial employers and also one of the oldest industries in the world. A decade ago, the construction industry lagged behind in terms of adopting new technologies and implementing innovation strategies. However, over the past century, a significant revolution has unfolded within the construction sector. The incorporation of numerous advanced technologies into the industry is compelling the construction sector to reevaluate traditional practices and embrace the opportunities presented by new technologies (Palos, 2021). As construction requires many moving parts and partners, more companies are embracing DX to coordinate their people and streamline business operations (Merrill, 2021). According to Shapiro et al. (2019), the construction industry is poised for a digital transformation. Confronted with issues pertaining to project

efficiency, persistent safety concerns, and stagnant labor productivity, the industry's sluggish adoption of new technologies has reached a critical turning point.

Only a limited number of engineering and construction companies have fully harnessed the advantages of digital technologies. The construction industry faces specific characteristics that present significant challenges in the context of digital transformation: (1) Fragmentation, (2) Lack of replication, (3) Transience and (4) Decentralization (Koeleman et al., 2019). To help overcoming this drawback, Koeleman et al. (2019) suggested five practices that can assist engineering and construction (E&C) companies in transitioning beyond isolated pilot projects and unlocking the full value of digital technologies throughout their entire organizations. Those are:

(1) Prioritize resolving pain points rather than merely implementing IT solutions.
(2) Implement digital use cases that foster collaboration.
(3) Re-skill and restructure engineering teams to adapt to DX.
(4) Adjust project baselines to capture value effectively.
(5) Establish connections between projects to unlock broader impact across the entire organization.

DX topic in the construction industry is incipient and nascent. There are very few research works related to DX implementation in the construction industry. Previous research works usually focus on specific technologies like Building Information Modeling (BIM) or drones, virtual reality (VR), augmented reality (AR), etc. Khosrowshahi and Arayici (2012) identified and examined the challenges and obstacles associated with Building Information Modeling (BIM) implementation in the UK construction industry. They gained a comprehensive understanding of BIM adoption and devised strategies and recommendations specifically tailored for the successful implementation of BIM in the UK construction sector. The roadmap is

shown in Figure 2-7. Migilinskas et al. (2013) also analyzed BIM adoption by reviewing the the advantages, challenges, and issues related to the practical implementation of BIM. The researchers provided valuable recommendations for the future utilization and application of BIM.

Regarding drones technology, Zaychenko et al. (2018) conducted a thorough examination of the efficacy of integrating modern digital technologies, specifically unmanned aerial vehicles (drones) equipped with laser scanning systems and automatic positioning systems, into the construction industry. Their findings suggested that drones can be effectively utilized in various industries that involve geographically dispersed objects. However, the users need to care about the disadvantages and risks associated with using drones.

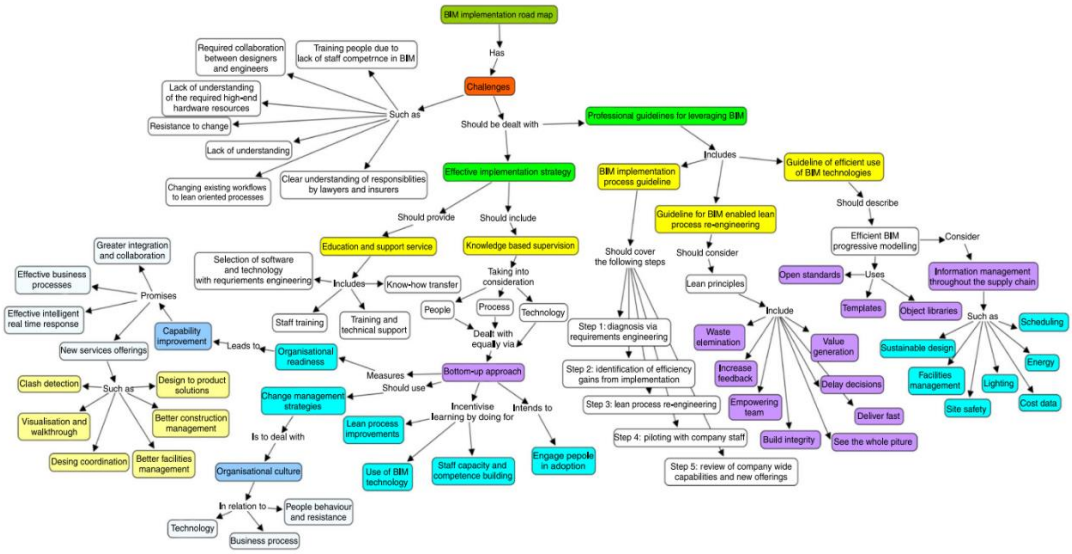

Figure 2-7. BIM implementation concept map as a roadmap for UK construction industry (Khosrowshahi & Arayici, 2012)

The construction industry is on the verge of significant transformation driven by innovations and digital technologies (Koscheyev et al., 2019). DX necessitates modifying processes and adopting new resources that leverage the potential of data to enhance communication, efficiency, productivity, and safety. Embracing DX can enable construction firms to achieve profitable growth in a fiercely competitive

industry while also addressing workforce-related challenges (Shapiro et al., 2019). The primary challenge for DX in the construction industry lies in transitioning from business models centered around physical products to those focused on information, digital products, data, and intellectual business models. Additionally, the construction industry faces competition from other engineering disciplines in terms of leading the integration of the digital realm with material aspects (Klinc & Turk, 2019). Despite evident advantages of DX, numerous construction companies are utilizing digital technologies in a fragmented manner, resulting in their failure to fully leverage the benefits associated with their implementation (Koscheyev et al., 2019).

Ezeokoli et al. (2016) examined the perception of construction professionals and the extent of DX in the Nigeria construction industry by conducting questionnaire survey. Figure 2-8 shows the key drivers of DX in the construction industry according to their research. They also revealed the threats against DX in the Nigeria construction industry. They suggested that the construction firms should form alliances with other firms either within or outside the industry that has attained formal digital transformation to help overcome the skill related problems.

Drivers	Frequency of Occurrence					(∑F)	∑Fx	Mean	RII	Rank
	5	4	3	2	1					
Generation of new revenue, revenue growth and profitability	24	36	8	12	0	80	312	3.90	0.78	7th
Customer satisfaction	28	36	12	3	1	80	327	4.09	0.82	5th
Increase in operational efficiency, convenience and achieve high- quality technical standard	35	25	11	9	0	80	326	4.08	0.82	6th
Increase business agility	43	17	11	8	1	80	333	4.16	0.83	4th
Increase employee productivity	44	24	12	0	0	80	352	4.40	0.88	2nd
Gain competitive advantage in order to stay relevant in a crowded and ever-changing market place	28	44	8	0	0	80	340	4.25	0.85	3rd
Reduce the burden of data storage and management	43	37	0	0	0	80	363	4.54	0.91	1st
(5)Critical (4)Very important (3)Somewhat important (2)Not very important (1)Not at all important										

Figure 2-8. Drivers for DX (Ezeokoli et al., 2016)

Linderoth et al. (2018) conducted a study using a combination of individual and focus group interviews to examine the dynamics among four key actors in the construction industry: architects, clients, contractors, and consultants. The research focused on understanding how these actors influence industry characteristics and explored the opportunities for digital transformation (DX) through the adoption and

utilization of BIM. The attributes of the industry, the focus on practical day-to-day action and lacking competencies from heterogeneous clients are barriers to DX adoption. Construction companies often encounter difficulties when attempting to restructure their organizational framework to fully capitalize on the adoption and implementation of BIM. Therefore, Ahn et al. (2016) investigated the transformation strategies employed by contractors to effectively adopt and implement BIM in significant construction projects. The researchers presented a comprehensive framework and organizational transformation strategies that can assist contractors in maximizing the potential benefits of BIM adoption.

Ernstsen et al. (2021) conducted a study involving interviews with construction professionals in the UK, which led to the identification of three prominent visions for digital transformation (DX) within the construction sector. These visions include (1) efficient construction, (2) user-data-driven built environment and (3) value-driven computational design. Figure 2-9 illustrates the various technologies emphasized by each vision and how they are influenced and interconnected with technology, business, and policy discourses. Prior research has also highlighted the critical role of innovation champions who shape the future by presenting compelling narratives or visions and influencing other stakeholders.

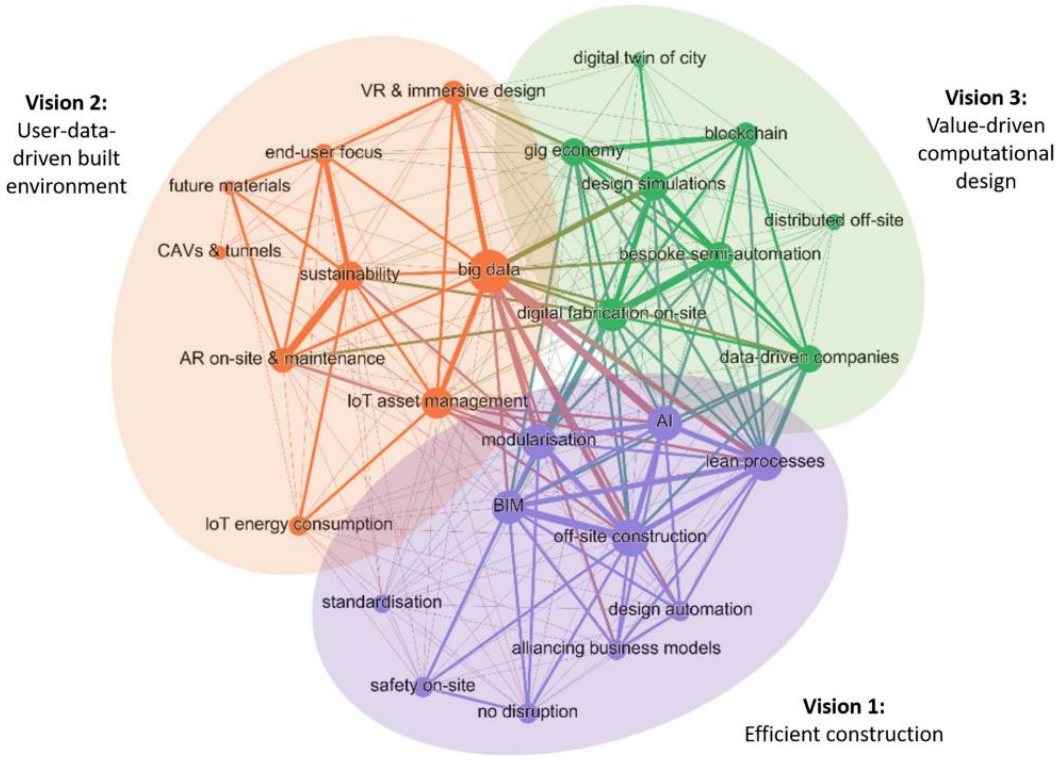

Figure 2-9. Three visions for DX (Ernstsen et al., 2021)

2.2.3 DX roadmap

As explained in Chapter 1, a roadmap can be described as a visual representation of a strategic plan that outlines a specific goal or desired outcome. It encompasses the significant steps or milestones necessary to achieve that objective (Aha! Labs Inc., 2022; ProductPlan, 2022). Zaoui and Souissi (2020) conducted a literature review to grasp the concept of digital transformation roadmaps and identify various proposed approaches and frameworks in this domain. Their goal is to stimulate discussion about how to digitize a firm and to enhance our vision with current road maps to create a different method than digital transformation. Figure 2-10 represents the roadmap to the DX of business models with the variousphases and activities (Schallmo et al., 2018). It includes five phases which are (1) Digital Reality, (2) Digital Ambition, (3) Digital Potential, (4) Digital Fit And (5) Digital Implementation.

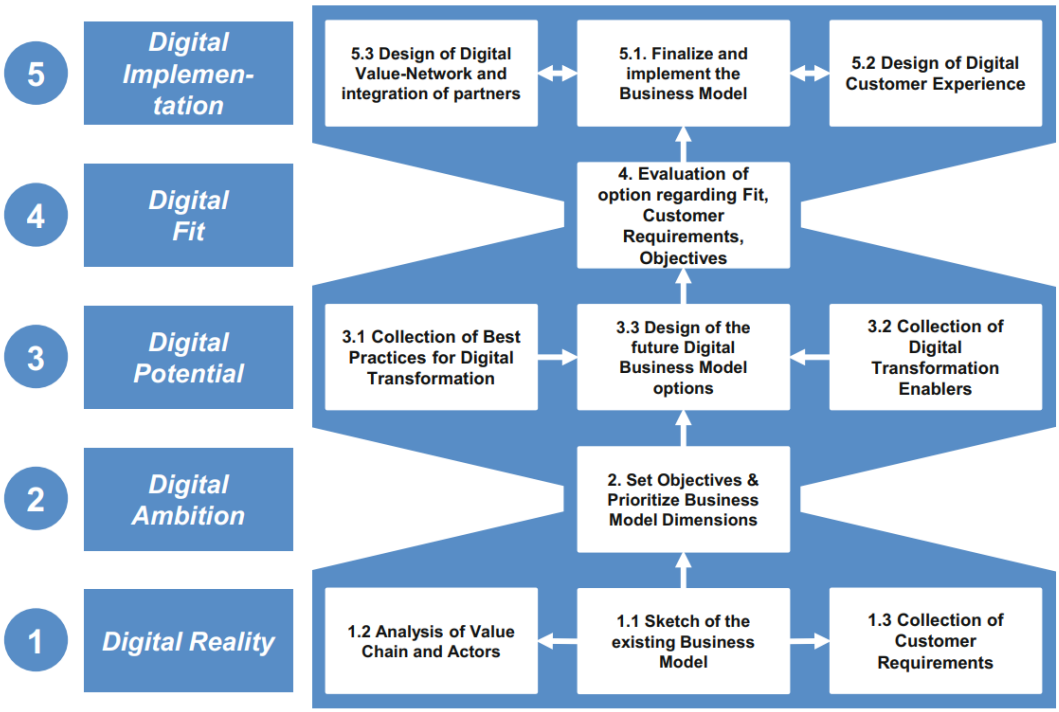

Figure 2-10. Roadmap to the DX of business models (Schallmo et al., 2018)

Issa et al. (2018) introduced a framework to evaluate and guide DX and Industry 4.0 implementations. Based on this, businesses can create their own roadmap to improve their success of adoption of DX and Industrt 4.0. In our research, roadmap is developed for construction contractors to implement DX into their business. Detailed steps of DX roadmap are presented in Chapter 3.

2.3 Critical success factors

Ronald (1961) initially introduced the concept of utilizing Critical Success Factors (CSFs) to address business challenges. However, Rockart (1979) is credited with pioneering a research methodology specifically designed for identifying CSFs. Rockart (1979) defined CSFs as "The limited number of areas in which results if they are satisfactory, will ensure successful competitive performance for the organization. They are the few key areas where things must go right for the business to flourish. If results in these areas are not adequate, the organization's efforts for the period will

be less than desired." Rockart (1979) also concluded that CSFs are "areas of activity that should receive constant and careful attention from management."

According to Janse (2019), CSFs can be described as indicators that signify the opportunities, activities, or conditions necessary to accomplish a specific objective within a project or mission. CSFs differ per organization and reflect current and future objectives. CSFs represent crucial and essential high-level objectives that a business must achieve. Identifying critical success factors in business involves more than a singular project; it necessitates a comprehensive cultural shift and transformation (Goggin, 2021). CSFs refer to distinct elements or areas of action that require focused attention and successful implementation by a business, team, or department in order to achieve their strategic objectives. Effective execution of these critical success factors is expected to yield favorable outcomes and generate significant value for the business (Center for Management & Organization Effectiveness, 2021). Table 2-3 summarizes definitions of CSFs from different sources.

Table 2-3. Definitions of CSFs

Definitions of CSFs	Sources
The specific areas that, if results in those areas are satisfactory, will lead to successful competitive performance for the organization. These CSFs represent the key focal points where success is crucial for the overall prosperity and growth of the business.	Rockart (1979)
Indicators that signify the opportunities, activities, or conditions necessary to accomplish a specific objective within a project or mission.	Janse (2019)
Crucial and essential high-level objectives that a business must achieve.	Goggin (2021)
Specific elements or action areas a business, team, or department must focus on and successfully implement	Center for Management &

Definitions of CSFs	Sources
to reach its strategic objectives.	Organization Effectiveness (2021)

Rockart (1979) identified four main types of CSFs, which are: (1) Industry factors, (2) Environmental factors, (3) Strategic factors and (4) Temporal factors. CSFs provide a means to monitor and evaluate the progress made in attaining strategic goals. They serve as metrics or indicators that help assess the advancement and effectiveness of the organization in accomplishing its desired objectives. Moreover, it helps to fulfill your organization's mission (MindTools, 2021). According to Rockart (1979), CSFs contribute to the progress and enhance the value of organizational processes by highlighting criteria that can impede or facilitate the achievement of specific goals. He emphasized the significance of CSFs in the strategic planning process and stressed the importance of identifying and leveraging the unique characteristics of a company to attain a competitive advantage.

There is some research related to CSFs in the construction industry. However, in terms of DX implementation, there is a lack of previous research works that try to discover and analyze CSFs for DX adoption. Leidecker and Bruno (1984) primarily concentrated on defining and exploring the concept of CSFs as inputs to be incorporated into the environmental analysis, resource analysis, and strategy evaluation stages of the strategic planning or strategy development process. Three factors may be responsible for issues regarding failure to obtain full value from deploying construction technology at Engineering and Construction (E&C) firms are revealed by Blanco et al. (2017). Those factors are (1) Insufficient commitment, (2) Difficulties with the company-wide rollout and (3) A lack of compatibility with legacy systems. From these factors, Koscheyev et al. (2019) identified three key factors that can potentially contribute to the effective implementation of the digital transformation (DX) strategy within a construction organization. These are (1) Adherence, (2) Declaration of value to employees and (3) Compatibility.

A research was conducted by Morakanyane et al. (2020) to understand what organizations do to bring successful DX. They came up with a list of seven success factors and twenty-three subfactors illustrated in Figure 2-11. These success factors serve as the foundational steps for constructing a DX framework that organizations aiming to embark on successful DX journeys can adopt. Holotiuk and Beimborn (2017) introduced CSFs for digital business strategy, which lay the groundwork for establishing a digital business model. Based on a structured review of twenty-one industry reports, they found eight generic dimensions with a total of forty CSFs for digital business strategy. The analytic hierarchy process is adopted by Chua et al. (1999) to determine the relative importance of success-related factors regarding the project objectives of budget, schedule and quality. A total of sixty-seven factors associated with success are categorized into four primary project aspects, namely, project characteristics, contractual arrangements, interactive processes and project participants. Their result is shown in Table 2-4.

Tsai et al. (2014) developed a questionnaire survey that included 123 influencing factors to evaluate the adoption of Building Information Modeling (BIM) at the organizational level within the architecture, engineering, and construction industry. Eighty key factors out of the 123 influencing factors were obtained by ranking analysis. Fifty-eight CSFs are derived from eighty key factors by further data analysis. Among the fifty-eight CSFs, the top two crucial factors in the adoption of BIM are “support from top management” and “functionality” of BIM tools. Ozorhon and Karahan (2017) investigated the CSFs of BIM implementation in developing countries where BIM is new to the construction industry. Among examined sixteen CSFs for BIM implementation, the three most significant factors are (1) availability of qualified staff, (2) effective leadership, and (3) availability of information and technology. Table 2-5 presents these sixteen CSFs.

	FACTORS	No. of Attributes	Presence Strength		
			W	M	S
1	**DETERMINE DIGITAL TRIGGER**	**16**	**6**	**3**	**7**
1.1	*Know the type of Triggers*	2	0	0	2
1.2	*Know the type of Inducers*	14	6	3	5
2	**CULTIVATE DIGITAL CULTURE**	**28**	**5**	**4**	**19**
2.1	*Ensure Shared Conceptualization of Digital Transformation*	7	0	1	6
2.2	*Exhibit Strong Organizational Leadership Traits*	10	1	1	8
2.3	*Adopt Good Governance Practices*	11	4	2	5
3	**DEVELOP DIGITAL VISION**	**16**	**0**	**4**	**12**
3.1	*Carry out Digital Present Awareness*	3	0	2	1
3.2	*Formulate Digital Future*	5	0	1	4
3.3	*Develop Digital Strategy*	2	0	0	2
3.4	*Establish a Digital Communication Strategy*	6	0	1	5
4	**DETERMINE DIGITAL DRIVERS**	**50**	**9**	**5**	**36**
4.1	*Determine Digital Technologies to Leverage*	12	4	0	8
4.2	*Determine Skill & Capabilities Required*	5	0	0	5
4.3	*Determine Other Resources Impacting Required*	3	1	1	1
4.4	*Exhibit Strong Digital Leadership Traits*	30	4	4	22
5	**ESTABLISH DIGITAL ORGANIZATION**	**15**	**4**	**3**	**8**
5.1	*Establish Digital Innovation Functional Structure*	12	4	3	5
5.2	*Create Digital Innovation Implementation Structure*	3	0	0	3
6	**DETERMINE TRANSFORMED AREAS**	**11**	**0**	**1**	**10**
6.1	*Determine Transformation Opportunities*	4	0	0	4
6.2	*Identify Target Transforming Areas*	4	0	0	4
6.3	*Building DX Initiatives*	3	0	1	2
7	**DETERMINE IMPACTS**	**38**	**1**	**5**	**32**
7.1	*Define Expected Customer Facing Impacts*	4	0	1	3
7.2	*Determine Realized Customer Facing Impacts*	9	0	1	8
7.3	*Define Expected Organizational Facing Impacts*	4	0	1	3
7.4	*Determine Realized Organization Facing Impacts*	17	1	2	14
7.5	*Determine Measure Of Impacts*	4	0	0	4

Figure 2-11. Attributes presence strength in DX success factors

(Morakanyane et al., 2020)

Table 2-4. Ranking of CSFs for different project objectives (Chua et al., 1999)

Success-related factor (1)	Av (2)	Organization Type O1 (3)	O2 (4)	O3 (5)	O4 (6)	Av (7)	Organization Type O1 (8)	O2 (9)	O3 (10)	O4 (11)
	Budget performance					Schedule performance				
Adequacy of plans and specifications	1	1	1	1	3	1	2	3	2	—
Constructability	2	3	4	2	—	2	4	5	1	—
Economic risks	3	4	—	3	2	—	—	—	—	—
Realistic obligations/clear objectives	3	—	2	—	5	6	—	1	3	3
PM competency	5	2	—	—	4	4	1	—	—	2
Adequacy of funding	6	5	—	—	—	—	—	—	—	5
Budget updates	7	—	3	—	—	—	—	—	—	—
PM commitment and involvement	8	—	—	—	—	3	5	—	—	—
Contractual motivation/incentives	9	—	5	—	—	5	3	—	—	4
Risk identification and allocation	10	—	—	3	—	—	—	—	—	—
Political risks	—	—	—	4	—	—	—	—	—	—
PM authority	—	—	—	—	1	—	—	—	—	1
Schedule updates	—	—	—	—	—	7	—	2	5	—
Construction control meetings	—	—	—	—	—	8	—	4	—	—
Capability of contractor key person	—	—	—	—	—	9	—	—	—	—
Site inspections	—	—	—	—	—	10	—	—	—	—
Pioneering status	—	—	—	—	—	—	—	—	4	—
	Quality performance					Overall				
Adequacy of plans and specifications	1	1	2	1	4	1	2	1	2	4
Constructability	2	3	3	3	5	2	3	3	1	—
Site inspections	3	4	4	2	—	7	—	—	5	—
PM commitment and involvement	4	—	—	—	—	3	5	—	—	—
Realistic obligations/clear objectives	5	—	1	5	2	4	—	2	3	3
PM competency	6	2	—	—	3	4	1	—	—	2
Construction control meetings	7	—	5	—	—	8	—	—	—	—
Formal communication (construction)	8	—	—	—	—	9	—	—	—	—
Capability of contractor key person	9	—	—	—	—	—	—	—	—	—
Design control meetings	10	—	—	—	—	—	—	—	—	—
Contractual motivation/incentives	10	—	—	—	—	6	4	4	—	—
Pioneering status	—	5	—	—	—	—	—	—	—	—
PM authority	—	—	—	—	1	—	—	—	—	1
Supplier level of service	—	—	—	3	—	—	—	—	4	—
Economic risks	—	—	—	—	—	9	—	—	—	5

Note: Av = average rank; O1 = consultant; O2 = contractor; O3 = client; O4 = project management.

Table 2-5. Descriptive statistics of CSFs (Ozorhon & Karahan, 2017)

Identifier	Variable	Mean	SD	Variance
V3	Availability of qualified staff	4.198	0.781	0.610
V9	Effective leadership	4.161	0.928	0.861
V1	Availability of information and technology	4.148	0.760	0.578
V10	Coordination among project parties	4.148	0.838	0.703
V4	Training of employees	4.062	0.780	0.609
V7	Experience level within the firm	3.926	0.771	0.594
V2	Availability of financial resources	3.889	0.935	0.875
V8	BIM policy of the company	3.815	1.174	1.378
V12	Client requirement	3.630	1.018	1.036
V13	Awareness level of the industry	3.605	1.008	1.017
V6	Supportive organizational culture	3.494	0.963	0.928
V15	Appropriate legislation	3.494	1.097	1.203
V14	Knowledge sharing within the industry	3.482	0.989	0.978
V11	Project size	3.346	1.063	1.129
V5	Consulting	3.333	0.922	0.850
V16	Governmental schemes	2.926	1.191	1.419

D. W. Chan et al. (2019) investigated the CSFs for implementing BIM in the architecture, engineering, and construction industry in Hong Kong. Their study

employed a structured empirical questionnaire survey and expert interviews. The researchers identified that the most influential factors for success were the client's acceptance of BIM projects, establishment of an appropriate organizational structure to support the BIM system within the company, and financial assistance from the government to facilitate the implementation of the BIM system. Their CSFs are shown in Table 2-6.

Table 2-6. CSFs for BIM implementation in Hong Kong (D. W. Chan et al., 2019)

CSFs for BIM implementation	All respondents		Client group		Consultant group		Contractor group	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Client's acceptance with BIM projects	4.57	1	4.57	1	4.50	1	4.61	1
Organizational structure to support BIM system within company	4.11	2	4.07	2	4.17	2	4.11	3
Financial support from the government to set up BIM system	3.91	3	3.79	3	3.33	9	4.39	2
BIM standards for the industry	3.86	4	3.64	4	4.00	3	3.94	6
BIM training programs	3.80	5	3.50	8	3.83	4	4.00	4
Information-sharing protocols	3.77	6	3.43	9	3.83	4	4.00	4
Competent technical support team within company	3.73	7	3.57	6	3.58	7	3.94	6
Professional BIM design team within company	3.50	8	3.64	4	3.75	6	3.22	10
Promotion from top management	3.50	8	3.57	6	3.50	8	3.44	9
Willingness of staff to learn new technology	3.43	10	3.07	11	3.17	10	3.89	8
Continuous investment/upgrade for BIM system within company	3.16	11	3.29	10	3.17	10	3.06	11

Regarding BIM-inclusive construction contracts, Dao and Chen (2021) proposed a set of CSFs and a contractual framework aimed at facilitating the effective adoption of BIM for construction projects in Vietnam. Table 2-7 presents the relationship between ten success factors and BIM legal issues which are defined in their research.

Table 2-7. CSFs and BIM legal issues (Dao & Chen, 2021)

	BIM legal issues										
Success factors	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Citing protocols and BIM standards	√		√	√	√	√	√	√	√		√
Expressing clauses on the status	√	√	√	√	√	√	√	√	√	√	√
Specifying the content of the agreements	√	√	√	√	√	√	√		√		√
Specifying the duties and power of information management	√	√	√	√	√	√	√				√
Integrated project insurance	√		√		√						
Insurance on data integrity and reliability	√	√	√		√		√				
Specifying the roles and responsibilities of each party	√	√	√	√	√	√	√	√	√	√	√
Specifying the ownership of the BIM data	√	√		√		√	√	√	√		
Procedures on information sharing and appointment	√	√	√	√	√	√	√				√
Specifying the content of the BIM model via CDEs	√	√	√	√	√	√	√				

2.4 Ranking analysis

2.4.1 Reliability test

Cronbach's alpha, α, (or coefficient alpha), was developed by Cronbach (1951). It measures reliability or internal consistency. It shows how closely related a set of items are as a group. Cronbach's alpha test is used to see if multiple-question Likert scale surveys are reliable. These questions evaluate underlying factors or traits that may not be readily observable, such as an individual's conscientiousness, neuroticism, or openness (Stephanie, 2021). Cronbach's alpha is a function of the number of test items and the average inter-correlation between them (UCLA: Statistical Consulting Group, 2021). The formula for Cronbach's alpha is presented in equation (2-1):

$$\alpha = \frac{N.\bar{c}}{\bar{v}+(N-1).\bar{c}} \qquad (2\text{-}1)$$

Where,

α = Cronbach's alpha or coefficient alpha

N = the number of items

$\bar{c}$ = average covariance between item-pairs

$\bar{v}$ = average variance

A rule of thumb for interpreting alpha for Likert scale questions (Streiner, 2003) is shown in Table 2-8.

Table 2-8. Score of Cronbach's alpha (Streiner, 2003)

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.7 \leq \alpha < 0.9$	Good
$0.6 \leq \alpha < 0.7$	Acceptable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

In general, a score of more than 0.6 is usually acceptable (Streiner, 2003). However, some authors suggest higher values of 0.90 to 0.95 (Stephanie, 2021). Nunnally (1978) suggested that a reliability of 0.70 or higher should suffice for the research. Furthermore, Zhang (2006) proposed that a reliability of 0.60 or higher indicates acceptable and good internal consistency reliability. In this research, Cronbach's alpha score of 0.6 or higher is acceptable.

Alaloul et al. (2020) employed a reliability test in their research to identify the primary challenges that impede the implementation of the Fourth Industrial Revolution (Industry 4.0). According to the study's findings, the key factor influencing the successful implementation of the Industry 4.0 is a combination of social and technical factors. Besides, two large surveys among Hong Kong construction industry participants were used to study and measure the level of change in sustainable culture by Robin and Poon (2009). Cronbach's alpha is also used in this research to test the reliability.

2.4.2 Mean scores and standard deviation

In mathematics and statistics, the notion of mean holds significant importance. In a set of numbers, the mean represents the average or most frequently occurring value. It serves as a measure of the central tendency of a probability distribution, alongside the median and mode in statistics. The term

"expected value" is used interchangeably to refer to the mean (CFI, 2021). The mean can be computed using various methods, with two of the most commonly used approaches being:

(1) *Arithmetic mean* is calculated by summing up all the values in a collection of numbers and then dividing the total by the count of numbers in that collection. It is calculated in the equation (2-2):

$$\text{Arithmetic mean} = \frac{x_1+x_2+\cdots+x_n}{n} \qquad (2\text{-}2)$$

(2) *Geometric mean* is determined by taking the *n*th root of the product of all the numbers in a collection. The formula for calculating the geometric mean is expressed as equation (2-3):

$$\text{Geometric mean} = \sqrt[n]{x_1 \times x_2 \times \ldots \times x_n} \qquad (2\text{-}3)$$

Arithmetic mean is used in this research to calculate mean scores.

The *standard deviation* is a statistical measure that computes the square root of the variance. It assesses the extent of dispersion within a dataset in relation to its mean value. If the data points are farther away from the mean, the data set exhibits a larger variance. As a result, the standard deviation increases when the data is more dispersed or spread out (Marshall, 2021). The formula for standard deviation is shown in equation (2-4):

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \qquad (2\text{-}4)$$

Where,

x_i = value of the i^{th} point in the data set

$\bar{x}$ = the mean value of the data set

n = the number of the data points in the data set

If multiple factors possess identical mean scores, the factors with lower standard deviations are assigned higher rankings (Tsai et al., 2014). According to the recommendation of Lu et al. (2008), factors with a mean value of 4 or higher on a 5-point Likert scale are regarded as significant factors. Besides, Yuan et al. (2009) established a cutoff point of 3 on the 5-point Likert scale to determine the

significance of factors. In this research, the cutoff point of 3 in the 5-point Likert scale is used to analyze the pilot survey responses and filter the factors used for large-scale survey and FCM.

Ametepey et al. (2015) identified the barriers to the successful adoption of sustainable construction in Ghana's construction industry, as well as strategies for overcoming them. The factors are evaluated and ranked according to their mean scores. Furthermore, D. W. Chan et al. (2011) arranged the individual risk factors associated with target cost contracts and guaranteed maximum price contracts in descending order based on the mean scores. This study assists key project stakeholders in identifying high-risk factors and implementing suitable risk mitigation measures.

In ranking analysis, both absolute value and relative value are used to assess and compare the positions or ranks of different entities or variables. While absolute value focuses on the actual numerical value assigned to entities in a ranking, relative value emphasizes the relative positions or ranks of entities within the ranking. Both approaches provide valuable insights for comparing and evaluating entities based on specific criteria or measures. The choice between absolute value and relative value depends on the specific requirements and objectives of the ranking analysis (Kirchsteiger, 1998).

2.4.3 One-way ANOVA test

T-tests and analysis of variance (ANOVA) are commonly employed statistical techniques for comparing group means. The independent sample t-test is suitable for comparing means between two groups, whereas the oneway ANOVA (Analysis of Variance) allows for comparisons among multiple groups. In ANOVA, the F statistic is used to test whether all groups have the same mean (Park, 2009). A comparison between two groups that are independent of each other and meet the assumptions of normality and equal variance can be made by utilizing a Student's t-test to

examine the disparities in their means. Nonetheless, it is necessary to assess whether there are variations in the means among three or more groups. It is widely acknowledged that the primary analytical approach for this scenario is the one-way analysis of variance (ANOVA) (Kim, 2017).

One-way ANOVA is employed to examine whether there exist noteworthy disparities in the means of three or more groups. It aids in ascertaining if there is a statistically significant variation in the dependent variable across various levels of an independent variable. In other words, it allows for the comparison of means between multiple groups to assess if there are significant differences among them. In one-way ANOVA test, the null hypothesis (H_o) in the comparison of different groups would be "there are no differences in the means of different groups" and the alternative hypothesis (H_1) is "there are significant differences in the means of different groups" (Corder & Foreman, 2014; Kim, 2017). The procedure for applying one-way ANOVA test is illustrated in Figure 2-12.

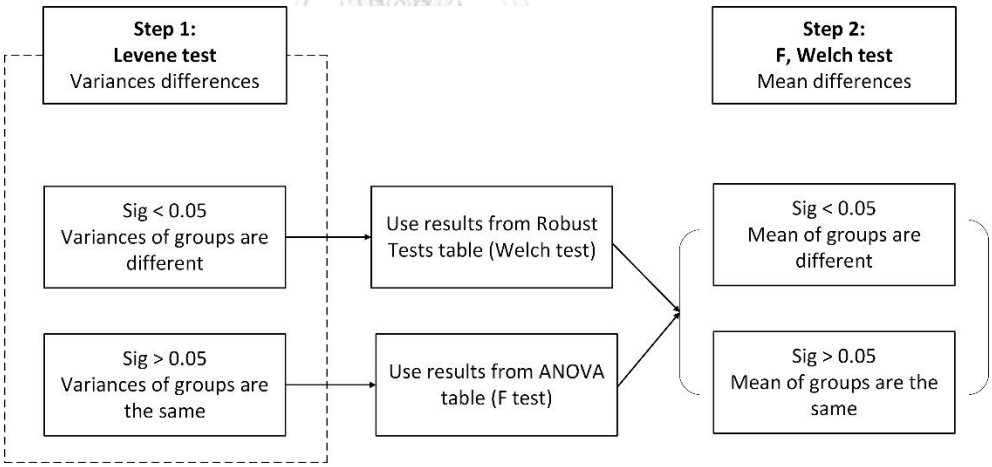

Figure 2-12. Procedure of one-way ANOVA test (Pham, 2023)

2.5 Fuzzy Cognitive Map

Fuzzy Cognitive Map (FCM) is developed by Kosko (1986) based on Cognitive Map. FCM is an approach utilized to organize and evaluate the challenges encountered by individuals and organizations (Kwahk & Kim, 1999). FCM incorporates key elements of fuzzy logic and Artificial Neural Networks (ANN) to visually depict the

logical connections within a specific domain of interest (Cosma et al., 2017). FCM has the capability to represent the cause-and-effect relationships among variables in a system that exhibits dynamic behavior (Papakostas et al., 2008). FCM provides a valuable method for simulating and consolidating the collective human perceptions contributed by multiple evaluators (Khan & Quaddus, 2004). One advantage of FCM over ANN is its transparency in capturing the causal dependencies within the domain of interest, making it easily interpretable by humans (Cosma et al., 2017).

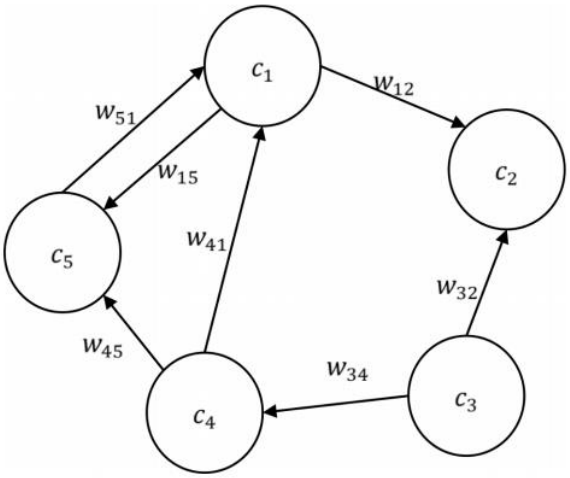

Figure 2-13. FCM's basic concept (Kosko, 1986; Mei et al., 2013)

Figure 2-13 illustrates the simple FCM network where C_i is the status value of concept i. The status value can be expressed numerically within the range of 0 to 1. The relation degree (weight), w_{ij}, indicates the influence degree from cause concept C_i to effect concept C_j, which can be expressed numerically within the range of -1 to 1. If $w_{ij} > 0$, there is positive causality between concepts C_i and C_j. It means if C_i increases (decreases), then C_j increases (decreases). If $w_{ij} < 0$, there is negative causality between concepts C_i and C_j. It means if C_i increases (decreases), then C_j decreases (increases). If $w_{ij} = 0$, there is no relationship between concepts C_i and C_j (Kosko, 1986; Mei et al., 2013; Papageorgiou et al., 2009).

Given an FCM with some concepts C_i (i = 1, 2, ..., n), the iterative computation can be used to determine the status value of each concept at various time periods (Carvalho, 2013; Dickerson & Kosko, 1994; Glykas, 2013):

$$A_i^{t+1} = f\left(\sum_{j=1}^{n} A_j^t . w_{ji}\right) \quad (2\text{-}5)$$

where, A_i^t is the the status value of concept C_i at period t; A_j^t is the status value of concept C_j at period t; A_i^{t+1} is the the status value of concept C_i at period t+1; w_{ji} is the corresponding fuzzy relation degree between C_j and C_i; and f is a threshold function that transforms the computing result into the interval [0,1].

In this research, status value C_i will be CSFs of DX implementation in the construction industry while w_{ij} represents the relationship between the factors. This research focuses specifically on the relationship w_{ij} of the factors regarding the successful adoption of DX in the construction industry. The application procedure of the suggested methodology can be outlined as follows (Büyüközkan et al., 2019):

(1) **Step 1:** Acquire the evaluation criteria.

CSFs obtained from step 2 in the research framework are used as evaluation criteria.

(2) **Step 2:** Determine the linguistic term.

During this stage, a linguistic term set or evaluation scale is established, and the computational steps involve the utilization of Triangular Fuzzy Numbers (TFNs). The used scale in this research is given in Table 2-9 and membership functions of relation degree are shown in Figure 2-14 (Chen & Chiu, 2021).

Table 2-9. Linguistic term scale with nine linguistic variables

Linguistic terms	TFNs	Cod
Very high positive	(1.00, 1.00,	VHP
High positive relation	(1.00, 0.75,	HP
Medium positive	(0.75, 0.50,	MP
Low positive relation	(0.50, 0.25,	LP
No relation, zero	(0.25, 0.00,	Z

Linguistic terms		TFNs	Cod
Low	negative	(0.00, -0.25,	LN
Medium	negative	(-0.25, -	MN
High	negative	(-0.50, -	HN
Very high	negative	(-0.75, -	VHN

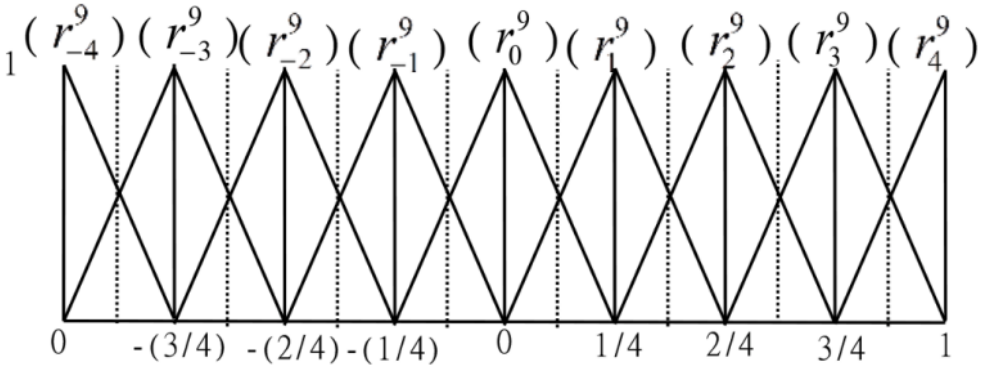

Figure 2-14. Membership functions for the degree of relationship with nine linguistic variables (Chen & Chiu, 2021)

(3) **Step 3:** Obtain evaluations of experts.

The relationships between the criteria are evaluated by experts using Table 2-9. Through this process, n evaluation matrices are generated, with n representing the number of experts.

(4) **Step 4:** Aggregate the evaluation matrices.

In this step, separate decision-making evaluations are combined. The weights derived from multiple experts are aggregated to generate the overall linguistic weights and the group adjacency matrix (Soner et al., 2015). In order to integrate individual matrices into one FCM, different techniques are used by different researchers (Chen & Chiu, 2021; Mazzuto et al., 2018; Soner et al., 2015; Stylios et al., 1998). Each relation degree between two nodes on individual FCMs is a set of triangular fuzzy numbers with lower value, middle value and upper value (see Table 2-9). For aggregating lower value and upper value, it is suggested that min and max operations can be used to integrate individual matrices, in which

researchers do not need to assign credibility weights for different experts (Stylios et al., 1998).

Selecting the aggregation method of experts' opinions depends on the researcher's view (Habibi et al., 2015). For aggregating middle value of each relation degree, Kosko (1986) proposed the average aggregation method as a means of consolidating a substantial number of FCMs by arithmetic mean. In other works, geometric mean is proposed rather than simple arithmetic mean (Cheng et al., 2009; Hsu & Chen, 2007; Wu & Fang, 2011). In summary, min and max operations are used for aggregating lower value and upper value while arithmetic mean is used for aggregating middle value of each relation degree.

Given that there are n experts who assign a relationship degree w_{ij}, between the nodes C_i and C_j in each individual FCM. Each relation degree w_{ij} is a set of triangular fuzzy numbers with lower value l_{ij}, middle value m_{ij} and upper value u_{ij}, i = 1, 2, 3, ..., n (n = number of experts). Then the aggregated relation degree $\widetilde{w}_{ij}^{agg}$ is defined as below:

$$\widetilde{w}_{ij}^{agg} = \left(l_{ij}^{agg}, m_{ij}^{agg}, u_{ij}^{agg}\right) \qquad (2\text{-}6)$$

where,

$$l_{ij}^{agg} = min\{l\} = min(l_1, l_2, l_3, \dots, l_n) \qquad (2\text{-}7)$$

$$m_{ij}^{agg} = \frac{1}{n}\sum(m_1, m_2, m_3, \dots, m_n) \qquad (2\text{-}8)$$

$$u_{ij}^{agg} = max\{u\} = max(u_1, u_2, u_3, \dots, u_n) \qquad (2\text{-}9)$$

n = number of experts

$\widetilde{w}_{ij}^{agg}$ = aggregated relation degree between the nodes C_i and C_j

l_{ij}^{agg} = lower value in triangular fuzzy numbers set of aggregated relation degree between the nodes C_i and C_j

m_{ij}^{agg} = middle value in triangular fuzzy numbers set of aggregated relation degree between the nodes C_i and C_j

u_{ij}^{agg} = upper value in triangular fuzzy numbers set of aggregated relation degree between the nodes C_i and C_j

(5) **Step 5:** Defuzzify the group-based fuzzy decision matrix

In this step, the triangular fuzzy numbers are converted to crisp number by using center of gravity method (Lin & Lee, 1996). It is shown as below:

$$w_{ij} = \frac{l_{ij}^{agg} + m_{ij}^{agg} + u_{ij}^{agg}}{3} \qquad (2\text{-}10)$$

where, w_{ij} represents defuzzified relation degree between the nodes C_i and C_j.

(6) **Step 6:** Construct the FCM

The FCM structure is depicted by representing the connections and the corresponding weights among the nodes.

(7) **Step 7:** Calculate the graph indices.

The nature of variables in a map is crucial in illustrating the association between a specific variable and other variables. The number of different types of variables in a cognitive map indicates an understanding of the map structure (Özesmi & Özesmi, 2004). There are three types of variables: (1) transmitter variables (tails), (2) receiver variables (heads) and (3) ordinary variables (means) (Bougon et al., 1977; Eden et al., 1992; Harary et al., 1965). These variables are defined by their outdegree od(v_i) and indegree id(v_i) and centrality c_i or total degree td(v_i).

Outdegree $od(C_i)$ is calculated as the summation of the absolute values in a row of the adjacency matrix for a specific variable. This value represents the collective intensity of connections exiting the variable, w_{ij} is the weight of the connection from node C_i to node C_j, where N is the total number of variables:

$$od(C_i) = \sum_{j=1}^{N} \overline{w_{ij}} \qquad (2\text{-}11)$$

Indegree $id(C_i)$ is determined by summing the absolute values of a variable in each column of the adjacency matrix. It represents the total

strength of variables that entering the variable, w_{ji} is the weight of the connection entering node C_i from node C_j, where N is the total number of variables:

$$id(C_i) = \sum_{j=1}^{N} \overline{w_{Ji}} \qquad (2\text{-}12)$$

The total degree or centrality of a variable is calculated by adding its indegree and outdegree values together (Bougon et al., 1977; Eden et al., 1992; Harary et al., 1965):

$$c_i = td(C_i) = od(C_i) + id(C_i) \qquad (2\text{-}13)$$

(8) **Step 8:** Rank the criteria.

Criteria are ranked according to their outdegree, indegree and centrality value.

Büyüközkan et al. (2019) analyzed success factors of DX in aviation industry by using FCM. They assumed these factors were related to each other and analyzed the relationship between them. The constructed FCM of these success factors are presented in Figure 2-15. In other research, Gan et al. (2019) determined how several elements interact to influence the broad use of prefabricated building technologies and intervention techniques to promote prefabrication development based on FCM. The visualization of collective FCM from their work is shown in Figure 2-16.

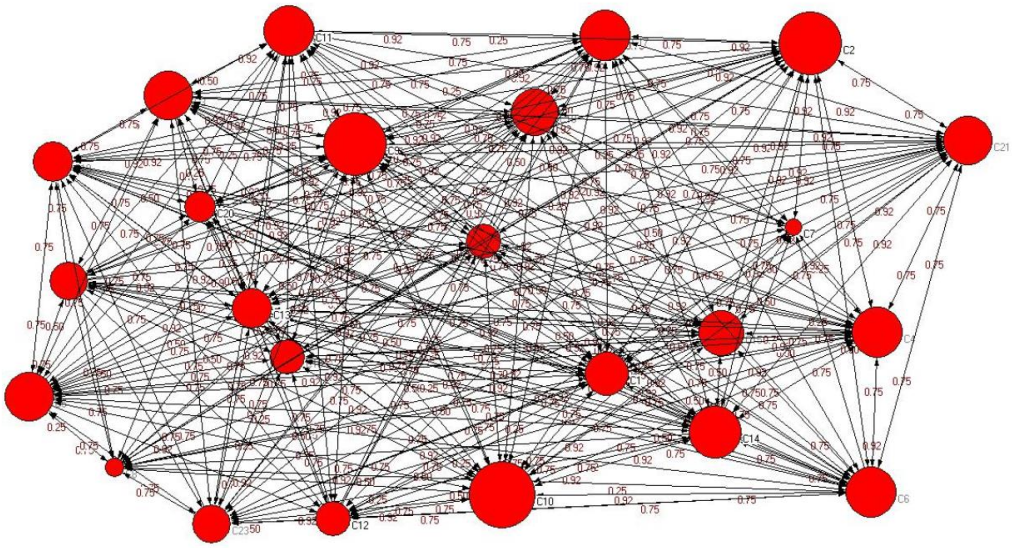

Figure 2-15. FCM of success factors for DX in aviation industry (Büyüközkan et al., 2019)

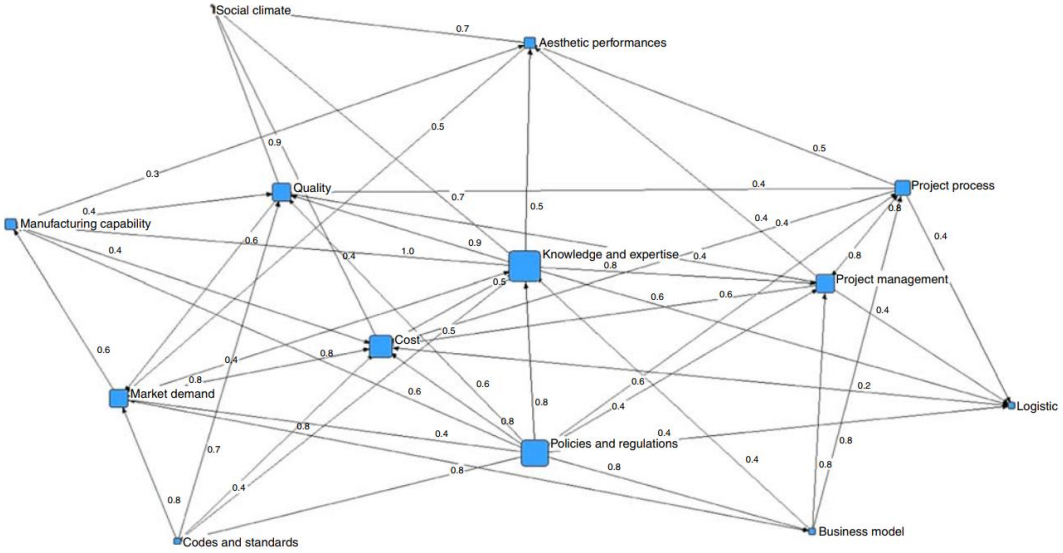

Figure 2-16. The visualization of collective FCM (Gan et al., 2019)

2.6 Research gaps

There is limited research related to DX implementation in the construction industry. In previous research works, researchers usually focus on specific technologies like BIM or AR, VR, drones, etc (D. W. Chan et al., 2019; Khosrowshahi & Arayici, 2012; Migilinskas et al., 2013; Ozorhon & Karahan, 2017; Tsai et al., 2014;

Zaychenko et al., 2018). They do not look at DX as a comprehensive strategy for construction firms. DX encompasses more than just technology; it involves the integration of technology, individuals, and processes to pursue innovative business models and generate new sources of revenue (Boulton, 2021). Moreover, there is some research exploring the CSFs for BIM implementation or DX adoption in construction industry, but they did not discover the relationship among the factors. Only ranking analysis is used in those research to rank the factors (D. W. Chan et al., 2019; Chua et al., 1999; Morakanyane et al., 2020; Ozorhon & Karahan, 2017). This research is designed to fill these research gaps.

2.7 Summary

Definitions of business strategy, general DX, DX in the construction industry and CSFs are presented in this chapter. Previous research works related to these topics are also provided. Details about the reliability test, mean scores, standard deviation and FCM are given. At the end of the chapter, the research gaps are discussed. In the next chapter, detailed steps of the research methodology are described.

Chapter 3

RESEARCH METHODOLOGY

This chapter presents the research methodology to develop roadmap for DX implementation of construction contractor. It also illustrates the step to identify and analyze Critical Success Factors (CSFs) regarding Digital Transformation (DX) of contractors in the construction industry. Besides, the steps to rank the CSFs are shown in detail. Moreover, this chapter illustrates the process of analyzing the relationship among the factors to help contractors in judging the factors that affect DX implementation; therefore, it supports contractors in their decision making in investing in DX at their firms.

3.1 Details of research methodology

The proposed research framework is described in Chapter 1. Table 3-1 summarizes five steps of research methodology. Each step will be presented in detail in the following sections.

Table 3-1. Summary of research methodology

Step	Description	Main techniques	Source of data	Respondents and/or interviewees	Result
1	Literature review	Three stages of literature review	Journal, proceedings, articles, reports, past theses.	No	Chapter 4

Step	Description	Main techniques	Source of data	Respondents and/or interviewees	Result
2	Defining final CSFs and DX roadmap	In-depth interview - Brainstorming	Result from step 1	Yes Expert and Professional group	Chapter 5
3	Ranking CSFs	Questionnaire (1st phase and 2nd phase), SPSS software, ranking analysis, one-way ANOVA test	Result from step 2	Yes Pilot survey Large-scale survey	Chapter 6
4	Analyzing interrelationship among CSFs	Fuzzy Cognitive Map (FCM) approach	Result from step 2	Yes Expert and Professional group	Chapter 7
5	Verification	Questionnaire (3rd phase)	Results from step 2, step 3 and step 4	Yes Expert and Professional group	Chapter 8

3.1.1 Step 1: Literature review

The first step of this research is to examine relevant knowledge from journals and proceedings, articles, reports and past theses by focusing on the following issues:

(a) Definition of business strategy and steps to develop business strategy

(b) Definition of DX and the current status of DX in the construction industry

(c) Definition of roadmap and CSFs related to DX implementation

Three stages of the literature review are conducted to find the preliminary CSF list and preliminary CSFs linked with steps of DX roadmap. The three stages are (1) Literature input, (2) Literature processing and (3) Literature output (Levy & Ellis, 2006) which are illustrated in Figure 3-1.

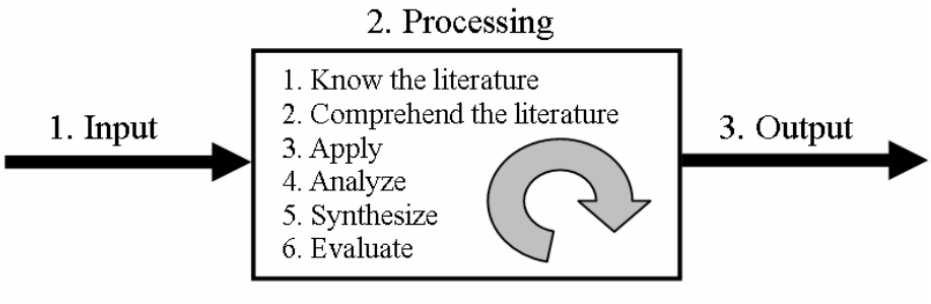

Figure 3-1. Three stages of literature review process (Levy & Ellis, 2006)

The input stage involves searching, identifying, and selecting high-quality and relevant literature. Bloom et al. (1956) outlined a series of consecutive steps that researchers should follow to enhance their ability to convert the raw data obtained from numerous literature sources into a cohesive and effective literature review. Those steps are (1) Know the literature to extract meaningful information from it, (2) Comprehend the literature by summarizing, differentiating, interpreting and contrasting the reported information, (3) Apply the literature by classifying the literature into relevant categories, (4) Analyze the literature by identifying the importance of presented information, (5) Synthesize the literature by assembling the reviewed literature and (6) Evaluate the literature by distinguishing among opinions or theories. The output stage involves transforming the findings from the preceding step into the format of an academic paper (Hart, 2018).

The process of this step is presented in Figure 3-2. Preliminary DX roadmap, preliminary CSF list and preliminary CSFs linked with steps of DX roadmap are the output of this step.

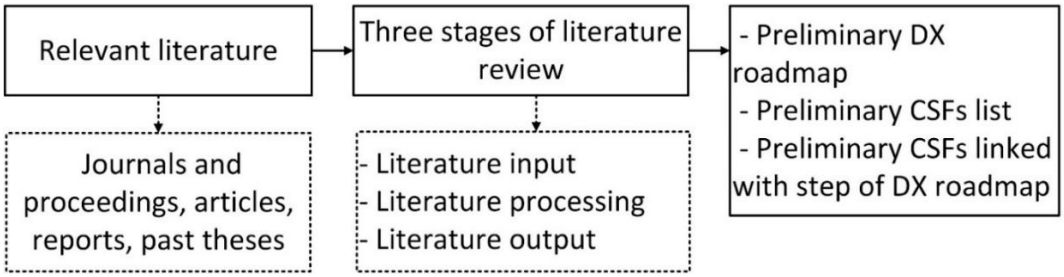

Figure 3-2. Step 1: Literature review

3.1.2 Step 2: Defining final CSFs and DX roadmap

The aim of this step is to define the final DX roadmap, the final CSF list and the final CSFs linked with each step of DX roadmap. A team of experts is consulted via in-depth interview. The preliminary DX roadmap, preliminary CSF list and preliminary CSFs linked with step of DX roadmap are presented to experts and they are asked to add, modify, rename, remove or merge the factors. Moreover, the experts are asked to group the factors into different clusters. Several rounds of personal interview with experts are conducted to finalize the CSFs linked with steps of DX roadmap. The interviews concluded when all the experts reached an agreement on the final CSFs linked with the steps of the DX roadmap. Finally, the final DX roadmap, the final CSF list and the final CSFs linked with each step of DX roadmap are achieved as the results of this step. The process of step 2 is presented in Figure 3-3.

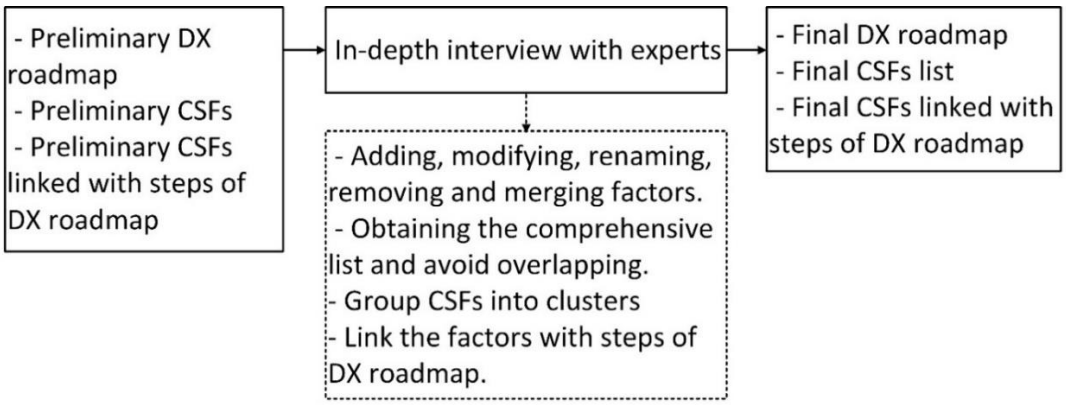

Figure 3-3. Step 2: Defining final CSFs and DX roadmap

The decision to choose a group of four to five experts for the interview in this research on DX implementation for construction contractors was based on several considerations. Firstly, a group of four to five experts provide a reasonable and manageable sample size that allows for in-depth and meaningful insights to be gathered. With a smaller number of experts, it may be challenging to capture a diverse range of perspectives and experiences. Conversely, involving a larger number of experts could lead to data overload and make it difficult to analyze and synthesize the information effectively.

Secondly, the selection of a group of four to five experts strikes a balance between expertise and practicality. Including a sufficient number of experts ensures a breadth of knowledge and experience in digital technologies and DX implementation in the construction industry. These experts can provide valuable insights, informed opinions, and expert recommendations based on their years of experience and expertise. At the same time, having a smaller panel of experts allows for efficient coordination and scheduling of interviews, ensuring a smooth research process.

Lastly, a group of four to five experts allow for robust discussion and validation of findings. By engaging a diverse group of experts, varying viewpoints and perspectives can be examined, leading to a richer analysis of the research data. Additionally, the involvement of multiple experts helps to validate the research findings and enhance the credibility of the research outcomes. Overall, selecting a

group of four to five experts strikes a balance between obtaining valuable insights and managing the practical aspects of the research process. It allows for a comprehensive exploration of the topic while maintaining the feasibility and efficiency of the research study.

In the context of DX implementation for construction contractors, defining the criteria for "success" in critical success factors (CSFs) can be approached from multiple perspectives. Below are some criteria that can be considered when defining success in this research:

1. Business Performance: Success can be measured by improvements in key performance indicators (KPIs) such as increased revenue, higher profit margins, improved project delivery time, enhanced productivity, and increased market share. These metrics reflect the overall success of the construction contractor in achieving their business objectives through DX implementation.

2. Adoption and integration: Success can be evaluated based on the level of adoption and integration of digital technologies within the construction contractor's operations. This includes the extent to which digital tools and processes are embraced, implemented, and integrated seamlessly into various aspects of the contractor's workflow.

3. Return on investment (ROI): Success can be measured by assessing the financial benefits derived from DX implementation. This includes evaluating the cost savings, efficiency gains, and return on investment resulting from the adoption of digital technologies.

4. Organizational transformation: Success can be evaluated based on the degree of organizational transformation achieved through DX implementation. This includes assessing changes in organizational culture, mindset, skills, and capabilities, as well as the ability to adapt to new ways of working and leveraging digital technologies to drive innovation and competitive advantage.

3.1.3 Step 3: Ranking the CSFs

The final CSF list from step 2 is used as input for the third step. Reliability test analysis and ranking analysis are applied to check internal consistency and rank the final CSF list. One-way ANOVA test is applied to check the differences of responses between different types and different sizes of construction firms. The process for step 3 is illustrated in Figure 3-4. The details of the ranking analysis are given in Chapter 2. In summary, ranking analysis has four main steps as follows:

(1) *Step 1:* use Cronbach's alpha to check internal consistency

(2) *Step 2:* summarize the data of respondent's characteristics

(3) *Step 3:* rank the factors by their mean scores and standard deviations

(4) *Step 4:* check the differences of responses between different types and different sizes of construction firms

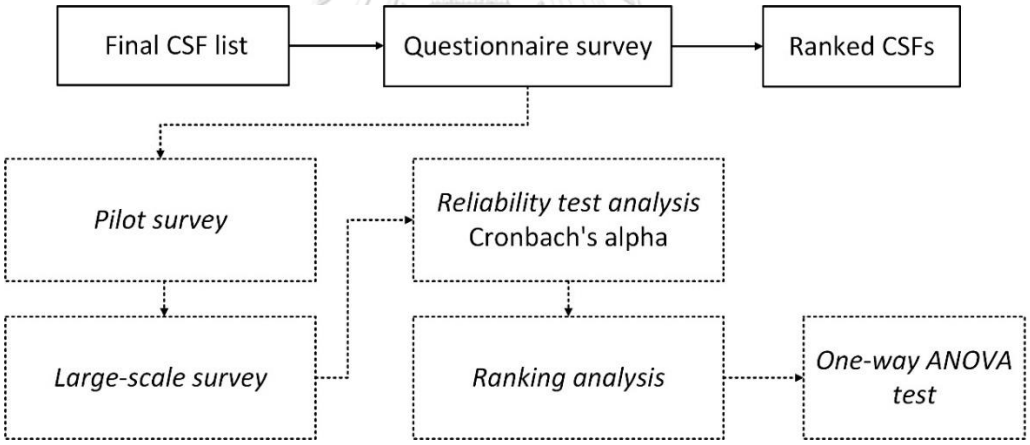

Figure 3-4. Step 3: Ranking CSFs

3.1.4 Step 4: Analyzing interrelationship among CSFs

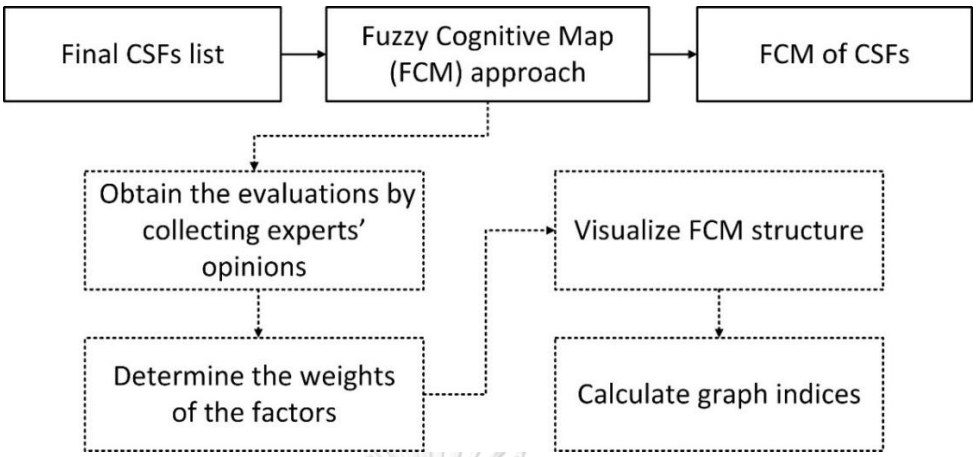

Figure 3-5. Step 4: Analyzing interrelationship among CSFs

This step uses the final CSF list from step 2 as input. Eight steps of Fuzzy Cognitive Map (FCM) are deployed to analyze the interrelationship among the factors. The process for step 4 is shown in Figure 3-5. FCM of CSFs related to DX implementation of contractors is the result of this step. FCM method is presented in detail in Chapter 2. In summary, FCM includes eight steps as follows:

(1) *Step 1:* Obtain the evaluation criteria

(2) *Step 2:* Determine the linguistic term

(3) *Step 3:* Obtain the evaluations of experts

(4) *Step 4:* Aggregate the evaluation matrices

(5) *Step 5:* Defuzzify the group-based fuzzy decision matrix

(6) *Step 6:* Construct the FCM

(7) *Step 7:* Calculate the graph indices

(8) *Step 8:* Rank the criteria

The Fuzzy Cognitive Map (FCM) technique is a suitable approach for analyzing the interrelationship between factors in complex systems like DX implementation. FCM allows for the representation of causal relationships and the capturing of uncertainty and vagueness in expert knowledge. The advantages of using FCM in DX implementation research include its ability to capture the dynamic nature of

relationships and its flexibility in handling subjective and imprecise information. FCM can capture the cognitive thinking process of experts, providing a comprehensive understanding of the factors and their interdependencies.

A study conducted by Ladeira et al. (2019) applied FCM in indentifying and analyzing the determinants of digital entrepreneurship. The study showcased the efficacy of FCM in comprehending the intricate cause-and-effect connections among the factors influencing digital entrepreneurship. Additionally, research by Stach et al. (2005) showed that FCM serves as a highly convenient, straightforward, and potent tool for simulating and analyzing dynamic systems.

Considering the complexity and uncertainty inherent in DX implementation, FCM emerges as a suitable technique for capturing the interrelationships among factors. It enables a holistic analysis and provides valuable insights for decision-making and strategy development.

3.1.5 Step 5: Verifying the results

The aim of this final step is to verify the results. The results from step 2, step 3 and step 4 are used as input for this step. In-depth interviews with experts are conducted via online platform. A team of five experts discuss the results from step 2, step 3 and step 4, rate the satisfaction and give the comments as well as suggestions. The verified results are the output of this step. The process of step 5 is provided in Figure 3-6.

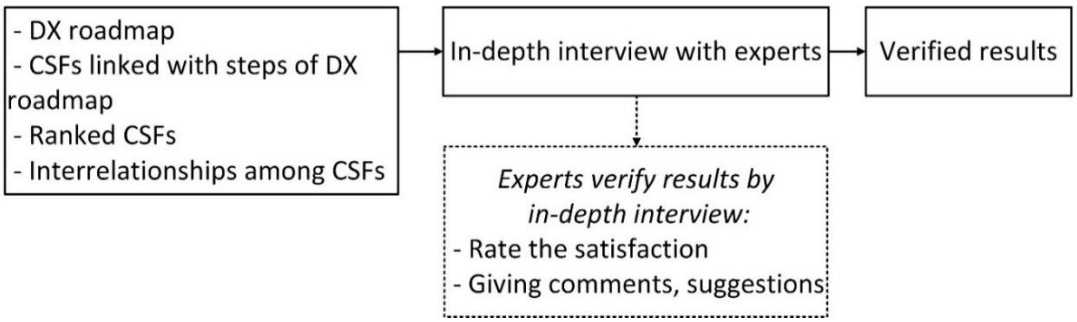

Figure 3-6. Step 5: Verifying the results

3.2 Data collection

Questionnaire survey and in-depth interviews are used in this research to collect the data. Pilot survey and large-scale questionnaires survey are designed to collect data for ranking of CSFs using a 1-5 point Likert scale (1=strongly disagree to 5=strongly agree). Another questionnaires survey is designed to ask a group of experts for evaluating the relationship among the CSFs using triangular fuzzy numbers with nine linguistic variables as presented in section 2.5, Chapter 2. In-depth interviews with experts are applied to finalize the DX roadmap, refine the preliminary CSF list and verify the research results.

3.2.1 Questionnaires survey

(1) Pilot survey: the questionnaire survey is sent out to predefined fourteen respondents who work in the construction industry in Vietnam. Fourteen responses were received. The response rate is one hundred percent. SPSS (Statistical Package for the Social Sciences) software is employed to run the reliability test and ranking analysis.

(2) Large-scale questionnaire survey: the questionnaire survey is sent out to the respondents who work in the construction industry in Vietnam. Eighty-six questionnaire survey forms were sent out. A total of seventy-two responses were received. The response rate is eighty-four percent. SPSS (Statistical Package for the Social Sciences) software is employed to run the reliability test and ranking analysis.

3.2.2 In-depth interviews

(1) Finalizing the DX roadmap interviews: from preliminary DX roadmap provided by researcher, five experts are asked to finalize the DX roadmap.

(2) Defining the CSF list interviews: four experts are asked to add, modify, rename, remove or merge the factors from the preliminary CSF list. Besides, these four experts are also asked to classify the factors into four groups: (a) Strategy &

Vision, (b) People & Culture, (c) Process & Governance and (d) Technology & Capabilities as presented in Chapter 5. They are also asked to associate the CSFs with steps of DX roadmap.

(3) Analyzing the relationship among CSFs interviews: seventeen experts are asked to evaluate the relationship between the CSFs via in-depth interviews. These seventeen experts also include five experts from the previous step.

(4) Verifying research results interviews: five experts are inquired to verify the research results by in-depth interviews. They are asked to give the satisfaction score for the research results as well as comments and suggestions.

3.3 Summary

In this chapter, the detailed research methodology is presented. To accomplish the objectives of the study, there are seven steps of the research methodology including:

(1) Developing DX roadmap from journals and proceedings, articles, reports, past theses and in-depth interviews with experts.

(2) Measuring DX process by using FAHP and other methods to measure DX goals.

(3) Establishing preliminary CSF list from journals and proceedings, articles, reports and past theses.

(4) Defining the finalized CSF list from the preliminary CSF list via in-depth interviews with experts.

(5) Ranking CSFs by using reliabitity test and ranking analysis.

(6) Defining relationship among CSFs by applying FCM method.

(7) Verrifying the results with expert's interviews.

The next chapter provides the details on developing DX roadmap by using literature review and in-depth interviews with experts. The process to measure each DX goals are also presented in the next chapter.

Chapter 4

PRELIMINARY CSFs AND DX ROADMAP

This chapter introduces the first step of the research framework, which involves defining the preliminary DX roadmap, preliminary CSF list, and preliminary CSFs linked with the steps of the DX roadmap. To achieve this, an extensive literature review was conducted across various sources including journals, proceedings, articles, reports, and past theses. The information gathered from these sources informed the development of the preliminary DX roadmap and CSFs, setting the foundation for the subsequent stages of the research.

4.1 Definition of DX roadmap

A roadmap is a visualization of a strategic plan (Aha! Labs Inc., 2022). In another definition, a roadmap is a strategic plan that establishes a specific goal or desired outcome, outlining the significant steps or milestones required to achieve it (ProductPlan, 2022). It is a visual way to quickly communicate a plan or strategy (Roadmunk, 2021). Construction contractors need to have a complete and comprehensive roadmap to implement DX into their business in an efficient and effective way. Every firm has a limited budget and resources. To implement DX successfully, they must allocate their resources wisely and suitably by setting the plan carefully.

The development of the DX roadmap in this research draws upon the insights from business strategy literature (Bunce, 2022; Emmer, 2020; MacDonald, 2022; MasterClass, 2021). The focus of the roadmap is at the organizational level and it is intended to be utilized by various departments within construction contractors. These departments may include design, tender, technical, construction, administration, human resources, finance & accounting, IT, and others. By considering the perspectives of different departments, the DX roadmap aims to provide a

comprehensive framework that guides the implementation of digital transformation throughout the entire organization.

4.2 Preliminary DX roadmap

From literature review, preliminary DX roadmap is developed. The roadmap has two stages which are “before DX implementation” and “during and after DX implementation”. It consists of six steps as shown in Figure 4-1. The details of six steps are as follows:

(1) Step 1 - Current state of contractor and market

In this step, the current state of contractors and the status of the current market are examined. SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is employed to assess and evaluate the internal strengths and weaknesses as well as the external opportunities and threats faced by contractors. To assess the current market, the contractors need to define their potential customers and main competitors. By assessing rightly the current state of the market and their own business, it helps the contractors in defining their goals and plans for DX implementation in step 2 and step 3 of DX roadmap.

(2) Step 2 – Goals

From the current state of contractor and market in step 1, the contractors determine their goals for DX implementation. There are seven referenced DX goals as follows:

- Improving customer experience - The customer experience encompasses the overall perception that customers have of your brand at every stage of their journey. It shapes their impression of your brand and has implications for various factors affecting your bottom line, such as revenue (Bordeaux, 2021).
- Reducing costs - When repetitive, time-consuming operations are automated, they can not only be finished more quickly and cheaply,

but the human effort that was previously put into them can also be transferred to other, more value-adding jobs (Bunce, 2022).

- Increasing revenue - Through the utilization of digital technologies to streamline tasks and processes, businesses can enhance their efficiency and productivity. This increased efficiency allows them to handle a larger volume of clients, leading to an expansion of their customer base and ultimately generating higher revenue (Bunce, 2022).
- Increasing collaboration - Any company's success is a result of the teamwork of the entire enterprise. DX links employees, enabling them to exchange ideas and knowledge and direct their efforts in the direction of your organizational objectives (Bunce, 2022).
- Increasing employee performance - Employee performance pertains to the conduct and job proficiency exhibited by employees within the workplace. It encompasses their behavior, actions, and the level of competence displayed in carrying out their assigned tasks and responsibilities (Donohoe, 2019).
- Increasing compliance - Compliance refers to the extent to which an organization conforms to and follows government regulations, industry standards, and internal policies. It involves ensuring that the organization operates within the legal and ethical boundaries set forth by governing bodies, meets industry-specific requirements, and upholds its own internal guidelines and protocols (Puterbaugh, 2022).
- Improving agility - In order to stay ahead of market trends and competitors, it is crucial to have the ability to adapt to changes. By establishing connections between the people, applications, and information within your organization, you can effectively and quickly adjust your operations to meet new demands and avoid falling

behind. This flexibility allows you to stay responsive and agile in an ever-changing business environment (Bunce, 2022).

(3) Step 3 – Plans

From DX goals in step 2, DX plans are drafted. Plans for contractors to implement DX into their business can be divided into two periods which are short-term (≤ 12 months) and long-term (> 12 months). To design their own DX implementation plans, the contractors need to answer carefully following questions:

- What department is this DX implemented for?
- How to allocate employees for the department?
- Are there training courses about DX for employees?
- How much budget covered for the plan?
- What technologies to invest in? Which providers?

(4) Step 4 – DX implementation

In this step, the contractors implement DX into the department based on plans specified in step 3. The contractors need to stick with the DX plans to get higher chances of success for DX implementation. By following the plans strictly, the contractors can allocate their limited resources reasonably and suitably for their DX journey.

(5) Step 5 – Measure the process

In this step, the score for each goal and overall score of the process are calculated.

(6) Step 6 – Adjust the roadmap

Based on the results of measuring DX goals from step 5, the DX roadmap is adjusted in this step to implement DX for other departments. Step 1, step 2 and step 3 in the DX roadmap are modified to make the roadmap better and more applicable for the next cycle of DX appliance. All the steps of DX roadmap are repeated when the contractors want to implement DX into the specific department. After each cycle of DX implementation, the DX roadmap is improved.

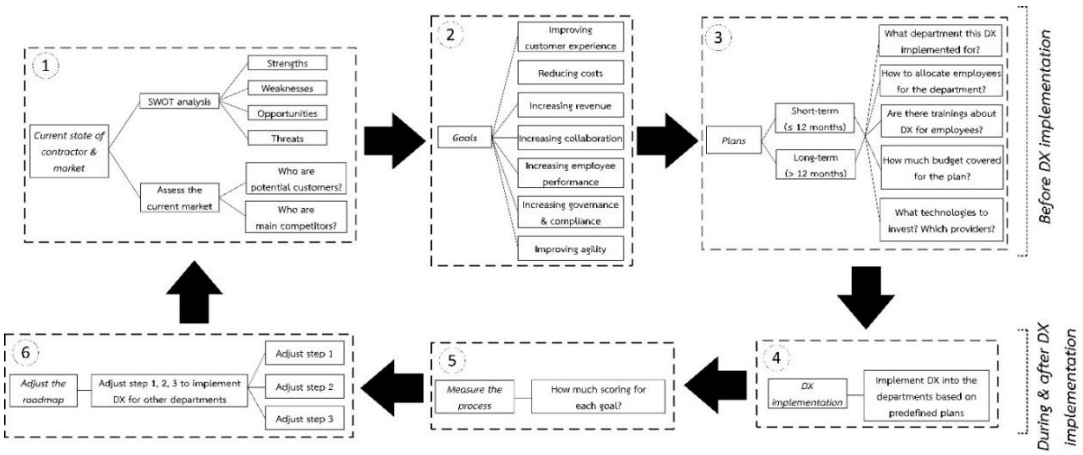

Figure 4-1. Preliminary DX roadmap

4.3 Preliminary CSF list

4.3.1 CSF list from literature review

From the literature review, sixty-nine preliminary CSFs are collected. After scanning, merging, combining and removing duplicated CSFs by researcher, thirty-seven CSFs is achieved and presented in Table 4-1. The description and sources for each factor are also provided.

Table 4-1. CSFs regarding DX implementation for contractors

Code	CSFs	Description	Sources
C1	Determining digital strategy	The strategy describes the why, the what and the how, which are tied to specific, quantified business outcomes.	BCG (2020); Holotiuk and Beimborn (2017); Kane et al. (2015); Vogelsang et al. (2018); Bharadwaj et al. (2013); Boström and Celik (2017); Desmet et al. (2015); Oswald and Kleinemeier (2017); Morakanyane et al. (2020)
C2	Effective monitoring of progress	Establishing clear metrics and targets around processes and	BCG (2020);

Code	CSFs	Description	Sources
		monitoring the progress rigidly.	
C3	Awareness level of the industry	Familiarity of the industry and current level of DX implementation within the industry.	Arayici et al. (2011); Khosrowshahi and Arayici (2012); Autodesk (2002)
C4	Effective leadership	Commitment and approach of the top management to facilitate DX within the organization.	Won et al. (2013); Lee et al. (2015); Jonathan (2020); Tsai et al. (2014)
C5	Willingness of staffs to learn new technology	Enthusiasm of organizational staffs related DX learning and knowledge.	Tsai et al. (2014); Won and Lee (2010); Morlhon et al. (2014); Enegbuma and Ali (2011)
C6	Organizational culture	Existence of an organizational culture to be prone to learning and implementing of innovative technology.	Boström and Celik (2017); Jonathan (2020); Kane et al. (2015); Matt et al. (2015); Oswald and Kleinemeier (2017); Sia et al. (2016); Singh and Hess (2017); Wade (2015); Westerman et al. (2014); Tsai et al. (2014); Enegbuma and Ali (2011); Won and Lee (2010); Ozorhon and Karahan (2017); Arayici and Coates (2012); Khosrowshahi and Arayici (2012); Baiden et al. (2006); Suermann and Issa

Code	CSFs	Description	Sources
			(2009); Jung and Joo (2011); Lee et al. (2015); Succar et al. (2013)
C7	Availability of information technology (IT)	Existence of necessary IT infrastructure within the organization for implementing DX.	Bharadwaj et al. (2013); Boström and Celik (2017); Desmet et al. (2015); Hess et al. (2016); Matt et al. (2015); Sia et al. (2016); Soule et al. (2016); Stief et al. (2016); Wade (2015); Westerman et al. (2014); Bernstein and Pittman (2004); Autodesk (2008); Becerik-Gerber and Rice (2010); Sacks et al. (2010); Azhar (2011); Hanna et al. (2013); Arayici and Coates (2012); Khosrowshahi and Arayici (2012); Boktor et al. (2014); Jonathan (2020); Vogelsang et al. (2018); Morakanyane et al. (2020)
C8	Financial support from the government	Existence of incentive from government in terms of financial support to promote DX.	Tsai et al. (2014); Enegbuma and Ali (2011); Ozorhon and Karahan (2017); Zakaria et al. (2013); Abubakar et al. (2014); Suermann and Issa (2009); Arayici and Coates (2012); Eadie et al. (2013); Succar et al. (2013); Arayici et al. (2011)
C9	DX training programs	The use of training and seminars to equip staffs with useful information	Jonathan (2020); Tsai et al. (2014); Ozorhon and Karahan (2017); Won and Lee (2010);

Code	CSFs	Description	Sources
		and skills to facilitate DX.	Morlhon et al. (2014); Enegbuma and Ali (2011); Suermann and Issa (2009); Jung and Joo (2011); Arayici et al. (2011); Arayici and Coates (2012); Succar et al. (2013); McGraw-Hill (2014)
C10	DX legislation	Existence of DX guidelines, standards, codes, rules, regulations, and roadmaps within the industry.	Tsai et al. (2014); Won and Lee (2010); Morlhon et al. (2014); Enegbuma and Ali (2011); C. Chan (2014); Zakaria et al. (2013); Abubakar et al. (2014); J. Rogers et al. (2015); Yeomans et al. (2006); Redmond et al. (2012); Antón and Díaz (2014); Howard and Björk (2008); Suermann and Issa (2009); Eadie et al. (2013); Succar et al. (2013); Chien et al. (2014); Vogelsang et al. (2018)
C11	Organizational restructuring	Restructure the organization to support DX implementation.	Berman (2012); Hess et al. (2016); Matt et al. (2015); Sia et al. (2016); Wade (2015); Tsai et al. (2014); Morlhon et al. (2014); Won and Lee (2010); Enegbuma and Ali (2011); Ozorhon and Karahan (2017); Morakanyane et al. (2020)
C12	Financial resources of	Ability of the organization to allocate	Manning and Messner (2008); Ganah and John (2013); Tsai et

Code	CSFs	Description	Sources
	organization	sufficient budget for DX implementation.	al. (2014); Bryde et al. (2013); Linderoth (2010); Succar et al. (2013); Won et al. (2013); Holotiuk and Beimborn (2017)
C13	Availability of qualified staff	Existence of competent personnel within the organization.	Berman (2012); Boström and Celik (2017); Kane et al. (2015); Sia et al. (2016); Soule et al. (2016); Wade (2015); Baiden et al. (2006); Suermann and Issa (2009); Arayici et al. (2011); Jung and Joo (2011); Ganah and John (2013); Succar et al. (2013); Won et al. (2013); Chien et al. (2014); Lee et al. (2015); Vogelsang et al. (2018)
C14	Relationships and knowledge sharing with other firms	Existence of a knowledge-sharing and collaborative platform within the industry.	D. Rogers (2016); Vogelsang et al. (2018); Ozorhon and Karahan (2017); Enegbuma and Ali (2011); Baiden et al. (2006); Suermann and Issa (2009); Harding et al. (2014); Hope and Alwan (2012)
C15	Innovate by rapid experimentation	Learn to experiment continuously and effectively, getting real data and real customer feedback, continuously iterating and testing new ideas.	D. Rogers (2016); Kane et al. (2018); Tsai et al. (2014)
C16	Turn data	Develop the clear vision	D. Rogers (2016); Holotiuk and

Code	CSFs	Description	Sources
	into assets	and the growing capability needed to put data to work in the service of innovation and value creation.	Beimborn (2017); Jonathan (2020)
C17	Competent technical support team within the company	Existence of necessary technology infrastructure and staff to augment DX implementation.	Ozorhon and Karahan (2017); Won and Lee (2010); Tsai et al. (2014); Morlhon et al. (2014); Enegbuma and Ali (2011)
C18	Consulting	Receiving consultancy services from specialized firms.	Gu et al. (2007); Isikdag et al. (2009); Suermann and Issa (2009); Khosrowshahi and Arayici (2012)
C19	Commitment of employees	Employees are fully engaged in the process of DX implementation.	Mark (2019); Holotiuk and Beimborn (2017); Tsai et al. (2014)
C20	Harness customer networks	Learn to view customers differently, understanding the dynamic, networked ways in which they interact, both with businesses and with each other, helping them to access, engage, connect and even collaborate with the	D. Rogers (2016); Berman (2012); Vogelsang et al. (2018)

Code	CSFs	Description	Sources
		business.	
C21	Data security	The process of protecting data from unauthorized access and data corruption throughout its lifecycle including data encryption, hashing, tokenization and key management practices that protect data across all applications and platforms.	Jonathan (2020); Vogelsang et al. (2018)
C22	Political stability	The low chance of government collapse either because of conflicts or rampant competition between various political parties.	Jonathan (2020)
C23	Business model innovation	Capability to design new business models.	Berman (2012); Bharadwaj et al. (2013); Hess et al. (2016); Oswald and Kleinemeier (2017); Stief et al. (2016); Wade (2015); Westerman et al. (2014); Holotiuk and Beimborn (2017)
C24	A growth mindset	Individuals who believe their abilities can be developed.	Kane et al. (2018)
C25	Determining	Identifying areas of	Morakanyane et al. (2020)

Code	CSFs	Description	Sources
	transformed areas	organizational business that need DX.	
C26	Coordination among project parties	Existence of a cooperative project environment between project parties to successfully implement DX.	Eastman et al. (2011); Manning and Messner (2008); Arayici et al. (2011); Azhar (2011); Khosrowshahi and Arayici (2012); Boktor et al. (2014); McGraw-Hill (2014); Tsai et al. (2014)
C27	Project size	The scale of the project in terms of its budget.	Bryde et al. (2013); Arayici et al. (2011); Jung and Joo (2011)
C28	Client's attitude with DX	The willingness of clients to adopt DX or existence of a requirement specified or pressure exerted by the client.	Enegbuma and Ali (2011); Tsai et al. (2014); Won and Lee (2010); Morlhon et al. (2014); C. Chan (2014); J. Rogers et al. (2015); Aibinu and Venkatesh (2014); Linderoth (2010); Amponsah (2010); Arayici and Coates (2012); Ganah and John (2013); Succar et al. (2013); Lee et al. (2015)
C29	Maintenance and upgrade cost (software, hardware)	Organization strategic policies that favor allocation of sufficient budget toward DX system maintenance and upgrade.	Won and Lee (2010); Ozorhon and Karahan (2017); Enegbuma and Ali (2011); Tsai et al. (2014)
C30	Work environment	The surrounding conditions in which an employee operates or refers to the elements	Tsai et al. (2014);

Code	CSFs	Description	Sources
		that comprise the setting in which employees work and impact workers.	
C31	Organizational flexibility or adaptability to market	The ability of organization to adapt the change of market.	Tsai et al. (2014);
C32	Perceived benefits from DX	Notice or become aware of benefits and advantages from DX implementation.	Tsai et al. (2014);
C33	Research and development capability of organization	The ability of organization to do research for innovation by themselves.	Tsai et al. (2014);
C34	Pressure from competitors	The pressure to compete with other competitors within the industry.	Tsai et al. (2014); D. Rogers (2016)
C35	Socioeconomic conditions	The social standing or class of an individual or group. It is often measured as a combination of education, income and	Tsai et al. (2014);

Code	CSFs	Description	Sources
		occupation.	
C36	Technical support from software and hardware suppliers	The support in terms of technical problems from software and hardware suppliers.	Tsai et al. (2014);
C37	Shared risks and rewards among team members	Risks and rewards are shared equally among team members.	Tsai et al. (2014);

4.3.2 Definitions of factors

(1) C1: Determining digital strategy

Table 4-2. Factor C1

Code	CSFs	Description
C1	Determining digital strategy	The strategy describes the why, the what and the how, which are tied to specific, quantified business outcomes

This factor involves developing a cohesive strategy with a well-defined vision, supported by a set of strategic imperatives and measurable business outcomes, by effectively aligning digital initiatives with the overall business strategy to establish a sustainable competitive advantage. The strategy must comprise specific and detailed actions in an actionable business roadmap that addresses technology, people and organizational capabilities (BCG, 2020). The digital strategy outlines the path that an

organization will follow to gain competitive advantages through the use of technology and specific tactics (Christine, 2021).

More specifically, a digital strategy sets the overall direction for a business in the digital realm. It outlines the necessary tools, channels, assets, and platforms to achieve specific objectives and deliver desired outcomes (Incremental, 2021). Some businesses are spending money on digital assets, but they do not have a clear digital strategy. This leads to the failure of attempting DX implementation in those businesses.

(2) C2: Effective monitoring of progress

Table 4-3. Factor C2

Code	CSFs	Description
C2	Effective monitoring of progress	Establishing clear metrics and targets around processes and outcomes, with sufficient data availability and quality

The most important job to keep business on the right track in achieving objectives from the digital strategy is keeping monitor the progress effectively and efficiently. The application of real-time data and analytics to establish metrics and track progress is critical but often ignored in assessing the success of a DX strategy (W. John, 2019). This is an important factor given the high rate of failure among modern enterprises. Measuring success adequately includes (BCG, 2020):

(a) Establishing a transparent directive and responsibility structure to monitor advancements and address obstacles and difficulties.

(b) Regularly monitoring and evaluating outcomes at both program and initiative levels.

(c) Developing specific operational or financial metrics that are aligned with strategic objectives.

(d) Maintaining a centralized and reliable data source to ensure consistency and accuracy.

(3) C3: Awareness level of the industry

Table 4-4. Factor C3

Code	CSFs	Description
C3	Awareness level of the industry	Familiarity of the industry and current level of DX implementation within the industry

The awareness level of the construction industry encompasses two key aspects: familiarity with the industry and the current level of DX implementation within the industry. The perception and understanding of DX implementation within the industry are crucial factors that influence its overall progress. By increasing awareness and knowledge about DX, the construction industry can better comprehend the potential benefits and the necessity of adopting DX practices. However, the current situation in Vietnam suggests that contractors still have a limited understanding of DX, and there is ambiguity surrounding its recognition within the industry. It is imperative to address this gap and elevate the industry's consciousness about DX. By doing so, the construction sector can embrace the transformative power of digital technologies, enhance operational efficiency, and unlock the full potential of DX in driving growth and competitiveness.

(4) C4: Effective leadership

Table 4-5. Factor C4

Code	CSFs	Description
C4	Effective leadership	Commitment and approach of the top management to facilitate DX within the organization

Effective leadership in the context of DX involves the commitment and approach of top management to facilitate the integration of DX within the organization. Leaders play a critical role in guiding the organization's resources towards the achievement of objectives. They provide clarity of purpose, motivate employees, and guide the organization towards realizing its mission (Indeed, 2021b). The commitment of leaders towards DX is crucial as it sets the tone and direction for the entire organization. Their approach to DX implementation influences the organization's readiness and ability to embrace digital technologies and adapt to the changing business landscape.

Effective leadership is a fundamental management function that maximizes efficiency and drives the organization towards its goals. By championing DX initiatives, leaders create a supportive environment for innovation, foster collaboration, and empower employees to embrace change. The commitment and approach of organizational leaders are key factors that contribute to the successful implementation and integration of DX within the organization.

(5) C5: Willingness of staffs to learn new technology

Table 4-6. Factor C5

Code	CSFs	Description
C5	Willingness of staffs to learn new technology	Enthusiasm of organizational staffs realated DX learning and knowledge

The willingness of staff to learn new technology is crucial for the successful implementation of DX within an organization. It refers to the enthusiasm and openness of organizational staff to acquire new knowledge and skills related to DX. Staff perception plays a significant role in embracing and adapting to new technologies and processes. Their willingness to learn and embrace new skills is

highly valued by employers, as it demonstrates a proactive attitude towards personal and professional development.

In the context of DX, staff members who are willing to learn new technology contribute to the overall readiness and capability of the organization to implement DX initiatives effectively. Their enthusiasm for DX learning and knowledge acquisition creates a positive environment for innovation and growth within the organization. By fostering a culture of continuous learning and providing opportunities for staff to enhance their skills, organizations can empower their workforce to adapt to the evolving digital landscape and drive successful DX implementation.

(6) C6: Organizational culture

Table 4-7. Factor C6

Code	CSFs	Description
C6	Organizational culture	Existence of an organizational culture to be prone to learning and implementing and supportive of innovative technology

Organizational culture encompasses the shared values, beliefs, and behaviors that guide the actions of individuals within a team or company. Cultivating a strong company culture is essential for fostering the desired qualities necessary for achieving business success. According to Kellie (2021), organizations with strong and positive cultures experience notable business outcomes. Over a three-year period, these companies were 1.5 times more likely to achieve revenue growth of 15% or higher and 2.5 times more likely to observe substantial stock growth. Organizational culture has a wide-ranging impact, influencing aspects such as punctuality, communication style, contractual agreements, and employee benefits. When the culture of the workplace aligns with the needs of employees, it fosters a sense of comfort, support, and value among the workforce.

(7) C7: Availability of information technology

Table 4-8. Factor C7

Code	CSFs	Description
C7	Availability of information technology (IT)	Existence of necessary IT infrastructure within the organization for implementing DX

An organization's IT infrastructure encompasses the hardware, software, and network resources necessary for delivering IT services. It serves as the foundation for providing both internal services within the organization and external services to its customers or clients. The availability and existence of necessary IT infrastructure within the organization are essential for DX adoption. If the organization already has a good IT infrastructure, it will lead to reducing the cost of purchasing new IT infrastructure. The components of IT infrastructure can be deployed, organized and executed in a variety of ways. Some or all the following components may be included in a typical IT infrastructure: software, hardware and networking.

(8) C8: Financial support from the government

Table 4-9. Factor C8

Code	CSFs	Description
C8	Financial support from the government	Existence of incentive from government to promote DX

Financial support from the government is a crucial factor in promoting DX among Vietnamese contractors, particularly in the challenging times of the COVID-19 pandemic. The government's assistance in terms of incentives and financial backing plays a significant role in helping contractors meet the budget requirements for DX initiatives. This financial support can be allocated towards various aspects of DX implementation, such as investing in human resources, acquiring software and hardware, and covering operational costs related to DX. Through measures like

providing loans, guarantees, and wage subsidies, the government can alleviate the financial burden on contractors and enable them to effectively embrace DX. By offering financial relief and support, the government contributes to creating an environment conducive to DX adoption and empowers contractors to navigate the digital landscape with greater ease and confidence.

(9) C9: DX training programs

Table 4-10. Factor C9

Code	CSFs	Description
C9	DX training programs	The use of training and seminars to equip staffs with useful information and skills to facilitate DX

DX training programs play a crucial role in equipping staff with the necessary knowledge and skills to facilitate DX within an organization. These training programs involve activities such as seminars and courses aimed at improving performance, productivity, and understanding of specific DX-related topics. By participating in these programs, staff members gain valuable insights into DX concepts, strategies, and tools, enabling them to effectively contribute to the organization's DX journey. The training programs serve as a cost-effective and flexible means to enhance the capabilities of employees and align them with the target level of DX proficiency. These programs cover a wide range of areas, including general DX knowledge as well as specific training on software and hardware relevant to the organization's DX implementation plans. Through these training initiatives, organizations can ensure that their staff members are well-equipped to embrace and leverage DX for improved operational efficiency and success.

(10) C10: DX legislation

Table 4-11. Factor C10

Code	CSFs	Description
C10	DX legislation	Existence of DX guidelines, standards, codes, rules, regulations and roadmaps within the industry

Standards exist in many areas of our lives and help to improve the quality of the many goods we use daily and the construction industry is no exception. DX guidelines, standards, codes, rules, regulations and roadmaps pave the pathway for contractors to follow in adopting DX. These standards ensure continuity of the implementation process and provide the contractor with the format they desire. They can also have a significant impact on productivity and assure the overall DX implementation is sustainable. In the absence of a national uniform standard, more and more organizations are establishing DX standards or guidelines of their own.

(11) C11: Organizational restructuring

Table 4-12. Factor C11

Code	CSFs	Description
C11	Organizational restructuring	Restructure the organization to support DX implementation

Organizational restructuring is a critical factor in facilitating the successful implementation of DX within an organization. Restructuring involves making changes to the business model to enhance performance and address external or internal triggers that necessitate a transition (Barman, 2021). This process may involve various aspects such as legal modifications, operational processes, ownership adjustments, and more. In the context of DX, organizational restructuring becomes imperative as organizations cannot sustain outdated organizational structures during the transition process. Instead, they must embrace change and restructure their firm to create a

flexible and adaptable environment that supports the DX journey. This may entail employee downsizing or upsizing, altering staffing requirements, and implementing new roles and responsibilities to align with the DX objectives. By undertaking organizational restructuring, companies can establish a solid foundation that enables efficient DX implementation and fosters a culture of innovation and adaptability.

(12) C12: Financial resources of organization

Table 4-13. Factor C12

Code	CSFs	Description
C12	Financial resources of organization	Ability of the organization to allocate sufficient budget for DX implementation

Financial resources play an important role in the successful implementation of DX within an organization. These resources encompass all financial funds and assets available to the organization. Financial resources can take various forms, including cash, bank accounts, investments such as shares and bonds, and other financial instruments. Having access to sufficient financial resources is essential for construction firms looking to invest in DX initiatives. Adequate funding enables organizations to allocate the necessary budget for acquiring technology, software, hardware, and other resources required for DX implementation. It also supports the training and development of employees, hiring specialized personnel, and covering operational costs associated with the transformation process. Without access to adequate financial resources, it becomes challenging for construction firms to turn their strategic plans for DX into reality. Therefore, ensuring the availability of sufficient financial resources is crucial to support the successful adoption and implementation of DX within the organization.

(13) C13: Availability of qualified staff

Table 4-14. Factor C13

Code	CSFs	Description
C13	Availability of qualified staff	Existence of competent personnel within the organization

The ability of a potential employee to perform a task or be trained for a specific skill set would be considered in the definition of "qualified staff". These capabilities are unquestionably crucial in completing a task. A well-trained workforce is the lifeblood of any company, ensuring its long-term sustainability and growth for the business (AIB, 2016). When determining the organizational need, it is the leader's responsibility to build a team that can keep moving forward on business requirements. Qualifications of good staff include technical skills and community skills. Without a doubt, this is a crucial factor for the DX strategy. DX implementation requires skillful and well-trained staff for its complicated and long-term plan.

(14) C14: Relationships and knowledge sharing with other firms

Table 4-15. Factor C14

Code	CSFs	Description
C14	Relationships and knowledge sharing with other firms	Existence of a knowledge-sharing and collaborative platform within the industry

Businesses must have a dynamic grasp of how enterprises compete and collaborate to succeed in the digital age. Rather than seeing their competitors as bitter enemies and unalloyed partnerships, businesses should perceive them as a fluid balance of competition and cooperation (D. Rogers, 2016). Contractors need to recognize the importance of collaborating with their direct competitors and the potential risks posed by asymmetric competitors, the significance of leverage in their

partnerships with other companies and the ability of digitally enabled platform business models to bring various parties together and create new value.

Building strong relationships with other firms is just as crucial as establishing networked and interconnected relationships with customers. The increasing digitization of interactions in both relationships will produce data. The next crucial domain of DX is figuring out how to use this data strategically as a source of new value for enterprises (D. Rogers, 2016). Knowledge sharing is also a necessary component while building the relationships network with other construction firms.

(15) C15: Innovate by rapid experimentation

Table 4-16. Factor C15

Code	CSFs	Description
C15	Innovate by rapid experimentation	Learn to experiment continuously and effectively, getting real data and real customer feedback, continuously iterating and testing new ideas

Rapid experimentation is an agile approach to the development process. Experiments are conducted frequently in this approach in order to identify new and innovative ideas (ProductPlan, 2021). In order to thrive in the digital era, construction companies need to embrace a culture of continuous and effective experimentation. This involves constantly iterating and testing new ideas, gathering real customer feedback, and analyzing real data to drive improvement and innovation. In a dynamically evolving environment, contractors have the ability to innovate rapidly, cost-effectively, and cleverly in order to generate novel value propositions for their customers (D. Rogers, 2016). Companies can build successful innovative campaigns by empowering employees at all levels to run fast and cheap experiments.

(16) C16: Turn data into assets

Table 4-17. Factor C16

Code	CSFs	Description
C16	Turn data into assets	Develop the clear vision and the growing capability needed to put data to work in the service of innovation and value creation

In today's digital era, data has emerged as a valuable asset for businesses. The analogy of data being the "oil" of the digital age, as referred to by The Economist (2017), highlights its immense value and potential. With the increasing integration of sensors, networks, and computing into our daily lives, businesses have access to an ever-expanding amount of data. However, the challenge lies in effectively harnessing this data to drive innovation and create value. To address this challenge, organizations must develop a clear vision and build the necessary capabilities to leverage data effectively.

Recognizing data as a significant intangible asset, organizations can design and implement a data strategy that informs critical decision-making and unlocks new value for both the business and its customers. By putting data to work in the service of innovation and value creation, organizations can stay ahead in today's data-driven world and drive sustainable growth. The development of a data-driven culture and the continuous enhancement of data capabilities are crucial for organizations to fully leverage the potential of data as a strategic asset (D. Rogers, 2016).

(17) C17: Competent technical support team within company

Table 4-18. Factor C17

Code	CSFs	Description
C17	Competent technical support team within the company	Existence of necessary technicians to deploy DX implementation

A technical support team can help businesses with any problems they are having, as well as execute some of the more time-consuming tasks that need to be completed. This allows organizations to focus on more critical business issues and help other employees (Michael, 2016). Businesses are defined by their technological capabilities in the digital area. Some of the primary benefits of technical assistance in the business include (1) Increasing client communication, (2) Fixing, optimizing and repairing hardware, (3) Helping companies reduce IT costs, (4) Updating equipment with the latest technology, (5) Providing technical support twenty-four hours a day, seven days a week, (6) Enhancing communication between employees and (7) Assisting with industry compliance issues (Unicom, 2021).

(18) C18: Consulting

Table 4-19. Factor C18

Code	CSFs	Description
C18	Consulting	Receiving consultancy services from specialized firms

Consultants provide a substantial amount of value for an organization. They can assist in the development of growth strategies or the management of projects (Denise, 2018). Consulting services are used by a wide range of enterprises. It is a simple and quick way to gain access to the required expertise. Consultants can play an important role in every firm, regardless of its size. Some key benefits of using consulting services are as follows: (1) Instant solutions are often provided, (2) Consultants can deliver results with speed, (3) Consultants often provide best practices, (4) Consultants can add specific skill set to any organization and (5) Consultants help when organizations want to create change. With the huge amount of required knowledge and experience for the DX process, this factor is undoubtedly vital.

(19) C19: Commitment of employees

Table 4-20. Factor C19

Code	CSFs	Description
C19	Commitment of employees	Employees are fully engaged in the process of DX implementation

Employee commitment refers to the level of dedication and enthusiasm that an employee has towards their assigned responsibilities in the workplace. It reflects their sense of responsibility towards the goals, mission, and vision of the organization they are affiliated with (QuestionPro, 2021). Employee commitment is achieved when there is alignment between an employee's personal goals and values and the goals and values of the organization. Committed employees contribute value to the organization through their dedication, proactive support, high productivity, and commitment to quality. Committed employees are also less likely to leave the organization. On the other hand, employees who lack commitment can have a negative impact on the organization and hinder its growth (Bronwyn, 2019). To be successful in the organizational long-term strategy of DX, employee commitment is clearly a crucial factor.

(20) C20: Harness customer networks

Table 4-21. Factor C20

Code	CSFs	Description
C20	Harness customer networks	View customers differently, understanding the dynamic, networked ways in which they interact, both with businesses and with each other

In the digital age, businesses need to adopt a new perspective on their customers. They must recognize and understand the dynamic and networked nature of customer interactions, both with the business itself and with each other. By viewing customers as networks, enterprises can enhance their customer strategies

and adapt to the changing landscape. This entails reimagining the customer journey and the traditional marketing funnel. Rather than focusing solely on the path to purchase, businesses can meet customers where they are and create value by facilitating access, engagement, connection, and even collaboration. By leveraging customer networks, companies can establish stronger relationships, foster loyalty, and drive innovation. This customer-centric approach, as proposed by (D. Rogers, 2016), enables businesses to tap into the collective intelligence and influence of their customers, empowering them to thrive in the digital era.

(21) C21: Data security

Table 4-22. Factor C21

Code	CSFs	Description
C21	Data security	The process of protecting data from unauthorized access and data corruption throughout its lifecycle

Data security is of paramount importance in today's digital landscape. Organizations worldwide are making significant investments in information technology cyber security capabilities to safeguard their valuable assets. Data security encompasses a range of strategies and practices aimed at protecting data from unauthorized access and corruption throughout its entire lifecycle. Encryption, hashing, tokenization, and key management are some of the key techniques employed to ensure data security across various applications and platforms (MicroFocus, 2021). Implementing robust data security measures is crucial as they not only shield organizations' information assets from cybercriminals but also mitigate the risks posed by insider threats and human errors, which remain leading causes of data breaches (IBM, 2021). By prioritizing data security, organizations can instill trust, maintain regulatory compliance, and safeguard their reputation in an increasingly interconnected digital environment.

(22) C22: Political stability

Table 4-23. Factor C22

Code	CSFs	Description
C22	Political stability	The low chance of government collapse either because of conflicts or rampant competition between various political parties

Political stability refers to the condition in which a government has a minimal risk of collapse as a result of internal conflicts or excessive competition among political parties (Zahid, 2014). The regularity of the flow of political exchange is referred to as political stability. Political stability is positively correlated with the frequency and regularity of political exchanges (Ake, 1975). Political stability plays a significant role in the development of a country, as it has been observed to both contribute to sustained economic growth and be a result of limited economic progress in the long run (Radu, 2015).

(23) C23: Business model innovation

Table 4-24. Factor C23

Code	CSFs	Description
C23	Business model innovation	Capability to design new business models

A business model is a plan or approach that outlines how a company delivers value to its customers. It encompasses various elements, such as the target market, customer needs, and the company's products or services that cater to those needs. Business model innovation refers to the process of adapting or transforming the existing business model. This innovation often involves significant changes in how the company creates value for its customers, such as introducing new revenue streams or exploring different distribution channels (Lauren, 2020). In other words, business

model innovation involves altering or creating a new business model to better meet customer needs and gain a competitive edge (Franz, 2018).

(24) C24: A growth mindset of staffs

Table 4-25. Factor C24

Code	CSFs	Description
C24	A growth mindset of staffs	Individuals who believe their abilities can be developed

A growth mindset is when individuals understand that their abilities can be developed (Dweck, 2014). A fixed mindset, as opposed to a growth mindset, considers that our personality, intelligence, and creative capacity are fixed characteristics that we can't change in any meaningful way. A growth mindset, on the other hand, thrives on challenge and sees failure as a motivating springboard for growth and pushing our present abilities, rather than a sign of unintelligence (Maria, 2021). Having a growth mindset offers numerous benefits as it allows individuals to reframe their problem-solving approach and maintain motivation for skill development. Therefore, staff with a growth mindset are key components of organizations implementing DX.

(25) C25: Determining transformed areas

Table 4-26. Factor C25

Code	CSFs	Description
C25	Determining transformed areas	Identifying areas of organizational business that need DX

Determining transformed areas is a crucial step in the DX implementation process for construction firms. Given the vast and complex nature of organizational structures, it becomes essential to identify the specific areas of the business that

require DX. With limited resources, it is imperative to prioritize and determine which areas should be the first to undergo DX, followed by subsequent phases. Careful planning and strategic decision-making are necessary to ensure the successful implementation of DX initiatives. Attempting to transform all areas of the business simultaneously may prove unwise and overwhelming. Therefore, construction firms must consider this factor and develop a comprehensive DX strategy that focuses on the areas that will benefit the most from digital transformation, enabling them to optimize resources and drive meaningful change.

(26) C26: Coordination among project parties

Table 4-27. Factor C26

Code	CSFs	Description
C26	Coordination among project parties	Existence of a cooperative project environment to successfully implement DX

The construction industry is often characterized by fragmentation, inefficiency, and project delays. Coordination plays a vital role in addressing these challenges and improving project performance. It is considered an effective solution to mitigate the issues associated with fragmentation in the construction industry. As a result, coordination aspects are critical to the effective completion of all project phases (Alaloul et al., 2016). Coordination among project parties is a key factor in improving construction project performance and DX implementation for construction firms is not an exception.

(27) C27: Project size

Table 4-28. Factor C78

Code	CSFs	Description
C27	Project size	The scale of the project in terms of its budget

Construction project size is defined based on the following components: total financial resources, number of team members involved, timeframes of project, etc. As the scale of the project grows, the complexity of the project grows as well. Project size can be divided into three types: (1) Large project, (2) Medium project and (3) Small project. The factor “project size” in this research focuses on the project’s budget only. The implementation of DX requires financial resources. Therefore, the scale of the project, particularly its budget, influences the contractor's decisions and plans for implementing DX in various aspects.

(28) C28: Client’s attitude with DX

Table 4-29. Factor C28

Code	CSFs	Description
C28	Client’s attitude with DX	The willingness of clients to adopt DX or existence of a requirement specified or pressure exerted by clients

Client organizations are widely recognized as significant drivers of construction innovation. The findings from Lindblad and Guerrero (2020) show insights into the various roles clients can enact in promoting innovation and contribute to a better knowledge of clients as the vital players in the construction industry's innovation. The attitude of clients toward DX is a critical factor to be taken into consideration. This attitude is illustrated via the willingness of clients to adopt DX or the presence of a requirement specified by clients.

(29) C29: Maintenance and upgrade cost

Table 4-30. Factor C29

Code	CSFs	Description
C29	Maintenance and upgrade cost (software, hardware)	Organization strategic policies that favor allocation of sufficient budget toward DX system maintenance and upgrade

Maintenance and upgrade costs, including those associated with software and hardware, are crucial considerations for successful DX implementation. Organizations need to develop strategic policies that prioritize the allocation of sufficient budget for the ongoing maintenance and upgrade of their DX systems. The software and hardware components of the DX system require regular attention to ensure they are functioning optimally and to take advantage of new features and advancements. Adequate financial resources must be allocated to cover the costs of maintenance and upgrades. This factor is essential for the smooth and effective operation of the DX system, as it ensures that the system remains up to date, secure, and capable of supporting the organization's digital transformation goals. By investing in maintenance and upgrades, organizations can enhance the performance, reliability, and longevity of their DX systems, enabling them to derive maximum value and benefit from their digital initiatives.

(30) C30: Work environment

Table 4-31. Factor C30

Code	CSFs	Description
C30	Work environment	The surrounding conditions in which an employee operates or refers to the elements that comprise the setting in which employees work and impact workers

The term "work environment" encompasses the physical setting where employees carry out their tasks. This includes factors like office conditions and equipment. It also includes aspects related to work procedures and processes. Interactions with colleagues, subordinates, and superiors are also part of the work environment. A positive work environment fosters employee safety, growth, and goal attainment. Such workplaces are conducive to high productivity as they inspire employees to perform at their best (Indeed, 2021a). Therefore, the work

environment factor also affects the overall performance of the organization and impacts the DX process.

(31) C31: Organizational adaptability to market

Table 4-32. Factor C31

Code	CSFs	Description
C31	Organizational adaptability to market	The ability of organization to adapt the change of market

Traditional business strategies operate under the assumption of a stable and predictable world. However, with globalization, emerging technologies, and heightened transparency, the business landscape has become increasingly turbulent. As a result, managers are recognizing the significance of organizational capabilities that enable swift adaptation as a crucial competitive advantage in a time of uncertainty and risk (Martin & Mike, 2011). And the construction industry is not an exception. To be successful in adopting DX, the construction firms must have flexibility and adaptability to the frequent change of the market.

(32) C32: Perceived benefits from DX

Table 4-33. Factor C32

Code	CSFs	Description
C32	Perceived benefits from DX	Notice or become aware of benefits and advantages from DX implementation

Becoming aware of the advantages and benefits of DX implementation from construction firms is also an important factor. Eric (2020) listed some benefits of DX implementation as follows:

(a) Improved efficiency: efficient communication among departments, smooth data flow across the organization, and seamless transitions throughout the customer

journey collectively enhance business processes, leading to time, cost, and resource savings.

(b) Cost savings: embarking on a DX can result in cost and time savings both during the implementation phase and after it is fully operational. This is achieved through the implementation of streamlined processes and improved detection of issues, leading to enhanced efficiency.

(c) Revenue growth: by increasing transparency across various aspects of the business, employees and management can enhance their best practices and identify revenue-generating opportunities through the recognition of patterns, assessment of trends, and capitalization of data-driven insights.

(d) Flexibility: if DX implementation is done effectively, the construction firms are able to respond to the market and customer needs.

(e) Improving competitive advantage: by improving their business infrastructure, contractors are enhancing their competitive advantage within the construction industry.

(33) C33: Research and development capability of organization

Table 4-34. Factor C33

Code	CSFs	Description
C33	Research and development capability of organization	The ability of organization to do research for innovation by themselves

The ability of an organization to innovate is a critical aspect in achieving improved competitive performance. Understanding how innovation aptitude emerges, develops and is applied could be beneficial to management and science (Silva & Cirani, 2020). The research and development capability of the organization is even more important when they try to adopt DX because DX requires a lot of innovation and research skills. Construction firms cannot rely only on external research ability. Within the organization, they need to establish their own research

department with the capability to do research for themselves. It can help them to save costs spent on innovation.

(34) C34: Pressure from competitors

Table 4-35. Factor C34

Code	CSFs	Description
C34	Pressure from competitors	The pressure to compete with other competitors within the industry

Competitive pressure is the motivation or necessity to adapt and keep pace with competitors' actions. It serves as a catalyst for change within an industry, prompting firms to enhance their performance and create challenges for their rivals. Consumers and nations gain from competitive pressure because it encourages businesses to add more value at the lowest possible cost (S. John, 2020). The pressure from competitors in the race for digitalization will be a massive motivation for contractors to pursue the DX journey.

(35) C35: Socioeconomic status

Table 4-36. Factor C35

Code	CSFs	Description
C35	Socioeconomic status	The social standing or class of an individual or group

Socioeconomic status refers to the social position or rank of an individual or group within society. It is often determined by factors such as education, income, and occupation. The examination of socioeconomic status often highlights disparities in access to resources and raises issues of privilege, power, and control (APA, 2021). The socioeconomic status of construction firms and organizational staff can impact their progress in DX in various aspects.

(36) C36: Technical support from software and hardware suppliers

Table 4-37. Factor C36

Code	CSFs	Description
C36	Technical support from software and hardware suppliers	The support in terms of technical problems from software and hardware suppliers

Besides the competent technical support team within the company, the support in terms of technical problems from software and hardware suppliers is also a critical factor. Software and hardware suppliers have a professional technical team for their specific software or hardware that the construction firms might not have. Thus, keeping close contact with suppliers and receiving prompt support from suppliers are important issues that contractors need to pay attention to.

(37) C37: Shared risks and rewards among team members

Table 4-38. Factor C37

Code	CSFs	Description
C37	Shared risks and rewards among team members	Risks and rewards are shared equally among team members

The risks and rewards resulting from DX implementation need to be shared and distributed equally between the employees. Those risks and rewards are challenges and motivation at the same time for all team members. Employees can recognize their responsibility to help their firms pursue the DX journey. They also know if their organization is successful in adopting DX, they can get the rewards that are worthy of their effort and hard work.

4.4 Preliminary CSFs linked with steps of DX roadmap

Figure 4-2 depicts the preliminary CSFs linked with the steps of the DX roadmap. The figure was presented to a team of five experts to gather their insights and suggestions for potential modifications. Multiple rounds of individual interviews with the experts will be conducted to refine and finalize the CSFs linked with the steps of the DX roadmap. The interviews will continue until a consensus is reached among all the experts regarding the final CSFs that are linked with the specific steps outlined in the DX roadmap.

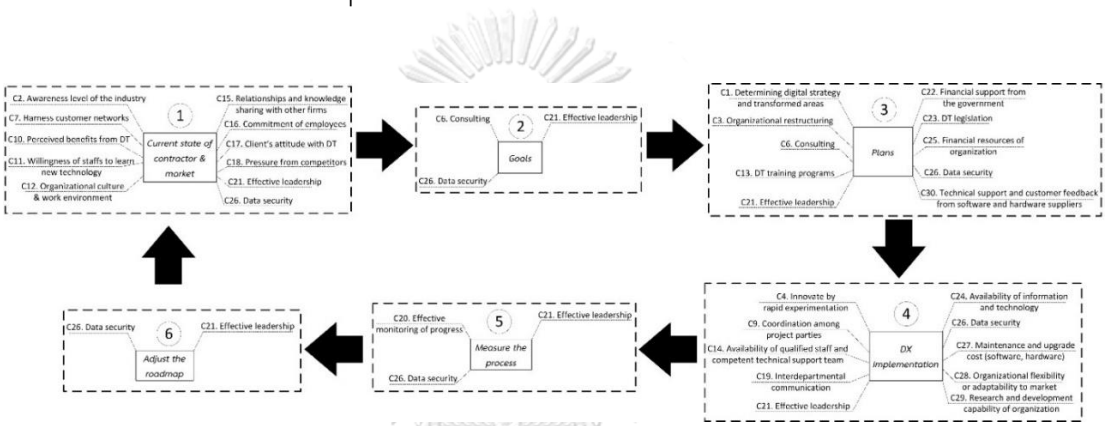

Figure 4-2. Preliminary CSFs linked with steps of DX roadmap

4.5 Summary

This chapter focuses on providing the preliminary DX roadmap, preliminary CSF list and preliminary CSFs linked with steps of DX roadmap. The chapter consists a total of four sections, each presenting a specific aspect of the DX implementation process.

In section 1, the definition of a DX roadmap is provided. This section explores the concept of a roadmap as a strategic tool for guiding the implementation of DX in construction firms. It highlights the importance of having a well-defined roadmap to navigate the transformation journey effectively.

Section 2 delves into the preliminary DX implementation roadmap. It outlines the key steps and milestones involved in the DX implementation process specific to

construction contractors. This section provides an overview of the roadmap, highlighting the sequence of activities necessary for a successful DX adoption.

Section 3 offers the preliminary list of CSFs related to the adoption of DX by construction contractors. This section explores the factors that play a crucial role in ensuring successful DX implementation. The preliminary CSFs are identified based on extensive literature review.

Lastly, section 4 delves into the preliminary CSFs linked with each step of the DX roadmap. It highlights the interrelation between the CSFs and the specific steps outlined in the DX roadmap. This section provides insights into how each CSF aligns with the corresponding stage of the DX implementation process.

Overall, this chapter serves as a comprehensive overview of the DX implementation process for construction contractors. It covers the definition of a DX roadmap, the preliminary DX implementation roadmap, the preliminary CSF list, and the preliminary CSFs linked with each step of the DX roadmap. This chapter lays the foundation for further analysis and investigation in subsequent chapters, contributing to a deeper understanding of DX implementation in the construction industry.

Chapter 5

DEFINING FINAL CSFs AND DX ROADMAP

This chapter presents step 2 in the research framework which is served to define the the final DX roadmap, the final CSF list and the final CSFs linked with each step of DX roadmap via in-depth interview with experts. The preliminary DX roadmap, preliminary CSFs linked with step of DX roadmap, the preliminary thirty-seven CSFs from the literature review are shown and thorough definitions of each factor are provided. Then, in-depth interviews with experts are conducted to finalize the DX roadmap, CSF list and CSFs linked with step of DX roadmap. The experts are asked to add, modify, rename, remove or merge the factors. Moreover, they are also asked to group CSFs into different clusters and link the factors with steps of DX roadmap.

5.1 Final DX roadmap

After conducting in-depth interviews with five experts, the final DX roadmap is achieved. In the preliminary DX roadmap, there are a total of seven goals for DX implementation for contractors. However, as comments from experts, there are some goals that are not clear. Therefore, some ambiguous goals are eliminated and some similar goals are combined. In summary, there are four goals left. The profiles of the five experts are shown in Table 5-1.The definitions of four goals are provided in Table 5-2 and the final DX roadmap is shown in Figure 5-1.

Table 5-1. Profiles of experts

Respondent No.	Experience	Type of company	Position	Size of company
1	> 10 years	DX consulting	Directors	Large
2	> 10 years	Contractors	Head of department	Large
3	5 - 10 years	Contractors	Engineer	Large
4	5 - 10 years	Contractors	Engineer	Medium
5	5 - 10 years	Contractors	Engineer	Medium

Table 5-2. Definitions of four DX goals

Goals	Definitions
(1) Improving customer experience	The customer experience encompasses the overall perception that customers have of your brand at every stage of their journey. It shapes their impression of your brand and has implications for various factors affecting your bottom line, such as revenue (Bordeaux, 2021).
(2) Increasing profit margin	Profit margin is a widely used measure of profitability that assesses the profitability of a company or business activity. It indicates the percentage of sales that has been converted into profits (Segal, 2021).
(3) Increasing employee performance	Employee performance pertains to the conduct and job proficiency exhibited by employees within the workplace. It encompasses their behavior, actions, and the level of competence displayed in carrying out their assigned tasks and responsibilities (Donohoe, 2019).
(4) Increasing compliance	Compliance refers to the extent to which an organization conforms to and follows government regulations, industry standards, and internal policies (Puterbaugh, 2022).

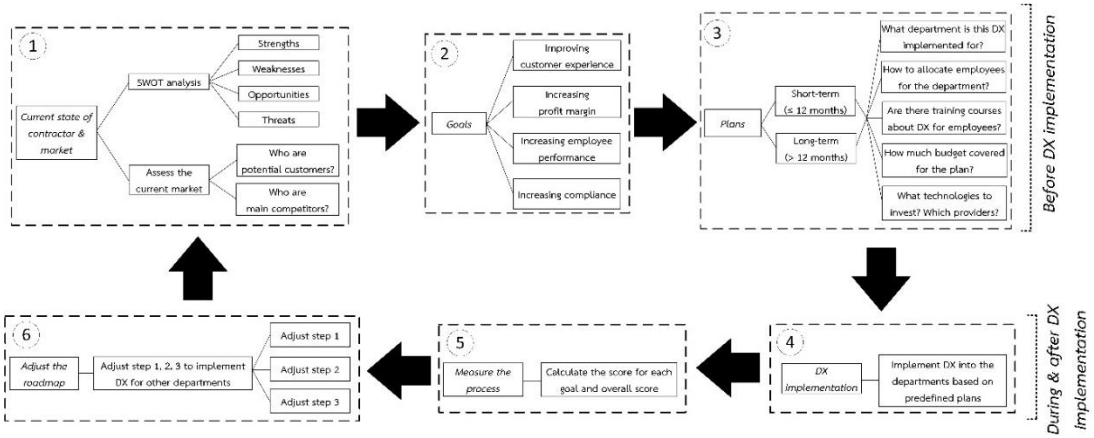

Figure 5-1. Final DX roadmap

Table 5-1 presents the profiles of the experts involved in the finalization process of the above DX roadmap. It is important to note that this roadmap is specifically applicable to construction firms that share similar characteristics to the sample set outlined in Table 5-1.

5.2 Final CSF list

5.2.1 In-depth interview with experts

This round of interviews with experts is served for step two in the overall research framework to define the final CSF list from the preliminary CSF list obtained from the literature review and associate CSFs with steps of DX roadmap. There are a total of four experts for this round of interviews. The basic data of the four experts are presented in Table 5-3. The contents of this interview are shown in Appendix A. This interview aims to achieve the complete CSF list and avoid overlapping by asking the experts to add, modify, rename, remove or merge the factors. Besides, the experts are asked to group the factors into different clusters. Moreover, the experts are also asked to link the CSFs with the steps of DX roadmap.

The four experts are provided the basic definitions of DX and CSFs regarding the implementation of DX in the construction industry. The table of preliminary

thirty-seven CSFs and the DX roadmap are also sent to the experts in advance. The experts have time to read documents and prepare before conducting the online in-depth interview. The table of preliminary thirty-seven CSFs, the DX roadmap and the questions used for the interview are also described in Appendix B. The result of the interview is presented in the next section.

Table 5-3. Basic data of the four experts

Expert	Position	Type of company	Years of working experience (construction industry)
E1	Directors	DX consulting	> 10 years
E2	Head of department	Research institute	> 10 years
E3	Project managers	Owner	3 - 5 years
E4	Technical Manager	Software and Platform Provider	5 - 10 years

5.2.2 Results of interview

After processing the results from in-depth interviews with experts, there is a total of thirty CSFs obtained from the initial thirty-seven CSFs. These thirty CSFs are presented in Table 5-4.

Table 5-4. CSFs regarding DX implementation for contractors

Code	CSFs	Description
C1	Determining digital strategy and transformed areas	The strategy describes the why, the what and the how, which are tied to specific, quantified business outcomes and identifying areas of organizational business that need DX
C2	Effective monitoring of progress	Establishing clear metrics and targets around processes and monitoring the progress rigidly
C3	Awareness level of the industry	Familiarity of the industry and current level of DX implementation within the industry

Code	CSFs	Description
C4	Effective leadership	Commitment and approach of the top management to facilitate DX within the organization
C5	Willingness of staffs to learn new technology	Enthusiasm of organizational staffs related DX learning and knowledge
C6	Organizational culture & work environment	Existence of an organizational culture to be prone to learning and implementing of innovative technology and the surrounding conditions in which an employee operates or refers to the elements that comprise the setting in which employees work and impact workers
C7	Availability of information and technology	Existence of necessary information and technology infrastructure within the organization for implementing DX
C8	Financial support from the government	Existence of incentive from government in terms of financial support to promote DX
C9	DX training programs	The use of training and seminars to equip staffs with useful information and skills to facilitate DX
C10	DX legislation	Existence of DX guidelines, standards, codes, rules, regulations and roadmaps within the industry from government and other construction associations
C11	Organizational restructuring	Restructure the organization to support DX implementation
C12	Financial resources of organization	Ability of the organization to allocate sufficient budget for DX implementation

Code	CSFs	Description
C13	Availability of qualified staff and competent technical support team within company	Existence of competent personnel and necessary technicians to deploy DX implementation within the organization
C14	Relationships and knowledge sharing with other firms	Existence of a knowledge-sharing and collaborative platform within the industry
C15	Innovate by rapid experimentation	Learn to experiment continuously and effectively, getting real data and real customer feedback, continuously iterating and testing new ideas
C16	Turn data into assets	Develop the clear vision and the growing capability needed to put data to work in the service of innovation and value creation
C17	Consulting	Receiving consultancy services from specialized firms
C18	Commitment of employees	Employees are fully engaged in the process of DX implementation
C19	Harness customer networks	Learn to view customers differently, understanding the dynamic, networked ways in which they interact, both with businesses and with each other, helping them to access, engage, connect and even collaborate with the business
C20	Data security	The process of protecting data from unauthorized access and data corruption throughout its lifecycle including data encryption, hashing, tokenization and key management practices that protect data across all applications and platforms

Code	CSFs	Description
C21	Business model innovation	Capability to design new business models
C22	Coordination among project parties	Existence of a cooperative project environment between project parties to successfully implement DX
C23	Client's attitude with DX	The willingness of clients to adopt DX or existence of a requirement specified or pressure exerted by the client
C24	Maintenance and upgrade cost (software, hardware)	Organization strategic policies that favor allocation of sufficient budget toward DX system maintenance and upgrade
C25	Organizational flexibility or adaptability to market	The ability of organization to adapt to the change of market
C26	Perceived benefits from DX	Notice or become aware of organizational benefits and advantages from DX implementation
C27	Research and development capability of organization	The ability of organization to do research for innovation by themselves
C28	Pressure from competitors	The pressure to compete with other competitors within the industry
C29	Technical support and customer feedback service from software and hardware suppliers	The support service in terms of technical problems and customer feedback from software and hardware suppliers

Code	CSFs	Description
C30	Interdepartmental communication	Communication and connection among different departments within organization

The above final thirty CSFs regarding DX implementation are used as material for another round of in-depth interviews. Experts are asked to classify these thirty CSFs into different clusters. According to Evans (2017), there are four key pillars of Digital Transformation (DX): (1) Strategy & Vision, (2) People & Culture, (3) Process & Governance and (4) Technology & Capabilities. Figure 5-2 visualizes these four key pillars. The details for these four key pillars are discussed in the next paragraph.

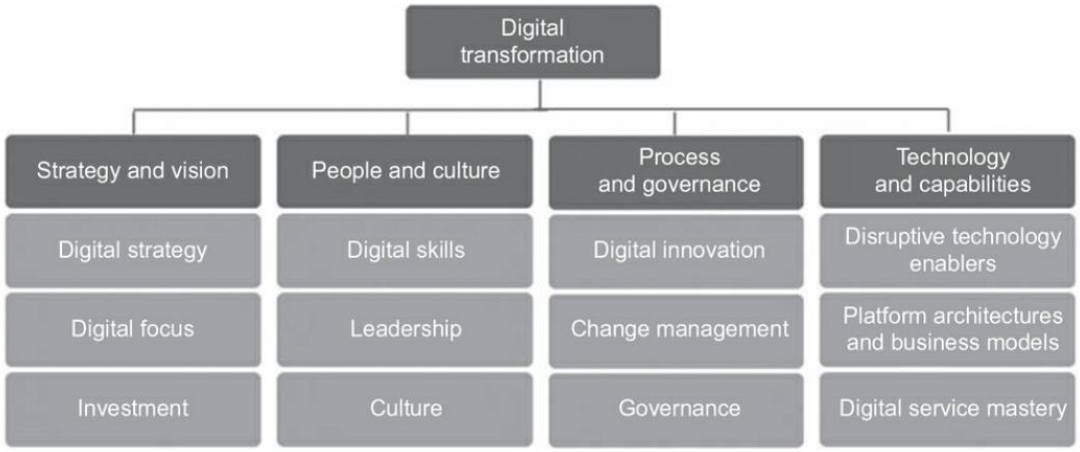

Figure 5-2. Key Pillars of DX (Evans, 2017)

(1) Strategy & Vision:

It is critical for the strategy to stake out a position in terms of desired business outcomes. The following areas frequently map to the primary targeted transformation objectives:

(a) To boost loyalty, revenues, productivity, and retention, enhancing the digital customer and end-user experience is important.

(b) Business processes are undergoing transformation in order to reduce expenses, enhance efficiency, integrate supply chain collaborators, and differentiate offerings.

(c) Leveraging analytics to improve decision-making, enhance operational efficiencies, and gain a competitive edge.

(d) Increasing agility, flexibility, and cost-effectiveness by optimizing infrastructure and operations.

(e) Simplifying management processes to reduce complexity, proactively prevent issues, and enhance visibility and control over assets.

(2) People & Culture:

The fundamental components of this aspect encompass effective leadership, a supportive culture, and proficient digital skills. It needs all these elements to make the transformation successful. Leadership is required to make innovation and digital transformation a requirement, to enforce behaviors and to keep programs chartered and linked with the external perspective in mind. It takes culture to enable tolerance and susceptibility to risk, as well as the acceptance and empowerment of change. To handle the heavy lifting using an entirely new set of tools and techniques, digital skills are required.

(3) Process & Governance:

The essential components of this aspect consist of effective management of innovation, change, and governance. Figure 5-3 shows the five critical pillars of innovation management capability. These five critical pillars assist organizations with evaluating their present innovation program and identifying any gaps or improvements that are required to guarantee that organizations have a robust innovation process that is integrated into the relevant corporate strategy, investment and product and service development processes.

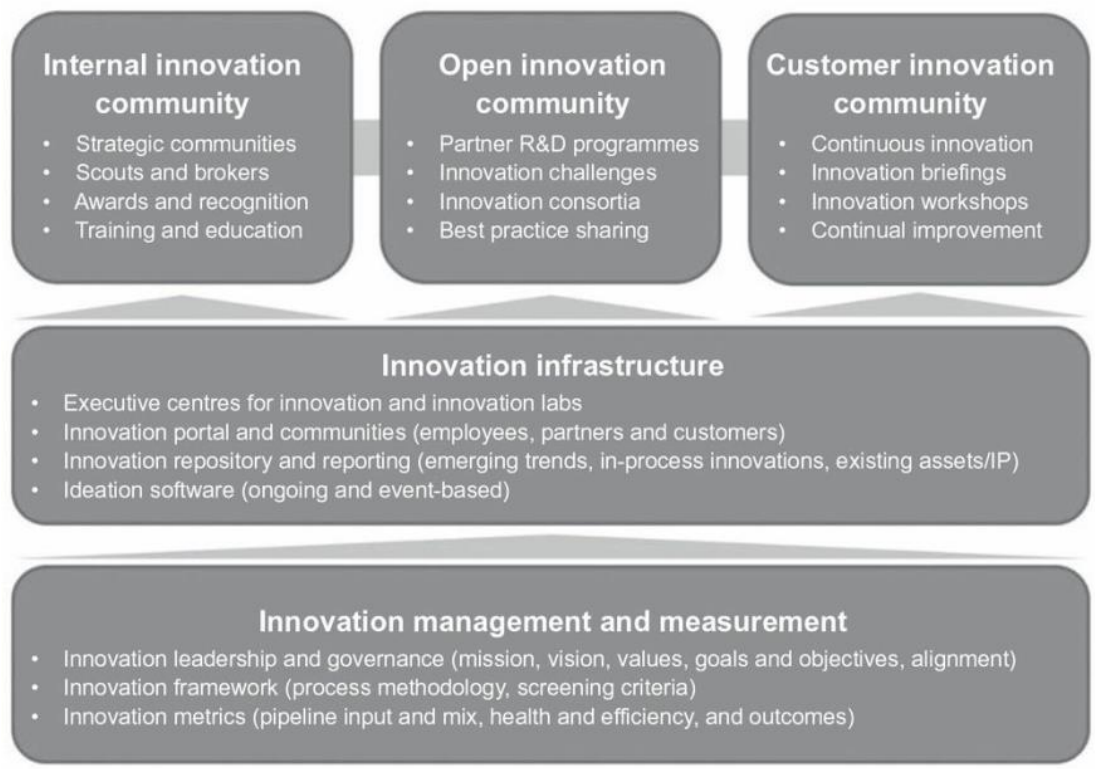

Figure 5-3. The five critical pillars of innovation management capability (Evans, 2017)

In terms of change management, to execute digital initiatives, business leaders do not need to establish totally new processes or reinvent the wheel. They can utilize existing corporate funding and innovation structures, but they need to make some changes to refocus their efforts on digital business. In terms of governance, governance now needs to span both the slower-paced initiatives and faster-paced initiatives. To keep up with the rapid pace of change and the numerous sprint cycles that come with transformation projects, the governance function needs to be more flexible and adaptable.

(4) Technology & Capabilities:

To have a comprehensive understanding of and effectively utilize the technology enablers available in the market, this key pillar corresponds to the components of the digital transformation journey that deal with technology and

capabilities. In terms of technologies and capabilities, it relates to how organizations construct their core technological enablers to develop digital business platform architectures and digital business platforms. The organization must be an expert in the areas of digital service design, development, deployment, management, and evolution. In the coming years, organizations will need to develop a strong proficiency in managing the digital services lifecycle in order to grow their business and stay ahead of the competition (Evans, 2017).

The above four key pillars are utilized as four categories for CSFs regarding the DX implementation. And the result is shown in Table 5-5 after in-depth interviews with experts. Experts are asked to classify thirty CSFs into four categories: (1) Strategy & Vision, (2) People & Culture, (3) Process & Governance and (4) Technology & Capabilities.

Table 5-5. CSFs categories

Code	CSFs	Categories			
		(1)	(2)	(3)	(4)
C1	Determining digital strategy and transformed areas	✓			
C2	Effective monitoring of progress			✓	
C3	Awareness level of the industry	✓			
C4	Effective leadership			✓	
C5	Willingness of staffs to learn new technology		✓		
C6	Organizational culture & work environment		✓		
C7	Availability of information and technology				✓
C8	Financial support from the government			✓	
C9	DX training programs		✓		
C10	DX legislation			✓	
C11	Organizational restructuring	✓			
C12	Financial resources of organization				✓

Code	CSFs	Categories			
		(1)	(2)	(3)	(4)
C13	Availability of qualified staff and competent technical support team within company		✓		
C14	Relationships and knowledge sharing with other firms		✓		
C15	Innovate by rapid experimentation	✓			
C16	Turn data into assets	✓			
C17	Consulting	✓			
C18	Commitment of employees		✓		
C19	Harness customer networks	✓			
C20	Data security				✓
C21	Business model innovation	✓			
C22	Coordination among project parties	✓			
C23	Client's attitude with DX		✓		
C24	Maintenance and upgrade cost (software, hardware)				✓
C25	Organizational flexibility or adaptability to market				✓
C26	Perceived benefits from DX	✓			
C27	Research and development capability of organization				✓
C28	Pressure from competitors		✓		
C29	Technical support and customer feedback from software and hardware suppliers				✓
C30	Interdepartmental communication		✓		

Thirty CSFs are arranged into four groups and all the factors are renumbered according to their new order. Table 5-6 shows the new code for all thirty CSFs.

Table 5-6. Final thirty CSFs

Code	CSFs Categories
Group 1	Strategy & Vision
C1	Determining digital strategy and transformed areas
C2	Awareness level of the industry
C3	Organizational restructuring
C4	Innovate by rapid experimentation
C5	Turn data into assets
C6	Consulting
C7	Harness customer networks
C8	Business model innovation
C9	Coordination among project parties
C10	Perceived benefits from DX
(2)	People & Culture
C11	Willingness of staffs to learn new technology
C12	Organizational culture & work environment
C13	DX training programs
C14	Availability of qualified staff and competent technical support team within company
C15	Relationships and knowledge sharing with other firms
C16	Commitment of employees
C17	Client's attitude with DX
C18	Pressure from competitors
C19	Interdepartmental communication
(3)	Process & Governance
C20	Effective monitoring of progress
C21	Effective leadership
C22	Financial support from the government
C23	DX legislation
(4)	Technology & Capabilities

Code	CSFs Categories
C24	Availability of information and technology
C25	Financial resources of organization
C26	Data security
C27	Maintenance and upgrade cost (software, hardware)
C28	Organizational flexibility or adaptability to market
C29	Research and development capability of organization
C30	Technical support and customer feedback from software and hardware suppliers

Table 5-7 summaries the CSFs by different categories.

Table 5-7. Categories of CSFs

Categories	CSFs
Strategy & Vision	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10
People & Culture	C11, C12, C13, C14, C15, C16, C17, C18, C19
Process & Governance	C20, C21, C22, C23
Technology & Capabilities	C24, C25, C26, C27, C28, C29, C30

5.3 Final CSFs linked with steps of DX roadmap

Figure 5-4 and Table 5-8 shows the final CSFs linked with the steps of DX roadmap. After conducting in-depth interviews with four experts, the CSFs linked with steps of DX roadmap are kept the same as preliminary CSFs linked with the steps of DX roadmap.

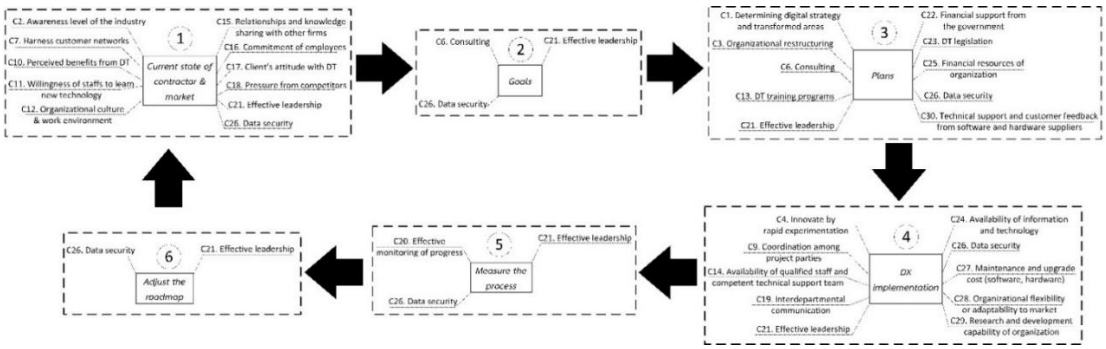

Figure 5-4. Final CSFs linked with steps of DX roadmap

Table 5-8. CSFs linked with steps of DX roadmap

Steps	Description	CSFs
Step 1	Current state of contractor & market	C2, C7, C10, C11, C12, C15, C16, C17, C18, C21, C26
Step 2	Goals	C6, C21, C26
Step 3	Plans	C1, C3, C6, C13, C21, C22, C23, C25, C26, C30
Step 4	DX implementation	C4, C9, C14, C19, C21, C24, C26, C27, C28, C29
Step 5	Measure the process	C20, C21, C26
Step 6	Adjust the roadmap	C21, C26

5.4 Summary

In this chapter, three rounds of in-depth interviews with experts were conducted. The first round of interviews was to finalize the DX roadmap from preliminary DX roadmap. The second round of interviews was to finalize the list of CSFs from the preliminary list. From preliminary thirty-seven CSFs, after processing the interview results, thirty CSFs were gained. The experts were asked to group thirty CSFs into four categories: (1) Strategy & Vision, (2) People & Culture, (3) Process & Governance and (4) Technology & Capabilities.

The purpose of the third round of interviews was to establish the linkage between the Critical Success Factors (CSFs) and the steps outlined in the DX roadmap. Multiple sub-rounds of personal interviews were conducted with the

experts to finalize the CSFs associated with each step of the DX roadmap. The interview process continued until a consensus was reached among all the experts regarding the final CSFs linked with the steps of the DX roadmap. In the next chapter, a pilot survey and large-scale survey are operated to rank the CSFs regarding contractors' DX implementation and check the internal consistency reliability.

Chapter 6

RANKING CSFs

This chapter demonstrates the steps to rank the CSFs. Pilot survey and large-scale survey are used to collect the data. Reliability test and ranking analysis are applied to analyze survey results. SPSS (Statistical Package for the Social Sciences) software is employed to run the reliability test and ranking analysis. One-way ANOVA is used to analyze whether there are significant differences in the means of different groups of respondents.

6.1 Pilot survey

The purpose of this pilot survey is to conduct the questionnaire survey on a small scale before distributing the questionnaire to the large-scale survey. The responses from the pilot survey are handled and analyzed to make the questionnaire better in terms of structure and ease of understanding. Ranking analysis is used for screening the CSFs. If the mean scores of factors are too low (mean score < 3.0), those factors are eliminated.

6.1.1 Data summary

The questionnaire survey was distributed to a predefined group of fourteen respondents who are employed in the construction industry in Vietnam. All fourteen respondents are experts in digital technologies relevant to the construction industry, such as BIM, AR, VR, IoT, and others. Fourteen responses were received, resulting in a response rate of one hundred percent. The profile of fourteen experts are shown in Table 6-1 of and summary of the basic data of fourteen respondents about the years of experience and type of company they are working for is shown in Table 6-2. Among the respondents, two have more than ten years of experience and twelve have five to ten years of experience. Furthermore, there are seven respondents from

contractor companies, five from consultant firms, and two from other types of companies.

Table 6-1. Profile of fourteen experts

Expert No	Type of companies	Position	Experience
1	Consultants	BIM coordinator	6 years
2	Contractors	BIM coordinator	8 years
3	Contractors	Engineers	8 years
4	Contractors	Engineers	6 years
5	Consultants	BIM manager	8 years
6	Others	Engineers	7 years
7	Contractors	BIM manager	12 years
8	Contractors	BIM coordinator	10 years
9	Consultants	Engineers	8 years
10	Consultants	Digital construction manager	14 years
11	Consultants	Engineers	8 years
12	Others	Project executive	8 years
13	Contractors	Site manager	8 years
14	Contractors	Engineers	8 years

Table 6-2. Basic data of the pilot survey ‘s respondents

Years of Experience		Types of Companies	
> 10 years	2 respondents	Contractors	7 respondents
5-10 years	12 respondents	Consultants	5 respondents
		Others	2 respondents

6.1.2 Results

In SPSS software, ranking analysis typically involves the calculation of ranks based on the absolute values of variables. SPSS uses the absolute values assigned to each item to determine their rank order. The ranks are determined by sorting the values in descending order.

The output from SPSS software after analyzing the data from the pilot survey is presented in Table 6-3. Thirty factors are arranged in descending order by mean score (absolute value). When two or more factors have the same mean score, the factors with the lower standard deviation are given higher rankings.

Table 6-3. SPSS output of the pilot survey

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C21	14	4	5	4.57	.514
C10	14	4	5	4.57	.514
C5	14	4	5	4.43	.514
C11	14	3	5	4.43	.646
C1	14	3	5	4.36	.633
C13	14	3	5	4.36	.745
C26	14	2	5	4.29	.914
C9	14	3	5	4.21	.699
C6	14	3	5	4.14	.663
C12	14	2	5	4.14	.949
C7	14	2	5	4.14	.864
C25	14	3	5	4.14	.663
C29	14	3	5	4.14	.770
C28	14	3	5	4.07	.829
C24	14	3	5	4.07	.730
C23	14	3	5	4.07	.730
C8	14	2	5	4.07	.917
C19	14	2	5	4.07	.917

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C17	14	1	5	4.00	1.038
C30	14	1	5	4.00	1.240
C27	14	2	5	3.93	.997
C18	14	2	5	3.93	.917
C20	14	2	5	3.86	.949
C4	14	3	5	3.86	.770
C14	14	2	5	3.79	.975
C16	14	3	5	3.79	.802
C2	14	2	5	3.71	.914
C3	14	2	5	3.64	.842
C15	14	2	5	3.57	.852
C22	14	2	5	3.50	.941

The top three CSFs for the pilot survey are illustrated in Table 6-4. The most important factor is C21 - Effective leadership with a mean score of 4.57 and a standard deviation of 0.514. The second important factor is C10 - Perceived benefits from DX has a mean score of 4.57 and a standard deviation of 0.514. The third important factor is C5 - Turn data into assets with a mean score of 4.43 and a standard deviation of 0.514.

Table 6-4. Top three CSFs for the pilot survey

Code	CSFs	Mean	Std. Deviation
C21	Effective leadership	4.57	0.514
C10	Perceived benefits from DX	4.57	0.514
C5	Turn data into assets	4.43	0.514

6.2 Large-scale survey

Once the pilot survey is accomplished, the large-scale survey is conducted. After analyzing the responses from the pilot survey, all the thirty CSFs have mean

scores equal to or over 3.0. Therefore, all the thirty CSFs are brought into the large-scale survey.

6.2.1 Data summary

The questionnaire survey is sent out to the respondents who work in the construction industry in Vietnam. Eighty-six questionnaire survey forms were sent out. A total of seventy-two responses were received. The response rate is eighty-four percent. The basic data of seventy-two respondents about the years of experience and type of company they are working for is shown in Table 6-5. There are ten respondents with experience of more than ten years, thirty-six respondents with five to ten years in experience, and twenty-six respondents with three to five years of working experience. There are thirty-nine respondents from contractors, seventeen respondents from consultants, nine respondents from owner, and seven respondents are from other types of company.

"There should be at least twice as many subjects as variables in factor analytic investigations" (Kline, 1979, 2014). In this research, the total number of factors is thirty, the total number of responses is seventy-two and the subjects-to-variables ratio = 72/30 = 2.4. Besides, DX in the construction industry is a new topic and not many people have knowledge about this. Therefore, seventy-five responses in this research are acceptable.

Table 6-5. Basic data of the large-scale survey 's respondents

Years of Experience		Types of Companies	
> 10 years	10 respondents	Contractors	39 respondents
5-10 years	36 respondents	Consultants	17 respondents
3-5 years	26 respondents	Owners	9 respondents
		Others	7 respondents

6.2.2 Reliability test

This section presents the results from the reliability test to show Cronbach's Alpha index for the large-scale questionnaire survey. It is necessary to do the reliability test for each group of factors because the CSFs are divided into four groups before conducting the large-scale survey. The Cronbach's Alpha for each group is described in Figure 6-1. Group 1 (Strategy & Vision) has the highest Cronbach's Alpha with 0.819. The next one is group 4 (Technology & Capabilities) with 0.821. Group 2 (People & Culture) is 0.789 and the third group (Process & Governance) has the lowest index with 0.659. The reason that the third group has the lowest Cronbach's Alpha is that the third group has the lowest number of factors with only four factors. The values are all greater than 0.6, indicating acceptable and good internal consistency reliability.

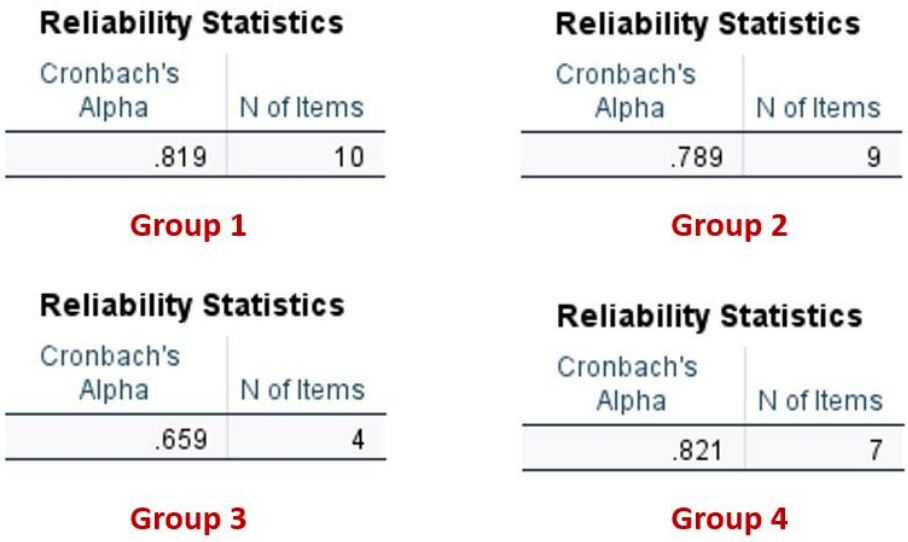

Figure 6-1. Cronbach's Alpha for four groups of CSFs

6.2.3 Ranking analysis

In SPSS software, ranking analysis typically involves the calculation of ranks based on the absolute values of variables. SPSS uses the absolute values assigned to

each item to determine their rank order. The ranks are determined by sorting the values in descending order.

In this research, the output from SPSS software after analyzing the data from the large-scale survey is presented in Table 6-5. Thirty factors are arranged in descending order by mean score (absolute value). When two or more factors have the same mean score, the factors with the lower standard deviation are given higher rankings.

Table 6-6. SPSS output of the large-scale survey

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C21	72	2	5	4.44	.767
C5	72	3	5	4.33	.671
C26	72	2	5	4.32	.766
C25	72	2	5	4.26	.769
C24	72	3	5	4.25	.765
C11	72	1	5	4.25	.852
C1	72	3	5	4.22	.736
C29	72	3	5	4.19	.642
C20	72	2	5	4.19	.781
C19	72	1	5	4.18	.954
C13	72	2	5	4.18	.757
C12	72	1	5	4.18	.877
C10	72	2	5	4.14	.718
C30	72	1	5	4.12	.838
C28	72	3	5	4.11	.662
C7	72	2	5	4.08	.746
C14	72	2	5	4.04	.830
C4	72	2	5	4.03	.822
C23	72	2	5	3.99	.896
C6	72	2	5	3.99	.896
C27	72	2	5	3.97	.769
C18	72	1	5	3.97	.993
C3	72	2	5	3.97	.872
C8	72	2	5	3.92	.852
C16	72	1	5	3.90	.937

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C17	72	1	5	3.86	.893
C9	72	2	5	3.86	.756
C22	72	1	5	3.81	1.030
C15	72	2	5	3.69	.816
C2	72	2	5	3.64	.909

The group rank of CSFs for Strategy & Vision, People & Culture, Process & Governance and Technology & Capabilities are presented in Table 6-7,

Table 6-8,

Table 6-9 and Table 6-10, respectively.

Table 6-7. Rank of CSFs of group 1 - Strategy & Vision

Code	CSFs Categories	Group	Overall
Group 1	Strategy & Vision	Rank	Rank
C5	Turn data into assets	1	2
C1	Determining digital strategy and transformed areas	2	7
C10	Perceived benefits from DX	3	13
C7	Harness customer networks	4	16
C4	Innovate by rapid experimentation	5	18
C6	Consulting	6	20
C3	Organizational restructuring	7	23
C8	Business model innovation	8	24
C9	Coordination among project parties	9	27
C2	Awareness level of the industry	10	30

Table 6-8. Rank of CSFs of group 2 - People & Culture

Code	CSFs Categories	Group	Overall
Group 2	People & Culture	Rank	Rank
C11	Willingness of staffs to learn new technology	1	6
C19	Interdepartmental communication	2	10

Code	CSFs Categories	Group Rank	Overall Rank
Group 2	People & Culture		
C13	DX training programs	3	11
C12	Organizational culture & work environment	4	12
C14	Availability of qualified staff and competent technical support team within company	5	17
C18	Pressure from competitors	6	22
C16	Commitment of employees	7	25
C17	Client's attitude with DX	8	26
C15	Relationships and knowledge sharing with other firms	9	29

Table 6-9. Rank of CSFs of group 3 - Process & Governance

Code	CSFs Categories	Group Rank	Overall Rank
Group 3	Process & Governance		
C21	Effective leadership	1	1
C20	Effective monitoring of progress	2	9
C23	DX legislation	3	19
C22	Financial support from the government	4	28

Table 6-10. Rank of CSFs of group 4 - Technology & Capabilities

Code	CSFs Categories	Group Rank	Overall Rank
Group 4	Technology & Capabilities		
C26	Data security	1	3
C25	Financial resources of organization	2	4
C24	Availability of information and technology	3	5
C29	Research and development capability of organization	4	8
C30	Technical support and customer feedback from software and hardware suppliers	5	14
C28	Organizational flexibility or adaptability to market	6	15
C27	Maintenance and upgrade cost (software, hardware)	7	21

The top three CSFs for the large-scale survey are illustrated in Table 6-11. The most important factor is C21 - Effective leadership with a mean score of 4.44 and a standard deviation of 0.767. The second important factor is C5 - Turn data into assets has a mean score of 4.33 and a standard deviation of 0.671. The third important factor is C26 - Data security with a mean score of 4.32 and a standard deviation of 0.766. The next section describes these three factors in detail.

(1) C21 - Effective leadership refers to the dedication and approach of senior management in facilitating digital transformation within an organization. It plays a crucial role in directing organizational resources towards the attainment of objectives. Effective leadership involves implementing the company's vision and mission, establishing the organizational tone and culture (Ramos, 2019). Effective leaders offer clear guidance and direction, motivating and guiding the organization towards achieving its mission and purpose (Indeed, 2021b). Moreover, leadership is an important function of management that helps to maximize efficiency and to achieve organizational goals.

(2) C5 - Turn data into assets is developing the clear vision and the growing capability needed to put data to work in the service of innovation and value creation. The Economist (2017) referred to data as the oil of the digital area. As sensors, networks and computing become more integrated into our daily lives, the amount of data available to businesses continues to expand at an exponential rate. Every organization can design a data strategy that informs essential decision-making and generates a new value for both business and customers by recognizing data as a significant intangible asset to be built over time (D. Rogers, 2016).

(3) C26 - Data security involves safeguarding data from unauthorized access and corruption throughout its lifecycle. By implementing robust data security measures, organizations can protect their information assets from cybercriminals, insider threats, and human errors, which are common causes of data breaches (IBM, 2021). Data encryption, hashing, tokenization, and key management are essential strategies for securing data across various applications and platforms (MicroFocus, 2021).

Table 6-11. Top three CSFs for the large-scale survey

Code	CSFs	Mean	Std. Deviation
C21	Effective leadership	4.44	0.767
C5	Turn data into assets	4.33	0.671
C26	Data security	4.32	0.766

To have a clear comparison between the top three CSFs for the pilot survey and the top three CSFs for the large-scale survey, the comparison details are provided in Table 6-12. In both survey, the pilot survey and the large-scale survey, C21 - Effective leadership and C5 - Turn data into assets stay in the top three CSFs. In the large-scale survey, C26 - Data security locates in the third position of the top three CSFs. From that, we can understand the importance of leadership and the factors related to data in the DX implementation. Commitment and approach of the

top management to facilitate DX within the organization play a critical role. Besides, the way that organizations use the data and transform it into assets and how organizations protect their data are also very essential.

Table 6-12. Comparison for the pilot survey and the large-scale survey

Pilot Survey		Large-scale survey	
Code	CSFs	Code	CSFs
C21	Effective leadership	C21	Effective leadership
C10	Perceived benefits from DX	C5	Turn data into assets
C5	Turn data into assets	C26	Data security

6.2.4 One-way ANOVA test

One-way ANOVA test is used to analyze whether there are significant differences in the means of different groups. In this research, one-way ANOVA test is applied to analyze the differences in the means of different types of construction firms (i.e. contractors, consultants, owners, and others) and different size of construction firms (i.e. large firms and medium-size firms). The procedure to apply one-way ANOVA test is presented in section 2.4.3.

a. Different types of construction firms

This section shows the results of one-way ANOVA test for factor C1 - Determining digital strategy and transformed areas. The results of thirty CSFs can be found in Appendix G. Descriptives, Levene test, ANOVA test, and Robust tests of factor C1 is shown in Table 6-13, Table 6-14, Table 6-15, and Table 6-16 respectively.

Table 6-13. Descriptives of factor C1

Descriptives

C1

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Contractors	39	4.05	.759	.122	3.81	4.30	3	5
Consultants	17	4.47	.717	.174	4.10	4.84	3	5
Owners	9	4.67	.500	.167	4.28	5.05	4	5
Others	7	4.00	.577	.218	3.47	4.53	3	5
Total	72	4.22	.736	.087	4.05	4.40	3	5

Table 6-14. Levene test of factor C1

Tests of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
C1	Based on Mean	1.378	3	68	.257
	Based on Median	.796	3	68	.500
	Based on Median and with adjusted df	.796	3	60.237	.501
	Based on trimmed mean	1.348	3	68	.266

Table 6-15. ANOVA test of factor C1

ANOVA

C1

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.312	3	1.437	2.863	.043
Within Groups	34.133	68	.502		
Total	38.444	71			

Table 6-16. Robust tests of factor C1

Robust Tests of Equality of Means

C1

	Statistic[a]	df1	df2	Sig.
Welch	3.678	3	20.217	.029

a. Asymptotically F distributed.

The Sig. value of factor C1 for Levene test is 0.257 > 0.05, it means the variances of four groups are the same. Therefore, we use the results from ANOVA

test table. The Sig. value of ANOVA test is 0.043 < 0.05, it means the mean of four groups are different or the alternative hypothesis (H_1) "there are significant differences in the means of different groups" is true. The same analysis is applied for other factors and presented in Appendix G.

b. Different size of construction firms

This section shows the results of one-way ANOVA test for factor C1 - Determining digital strategy and transformed areas. The full results of thirty CSFs can be found in Appendix G. Descriptives, Levene test, ANOVA test, and Robust tests of factor C1 is shown in Table 6-17, Table 6-18, Table 6-19, and Table 6-20 respectively.

Table 6-17. Descriptives of factor C1

Descriptives

C1

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Large firms	28	4.29	.659	.124	4.03	4.54	3	5
Medium-size firms	44	4.18	.786	.118	3.94	4.42	3	5
Total	72	4.22	.736	.087	4.05	4.40	3	5

Table 6-18. Levene test of factor C1

Tests of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
C1	Based on Mean	1.442	1	70	.234
	Based on Median	1.296	1	70	.259
	Based on Median and with adjusted df	1.296	1	69.861	.259
	Based on trimmed mean	1.416	1	70	.238

Table 6-19. ANOVA test of factor C1

ANOVA

C1

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.185	1	.185	.338	.563
Within Groups	38.260	70	.547		
Total	38.444	71			

Table 6-20. Robust tests of factor C1

Robust Tests of Equality of Means

C1

	Statistic[a]	df1	df2	Sig.
Welch	.366	1	64.716	.548

a. Asymptotically F distributed.

The Sig. value of factor C1 for Levene test is 0.234 > 0.05, it means the variances of four groups are the same. Therefore, we use the results from ANOVA test table. The Sig. value of ANOVA test is 0.563 > 0.05, it means the mean of four groups are the same or the null hypothesis (H_o) "there are no differences in the means of different groups" is true. The same analysis is applied for other factors and presented in Appendix G.

6.3 Summary

In this chapter, the responses from the pilot survey and the large-scale survey are analyzed to rank the CSFs and the reliability tests are conducted. One-way ANOVA test is used to analyze whether there are significant differences in the means of responses from different construction firms.

After the pilot survey, zero factors are excluded and all thirty CSFs are taken into the large-scale survey. The values of Cronbach's Alpha for four groups of CSFs are all greater than 0.6, indicating acceptable and good internal consistency reliability. The top three CSFs for the large-scale survey are Effective Leadership, Turn Data Into Assets and Data Security. When comparing the responses from different type of construction firms, C1, C8, C16, C17, C21, C27, C28 and C30 have the alternative hypothesis H_1, while other factors have null hypothesis H_0. Similarly, when comparing the responses from different size of construction firms, C22 and C29 have the alternative hypothesis H_1, while other factors have null hypothesis H_0.

In the next chapter, the relationships among the CSFs are investigated by using FCM method. Experts are asked to evaluate the relationship of each pair of

CSFs via in-depth interviews. FCM structure will be visualized, the graph indices will be calculated and the criteria will be ranked based on their outdegree, indegree and centrality value.

Chapter 7

ANALYZING RELATIONSHIP AMONG CSFs

This chapter presents the steps of Fuzzy Cognitive Map (FCM) to analyze the causal relationship among the CSFs. FCM comprises eight steps as described in Chapter 2, those steps are obtaining the evaluation criteria, determining the linguistic term, obtaining the evaluations of experts, aggregating the evaluation matrices, defuzzification of the group-based fuzzy decision matrix, constructing the FCM, calculating the graph indices and ranking the criteria. “FCM Expert” software developed by Nápoles et al. (2018) is used to visualize the interrelationship among the factors.

7.1 Fuzzy Cognitive Map

Using the FCM technique helps construction contractors gain insights into the relationships among the factors, so they know how the factors affect each other to help them wisely invest their resources in the DX journey. An FCM allows simulating a system or phenomenon by using important concepts and causal links. In the case of complex systems, FCM models are highly suited and beneficial for modeling and decision-making (Poczeta et al., 2020). FCM also allows scenario analysis for future situations (Büyüközkan et al., 2019). FCM includes eight main steps (1) Obtain the evaluation criteria, (2) Determine the linguistic term, (3) Obtain the evaluations of experts, (4) Aggregate the evaluation matrices, (5) Defuzzify the group-based fuzzy decision matrix, (6) Construct the FCM, (7) Calculate the graph indices and (8) Rank the criteria. In the next section, each step will be presented in detail.

7.1.1 Obtaining the evaluation criteria

The final CSFs obtained from Chapter 5 are used as evaluation criteria for the FCM analyses. There is a total of thirty CSFs and these thirty CSFs are grouped into four different clusters (1) Strategy & Vision, (2) People & Culture, (3) Process & Governance and (4) Technology & Capabilities. The details about these thirty CSFs are illustrated in Table 7-1.

Table 7-1. Evaluation criteria

Code	CSFs Categories
Group 1	Strategy & Vision
C1	Determining digital strategy and transformed areas
C2	Awareness level of the industry
C3	Organizational restructuring
C4	Innovate by rapid experimentation
C5	Turn data into assets
C6	Consulting
C7	Harness customer networks
C8	Business model innovation
C9	Coordination among project parties
C10	Perceived benefits from DX
(2)	People & Culture
C11	Willingness of staffs to learn new technology
C12	Organizational culture & work environment
C13	DX training programs
C14	Availability of qualified staff and competent technical support team within company
C15	Relationships and knowledge sharing with other firms
C16	Commitment of employees
C17	Client's attitude with DX
C18	Pressure from competitors

Code	CSFs Categories
C19	Interdepartmental communication
(3)	Process & Governance
C20	Effective monitoring of progress
C21	Effective leadership
C22	Financial support from the government
C23	DX legislation
(4)	Technology & Capabilities
C24	Availability of information and technology
C25	Financial resources of organization
C26	Data security
C27	Maintenance and upgrade cost (software, hardware)
C28	Organizational flexibility or adaptability to market
C29	Research and development capability of organization
C30	Technical support and customer feedback from software and hardware suppliers

7.1.2 Determining the linguistic term

After obtaining the evaluation criteria, a linguistic term set or evaluation scale is determined in the next step. Triangular fuzzy numbers (TFNs) are used during the computational steps. The used scale in this research is given in Table 7-2. This evaluation scale along with the evaluation criteria (thirty CSFs) are presented to experts to ask for their evaluation. To help experts understand the evaluation scale more easily, additional explanations are provided:

1) Positive relation: A increases (decreases) → B increases (decreases)

2) Negative relation: A increases (decreases) → B decreases (increases)

3) Ex1: A increases by a small amount, B increases by a large amount → high positive

4) Ex2: A increases by a large amount, B increases by a small amount → low positive

5) Ex3: A increases by a small amount, B decreases by a large amount → high negative

6) Ex4: A increases by a large amount, B decreases by a small amount → low negative

Table 7-2. Evaluation scale

Linguistic terms	TFNs	Code
Very high positive relation	(1.00, 1.00, 0.75)	VHP (4)
High positive relation	(1.00, 0.75, 0.50)	HP (3)
Medium positive relation	(0.75, 0.50, 0.25)	MP (2)
Low positive relation	(0.50, 0.25, 0.00)	LP (1)
No relation, zero	(0.25, 0.00, -0.25)	Z (0)
Low negative relation	(0.00, -0.25, -0.50)	LN (-1)
Medium negative relation	(-0.25, -0.50, -0.75)	MN (-2)
High negative relation	(-0.50, -0.75, -1.00)	HN (-3)
Very high negative relation	(-0.75, -1.00, -1.00)	VHN (-4)

7.1.3 Obtaining the evaluations of experts

Experts are asked to rate the relationships between the evaluation criteria in Table 7-1 by using evaluation scale in Table 7-2. In-depth interviews are conducted via online platforms. There is total of seventeen experts joining this round of interviews and seventeen evaluation matrices are obtained. The basic data of seventeen experts about the years of experience and type of company they are working for is shown in Table 7-3. Due to page limitation, only one expert response is shown in Table 7-4 and transformed linguistic terms into TFNs shown in Table 7-5.

Table 7-3. Basic data of the experts for FCM

Years of Experience		Types of Companies	
> 10 years	5 experts	Contractors	9 experts

Years of Experience		Types of Companies	
5-10 years	9 experts	Consultants	6 experts
3-5 years	3 experts	Others	2 experts

Table 7-4. Linguistic terms evaluation from one expert

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**...**	**C30**
C1	0	4	3	3	4	...	3
C2	4	0	3	3	4	...	3
C3	3	3	0	3	4	...	2
C4	3	3	3	0	4	...	3
C5	4	4	4	4	0	...	4
...	...	...	...	...	...	...	...
C30	3	3	2	3	4	...	0

Table 7-5. Transformed linguistic terms into TFNs from one expert

Criteria	C1	C2	C3	C4	C5	...	C30
C1	(0.25, 0.00, -0.25)	(1.00, 1.00, 0.75)	(1.00, 0.75, 0.50)	(1.00, 0.75, 0.50)	(1.00, 1.00, 0.75)	...	(1.00, 0.75, 0.50)
C2	(1.00, 1.00, 0.75)	(0.25, 0.00, -0.25)	(1.00, 0.75, 0.50)	(1.00, 0.75, 0.50)	(1.00, 1.00, 0.75)	...	(1.00, 0.75, 0.50)
C3	(1.00, 0.75, 0.50)	(1.00, 0.75, 0.50)	(0.25, 0.00, -0.25)	(1.00, 0.75, 0.50)	(1.00, 1.00, 0.75)	...	(0.75, 0.50, 0.25)
C4	(1.00, 0.75, 0.50)	(1.00, 0.75, 0.50)	(1.00, 0.75, 0.50)	(0.25, 0.00, -0.25)	(1.00, 1.00, 0.75)	...	(1.00, 0.75, 0.50)
C5	(1.00, 1.00,	(1.00, 1.00,	(1.00, 1.00,	(1.00, 1.00, 0.75)	(0.25, 0.00,	...	(1.00, 1.00, 0.75)

Criteria	C1	C2	C3	C4	C5	...	C30
	0.75)	0.75)	0.75)		-0.25)		
...	...	...	...	...	...	...	...
C30	(1.00, 0.75, 0.50)	(1.00, 0.75, 0.50)	(0.75, 0.50, 0.25)	(1.00, 0.75, 0.50)	(1.00, 1.00, 0.75)	...	(0.25, 0.00, -0.25)

7.1.4 Aggregating the evaluation matrices

As presented in Chapter 2, the aggregated relation degree $\widetilde{w}_{ij}^{agg}$ is defined as below:

$$\widetilde{w}_{ij}^{agg} = \left(l_{ij}^{agg}, m_{ij}^{agg}, u_{ij}^{agg}\right) \quad (6.1)$$

where,

$$l_{ij}^{agg} = min\{l\} = min(l_1, l_2, l_3, \dots, l_n) \quad (6.2)$$

$$m_{ij}^{agg} = \frac{1}{n}\sum(m_1, m_2, m_3, \dots, m_n) \quad (6.3)$$

$$u_{ij}^{agg} = max\{u\} = max(u_1, u_2, u_3, \dots, u_n) \quad (6.4)$$

n = number of experts

$\widetilde{w}_{ij}^{agg}$ = aggregated relation degree between the nodes C_i and C_j

l_{ij}^{agg} = lower value in triangular fuzzy numbers set of aggregated relation degree between the nodes C_i and C_j

m_{ij}^{agg} = middle value in triangular fuzzy numbers set of aggregated relation degree between the nodes C_i and C_j

u_{ij}^{agg} = upper value in triangular fuzzy numbers set of aggregated relation degree between the nodes C_i and C_j

7.1.5 Defuzzification of the group-based fuzzy decision matrix

As presented in Chapter 2, the triangular fuzzy numbers are converted to crisp number by using center of gravity method. It is shown as below:

$$w_{ij} = \frac{l_{ij}^{agg} + m_{ij}^{agg} + u_{ij}^{agg}}{3} \quad (6.5)$$

7.1.6 Constructing the FCM

The FCM structure is visualized by using the links and the weights of the links between the nodes. “FCM Expert” software developed by Nápoles et al. (2018) is used in this step. The detailed FCM structure is illustrated in Figure 7-1. The weights of links are shown in Appendix H.

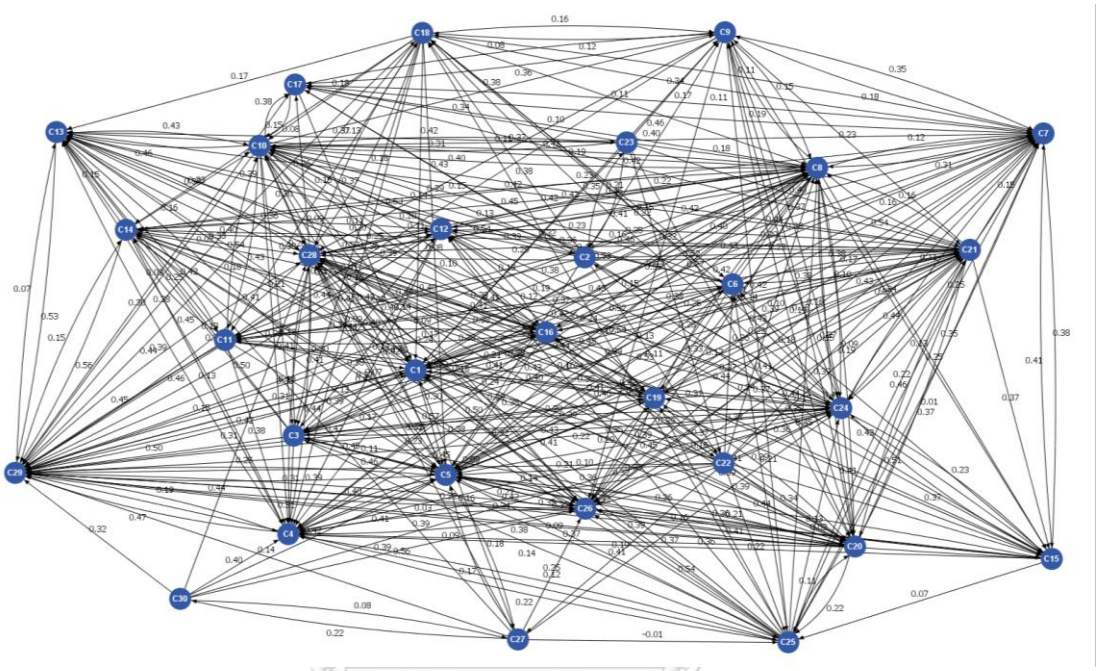

Figure 7-1. Constructed FCM for the CSFs of DX implementation

7.1.7 Calculating the graph indices

Outdegree, indegree and centrality value are calculated as follows:

$$od(C_i) = \sum_{j=1}^{N} \overline{w_{ij}} \qquad (6.6)$$

$$id(C_i) = \sum_{j=1}^{N} \overline{w_{ji}} \qquad (6.7)$$

$$c_i = td(C_i) = od(C_i) + id(C_i) \qquad (6.8)$$

Calculated values for thirty criteria are shown in Table 7-6 as follows:

Table 7-6. Graph index values

Criteria	Indegree	Outdegree	Total degree
C1	4.59	6.61	11.20
C2	1.15	2.65	3.80
C3	3.36	3.68	7.04

Criteria	Indegree	Outdegree	Total degree
C4	6.87	1.91	8.78
C5	7.79	4.82	12.61
C6	2.64	4.61	7.25
C7	5.38	2.82	8.20
C8	6.47	3.73	10.20
C9	2.71	2.95	5.66
C10	5.02	6.81	11.83
C11	3.88	3.87	7.75
C12	3.47	3.76	7.23
C13	6.04	2.14	8.18
C14	2.84	4.31	7.15
C15	3.65	3.28	6.93
C16	2.90	5.48	8.38
C17	3.10	0.54	3.64
C18	0.83	2.31	3.14
C19	4.15	3.36	7.51
C20	4.90	4.74	9.64
C21	5.02	8.65	13.67
C22	0.90	4.22	5.12
C23	0.77	3.47	4.24
C24	4.10	5.68	9.78
C25	1.47	5.63	7.10
C26	4.89	2.47	7.36
C27	0.45	1.44	1.89
C28	8.18	5.19	13.37
C29	9.18	3.34	12.52
C30	0.22	2.45	2.67

7.1.8 Ranking the criteria

Thirty criteria are ranked according to their indegree, outdegree and centrality value in desending order. It shows the most influenced criteria, the most influencing

criteria and the most important criteria, respectively. These values are presented in Table 7-7.

Table 7-7. Ranked graph index values

Ranked Order	Criteria	Indegree	Criteria	Outdegree	Criteria	Total Degree
1	C29	9.18	C21	8.65	C21	13.67
2	C28	8.18	C10	6.81	C28	13.37
3	C5	7.79	C1	6.61	C5	12.61
4	C4	6.87	C24	5.68	C29	12.52
5	C8	6.47	C25	5.63	C10	11.83
6	C13	6.04	C16	5.48	C1	11.20
7	C7	5.38	C28	5.19	C8	10.20
8	C10	5.02	C5	4.82	C24	9.78
9	C21	5.02	C20	4.74	C20	9.64
10	C20	4.9	C6	4.61	C4	8.78
11	C26	4.89	C14	4.31	C16	8.38
12	C1	4.59	C22	4.22	C7	8.20
13	C19	4.15	C11	3.87	C13	8.18
14	C24	4.1	C12	3.76	C11	7.75
15	C11	3.88	C8	3.73	C19	7.51
16	C15	3.65	C3	3.68	C26	7.36
17	C12	3.47	C23	3.47	C6	7.25
18	C3	3.36	C19	3.36	C12	7.23
19	C17	3.1	C29	3.34	C14	7.15
20	C16	2.9	C15	3.28	C25	7.10
21	C14	2.84	C9	2.95	C3	7.04
22	C9	2.71	C7	2.82	C15	6.93
23	C6	2.64	C2	2.65	C9	5.66
24	C25	1.47	C26	2.47	C22	5.12
25	C2	1.15	C30	2.45	C23	4.24
26	C22	0.9	C18	2.31	C2	3.80
27	C18	0.83	C13	2.14	C17	3.64
28	C23	0.77	C4	1.91	C18	3.14

Ranked Order	Criteria	Indegree	Criteria	Outdegree	Criteria	Total Degree
29	C27	0.45	C27	1.44	C30	2.67
30	C30	0.22	C17	0.54	C27	1.89

The results show that the three most influencing criteria are ‘C21 - Effective leadership’, ‘C10 - Perceived benefits from DX’ and ‘C1 - Determining digital strategy and transformed areas’. The three most influenced criteria are ‘C29 - Research and development capability of organization’, ‘C28 - Organizational flexibility or adaptability to market’ and ‘C5 - Turn data into assets’.

The three most important criteria are ‘C21 - Effective leadership’, ‘C28 - Organizational flexibility or adaptability to market’ and ‘C5 - Turn data into assets’. From that, we can understand the importances of leadership, the flexibility of organization and the factor related to data in the DX implementation. The commitment and approach of the top management to facilitate DX within the organization plays a critical role in the DX journey. Besides, the ability of organization to adapt to the change of market is crucial in the present dynamic construction industry. Finally, the way that organizations use the data and transform it into assets is also essential.

Table 7-8 compares the results from large-scale survey and FCM. C21 - Effective leadership and C5 - Turn data into assets stay in the top three CSFs. This result matches with the result from the comparison of top three CSFs of pilot survey and large-scale survey. From that, we can understand the importance of the leadership and the factors related to data in the DX implementation. Moreover, the flexibility of organization and adaptability to market also play a critical role in the DX transformation journey.

Table 7-8. Comparison for the large-scale survey and FCM results

Large-scale survey		FCM	
Code	CSFs	Code	CSFs
C21	Effective leadership	C21	Effective leadership
C5	Turn data into assets	C28	Organizational flexibility or adaptability to market
C26	Data security	C5	Turn data into assets

7.2 Summary

In this chapter, eight steps of the FCM technique are presented. The relationship among the thirty CSFs is analyzed. The results show that the three most influencing criteria are C21, C10 and C1. The three most influenced criteria C29, C28 and C5. The three most important criteria are C21, C28 and C5.

In the next chapter, the steps for verifying the research results are described. The results of DX roadmap, DX process measuring, final CSF list, CSFs ranking and relationships among CSFs are presented to the experts. The experts are asked whether they are satisfied with the results. They are also asked if they have any comments or suggestions about the research results.

Chapter 8

VERIFYING THE RESEARCH RESULTS

In this chapter, the final research step is conducted. It is the process of research results verification. The results of previous steps of the research, which are DX roadmap, final CSFs linked with steps of DX roadmap, CSFs ranking and relationships among CSFs (FCM), respectively, are the input of this process. Questionnaire surveys are distributed to five experts to review the research results as well as get their comments and suggestions. The chapter starts with the concept of research verification. Next, there are sections dedicated to verifying each research result. Finally, the summary section is presented.

8.1 Concept of research verification

Verification in qualitative research encompasses various procedures utilized throughout the research process to ensure reliability, validity, and rigor. This includes checking, verifying, assuring, and establishing certainty as part of the verification process (Morse et al., 2002). Respondent validation can also be used to assess the validity of qualitative research. This method involves having participants test initial results to check if they are still valid. The reliability of outcomes is the foundation of good qualitative research. Member checking, also referred to as participant or respondent validation, is a method used to assess the credibility of research findings. In this technique, participants are provided with the research data or outcomes to review and confirm their accuracy and relevance based on their own experiences (Pegaswitch, 2022).

Respondent validation is a technique that can be used to assess the validity of qualitative research. This method entails evaluating preliminary findings with participants to see if they are still valid. Participants should still accept the results as authentic, even if the research has been interpreted and shortened. At this point,

they may even be able to refine the researcher's knowledge. One measure of validity in qualitative research is to ask questions such as: “Does it make sense?” and “Can I trust it?” (Statistics Solutions, 2022)

In this research, questionnaire surveys are utilized to get feedback from experts for research verification. There is a total of five experts involved in this process. The profiles of the respondents are summarized in Table 8-1. The verification process is conducted by presenting the research results to the experts and getting the satisfaction rating, comments as well as suggestions. The results of the verification process are summarized at the end of this chapter.

Table 8-1. Profiles of respondents

Respondent No.	Experience	Type of company	Position
1	> 10 years	DX consulting	Directors
2	> 10 years	Contractors	Head of department
3	5 - 10 years	Contractors	Engineer
4	5 - 10 years	Contractors	Engineer
5	5 - 10 years	Contractors	Engineer

8.2 Verification of research results

8.2.1 Verification of DX roadmap

DX roadmap is shown to the experts and they are asked about their satisfaction with the roadmap. The experts are also asked to give comments and suggestions for the DX roadmap result. Figure 8-1 shows the DX roadmap.

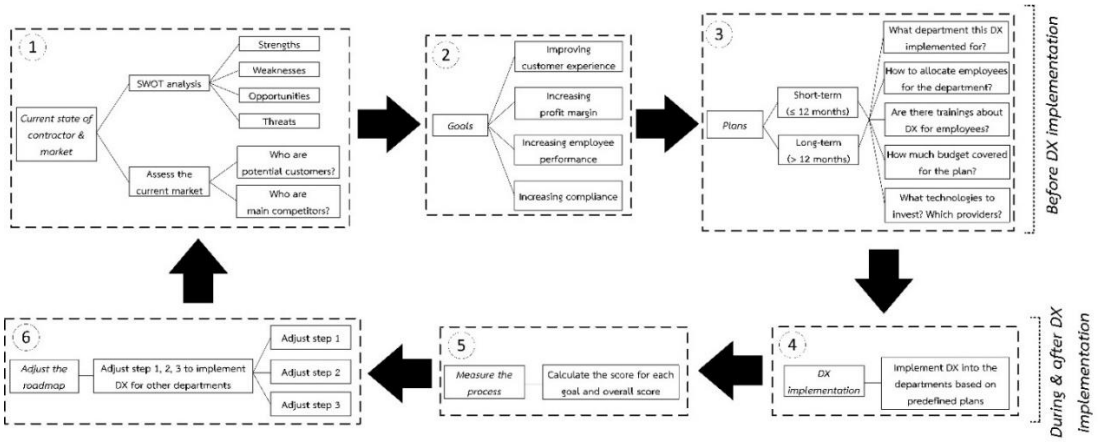

Figure 8-1. DX roadmap

8.2.2 Verification of final CSF list

The final thirty CSF list and the CSFs linked with steps of DX roadmap are presented to the experts and they are asked about their satisfaction with the results. They are also asked to provide comments and suggestions. Table 8-2 illustrates the final thirty CSFs.

Table 8-2. Final thirty CSFs

Code	CSFs Categories
Group 1	Strategy & Vision
C1	Determining digital strategy and transformed areas
C2	Awareness level of the industry
C3	Organizational restructuring
C4	Innovate by rapid experimentation
C5	Turn data into assets
C6	Consulting
C7	Harness customer networks
C8	Business model innovation
C9	Coordination among project parties
C10	Perceived benefits from DX
(2)	People & Culture
C11	Willingness of staffs to learn new technology

Code	CSFs Categories
C12	Organizational culture & work environment
C13	DX training programs
C14	Availability of qualified staff and competent technical support team within company
C15	Relationships and knowledge sharing with other firms
C16	Commitment of employees
C17	Client's attitude with DX
C18	Pressure from competitors
C19	Interdepartmental communication
(3)	Process & Governance
C20	Effective monitoring of progress
C21	Effective leadership
C22	Financial support from the government
C23	DX legislation
(4)	Technology & Capabilities
C24	Availability of information and technology
C25	Financial resources of organization
C26	Data security
C27	Maintenance and upgrade cost (software, hardware)
C28	Organizational flexibility or adaptability to market
C29	Research and development capability of organization
C30	Technical support and customer feedback from software and hardware suppliers

Figure 8-2 illustrates the CSFs linked with steps of DX roadmap and Table 8-3 summaries the CSFs linked with steps of DX roadmap.

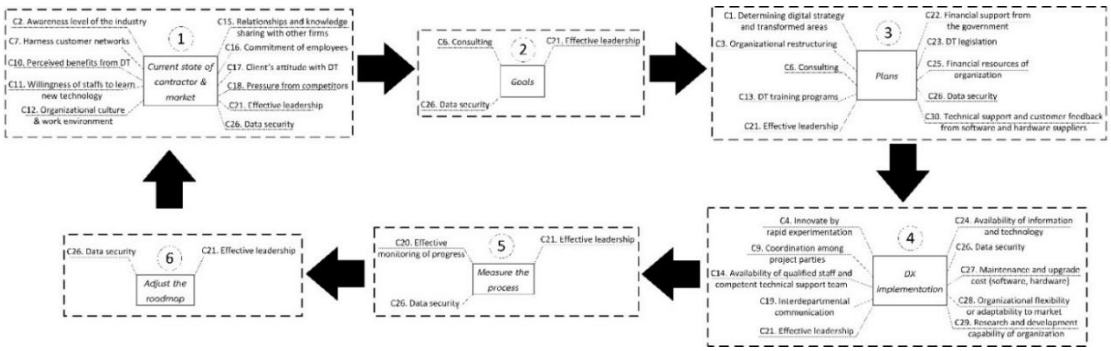

Figure 8-2. CSFs linked with steps of DX roadmap

Table 8-3. CSFs linked with steps of DX roadmap

Steps	Description	CSFs
Step 1	Current state of contractor & market	C2, C7, C10, C11, C12, C15, C16, C17, C18, C21, C26
Step 2	Goals	C6, C21, C26
Step 3	Plans	C1, C3, C6, C13, C21, C22, C23, C25, C26, C30
Step 4	DX implementation	C4, C9, C14, C19, C21, C24, C26, C27, C28, C29
Step 5	Measure the process	C20, C21, C26
Step 6	Adjust the roadmap	C21, C26

8.2.3 Verification of CSFs ranking

The ranking result of thirty CSFs is presented to the expert and they are asked to rate their satisfaction with the results. They are also asked to provide comments and suggestions. The ranking of thirty CSFs is described in Table 8-4.

Table 8-4. CSFs ranking

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C21	75	2	5	4.45	0.759
C5	75	3	5	4.35	0.668
C26	75	2	5	4.33	0.759
C11	75	1	5	4.28	0.847
C25	75	2	5	4.27	0.759
C24	75	3	5	4.27	0.759
C1	75	3	5	4.25	0.737

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C29	75	3	5	4.20	0.637
C20	75	2	5	4.20	0.771
C12	75	1	5	4.19	0.865
C19	75	1	5	4.19	0.940
C13	75	2	5	4.19	0.748
C10	75	2	5	4.16	0.717
C30	75	1	5	4.12	0.838
C28	75	3	5	4.11	0.669
C7	75	2	5	4.08	0.731
C14	75	2	5	4.04	0.829
C4	75	2	5	4.04	0.813
C6	75	2	5	4.01	0.893
C23	75	2	5	4.00	0.885
C18	75	1	5	3.99	0.979
C3	75	2	5	3.99	0.862
C27	75	2	5	3.99	0.762
C8	75	2	5	3.95	0.853
C16	75	1	5	3.91	0.932
C9	75	2	5	3.89	0.764
C17	75	1	5	3.85	0.896
C22	75	1	5	3.80	1.027
C15	75	2	5	3.71	0.818
C2	75	2	5	3.67	0.905

8.2.4 Verification of FCM of CSFs

The FCM of CSFs is presented to the expert and they are asked to rate their satisfaction with the results. They are also asked to provide comments and suggestions. Constructed FCM for the CSFs of DX implementation for contractors is indicated Figure 8-3. Outdegree, indegree and centrality values for each factors are shown in Table 8-5 and ranked graph index values are illustrated in Table 8-6.

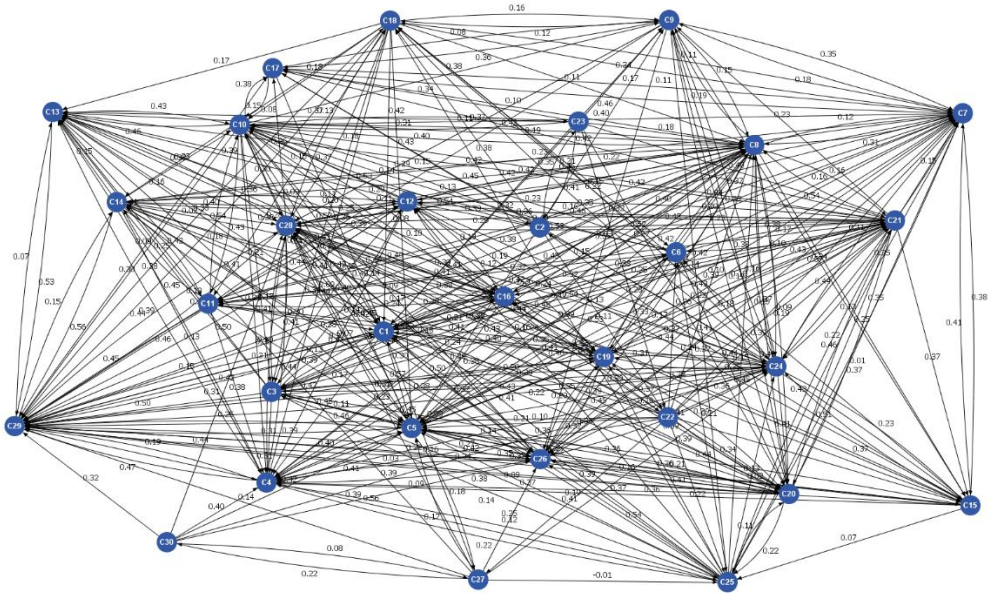

Figure 8-3. Constructed FCM for the CSFs of DX implementation

Table 8-5. Graph index values

Criteria	Indegree	Outdegree	Total degree
C1	4.59	6.61	11.20
C2	1.15	2.65	3.80
C3	3.36	3.68	7.04
C4	6.87	1.91	8.78
C5	7.79	4.82	12.61
C6	2.64	4.61	7.25
C7	5.38	2.82	8.20
C8	6.47	3.73	10.20
C9	2.71	2.95	5.66
C10	5.02	6.81	11.83
C11	3.88	3.87	7.75
C12	3.47	3.76	7.23
C13	6.04	2.14	8.18
C14	2.84	4.31	7.15
C15	3.65	3.28	6.93
C16	2.90	5.48	8.38
C17	3.10	0.54	3.64
C18	0.83	2.31	3.14

Criteria	Indegree	Outdegree	Total degree
C19	4.15	3.36	7.51
C20	4.90	4.74	9.64
C21	5.02	8.65	13.67
C22	0.90	4.22	5.12
C23	0.77	3.47	4.24
C24	4.10	5.68	9.78
C25	1.47	5.63	7.10
C26	4.89	2.47	7.36
C27	0.45	1.44	1.89
C28	8.18	5.19	13.37
C29	9.18	3.34	12.52
C30	0.22	2.45	2.67

Table 8-6. Ranked graph index values

Ranked Order	Criteria	Indegree	Criteria	Outdegree	Criteria	Total Degree
1	C29	9.18	C21	8.65	C21	13.67
2	C28	8.18	C10	6.81	C28	13.37
3	C5	7.79	C1	6.61	C5	12.61
4	C4	6.87	C24	5.68	C29	12.52
5	C8	6.47	C25	5.63	C10	11.83
6	C13	6.04	C16	5.48	C1	11.20
7	C7	5.38	C28	5.19	C8	10.20
8	C10	5.02	C5	4.82	C24	9.78
9	C21	5.02	C20	4.74	C20	9.64
10	C20	4.9	C6	4.61	C4	8.78
11	C26	4.89	C14	4.31	C16	8.38
12	C1	4.59	C22	4.22	C7	8.20
13	C19	4.15	C11	3.87	C13	8.18
14	C24	4.1	C12	3.76	C11	7.75
15	C11	3.88	C8	3.73	C19	7.51
16	C15	3.65	C3	3.68	C26	7.36
17	C12	3.47	C23	3.47	C6	7.25
18	C3	3.36	C19	3.36	C12	7.23

Ranked Order	Criteria	Indegree	Criteria	Outdegree	Criteria	Total Degree
19	C17	3.1	C29	3.34	C14	7.15
20	C16	2.9	C15	3.28	C25	7.10
21	C14	2.84	C9	2.95	C3	7.04
22	C9	2.71	C7	2.82	C15	6.93
23	C6	2.64	C2	2.65	C9	5.66
24	C25	1.47	C26	2.47	C22	5.12
25	C2	1.15	C30	2.45	C23	4.24
26	C22	0.9	C18	2.31	C2	3.80
27	C18	0.83	C13	2.14	C17	3.64
28	C23	0.77	C4	1.91	C18	3.14
29	C27	0.45	C27	1.44	C30	2.67
30	C30	0.22	C17	0.54	C27	1.89

8.3 Results of verification

The scored survey result is presented in Table 8-7 and the comments from experts are shown in Table 8-8.

Table 8-7. Scored survey results of verification

Results	Score
Digital transformation (DX) roadmap	4.4
Final Critical Success Factors (CSFs) list	4.2
Final CSFs linked with steps of DX roadmap	4.4
Ranked CSFs	4.2
Fuzzy Cognitive Map (FCM) of CSFs	3.8

Table 8-8. Comments from experts

Results	Comments
Digital transformation (DX) roadmap	- The DX roadmap is clear and easy to understand; - The roadmap consists sufficient steps for implementing DX;

Results	Comments
Final Critical Success Factors (CSFs) list	- The CSFs are divided into four groups, cover all the aspects of an organization in transforming their business; - Consider combining or removing some CSFs to make the list shorter;
Final CSFs linked with steps of DX roadmap	Step 1, Step 3, and Step 4 of the roadmap are linked with many CSFs, while Step 2, Step 5, and Step 6 are linked with fewer CSFs;
Ranked CSFs	The result is from large-scale survey, so there are no comments;
Fuzzy Cognitive Map (FCM) of CSFs	The map is quite complicated and difficult to follow, it should be improved for better visualization.

8.4 Summary

In this chapter, the process for verifying the results of DX roadmap, CSFs linked with steps of DX roadmap, ranked CSFs and interrelationship among CSFs is conducted. A team of five experts are asked to rate the satisfaction as well as giving comments for each research result. Conclusions and recommendations are composed in the next chapter.

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

The final chapter focuses on summarizing the steps of the reseach to develop the DX roadmap, the CSFs ranking and FCM of CSFs regarding the DX implementation of contractors in the construction industry. The first section of this chapter presents the summaries of the study. The next section provides conclusions and contributions of the study. In the final section, limitations and future works are described.

9.1 Summaries of the study

This study provides important referenced factors regarding DX for construction contractors to consider carefully and to prepare the most suitable plan for themselves before adopting DX to get a higher success rate of transforming their business. The findings of this study are expected to provide a better understanding of the essential elements of DX implementation in the construction industry and guide the contractors in transforming business strategies for effective management of the DX implementation process. The DX roadmap and the CSFs identified in this research can be used to gain some insights into DX implementation within Vietnamese construction industry.

The study consists of five steps which are (1) Doing literature review, (2) Defining final CSFs and DX roadmap, (3) Ranking the CSFs, (4) Analyzing interrelationship among CSFs and (5) Verifying the results. In the first step, sixty-nine preliminary CSFs are collected from the literature review. After scanning, merging, combining and removing duplicated CSFs by researcher, thirty-seven CSFs are achieved. Preliminary DX roadmap and preliminary CSFs linked with step of DX roadmap are also defined in this step.

The second step of the study aims at defining the final DX roadmap, the final CSF list and the final CSFs linked with each step of DX roadmap. Preliminary DX roadmap, thirty-seven preliminary CSFs and preliminary CSFs linked with step of DX roadmap are presented to experts. The experts are asked to modify the DX roadmap. They are also asked to add, modify, rename, remove or merge the factors with the purpose of achieving the complete CSF list and avoiding overlapping. Moreover, they are asked to group thirty CSFs into four categories: (1) Strategy & Vision, (2) People & Culture, (3) Process & Governance and (4) Technology & Capabilities. Finally, the experts are asked to finalize the CSFs linked with steps of DX roadmap. The final DX roadmap, thirty final CSFs and the final CSFs linked with each step of DX roadmap are the outcome of the second step.

In the third step, reliability test analysis and ranking analysis are utilized to check the internal consistency and rank the thirty CSFs. One-way ANOVA test is used to analyze whether there are significant differences in the means of responses from different construction firms. There are two rounds of surveys for this process including (1) the pilot survey and (2) the large-scale survey. The values of Cronbach's Alpha for four groups of CSFs are all greater than 0.6, indicating acceptable and good internal consistency reliability. The top three CSFs are Effective Leadership, Turn Data Into Assets and Data Security. When comparing the responses from different type of construction firms, C2 and C17 have the alternative hypothesis H_1, while other factors have null hypothesis H_0. Similarly, when comparing the responses from different size of construction firms, C6, C20 and C29 have the alternative hypothesis H_1, while other factors have null hypothesis H_0.

In the fourth step, FCM technique is applied to analyze the interrelationship among the CSFs. Eight steps of FCM are presented including (1) obtaining the evaluation criteria, (2) determining the linguistic term, (3) obtaining the evaluations of experts, (4) aggregating the evaluation matrices, (5) defuzzification of the group-based fuzzy decision matrix, (6) constructing the FCM, (7) calculating the graph indices and

(8) ranking the criteria. After analyzing the responses from experts, the three most influencing criteria are C21, C10 and C1. The three most influenced criteria C29, C28 and C5. The three most important criteria are C21, C28 and C5.

In the final step, the process of research results verification is conducted. The results from step 2, step 3 and step 4 of the research, which are DX roadmap, CSF list, CSFs linked with each step of DX roadmap, CSFs ranking and FCM of CSFs are verified by experts via in-depth interview and questionnaire survey. The results of the surveys show that all the experts are satisfied with the research results.

9.2 Conclusions

This research has undertaken an in-depth exploration and development of several crucial components related to Digital Transformation (DX) implementation by construction contractors. These components include the DX roadmap, the linkage of Critical Success Factors (CSFs) with the steps of the DX roadmap, the ranking of CSFs, and the development of a Fuzzy Cognitive Map (FCM) to analyze the interrelationships among CSFs.

The DX roadmap, along with the CSFs linked to each step, serves as a valuable guide for construction contractors seeking to implement DX within their organizations. By presenting a step-by-step roadmap and associating the necessary CSFs with each stage, the roadmap enables contractors to navigate the DX implementation process effectively. It provides a structured approach and insights into the critical factors that need to be addressed at each step, enhancing the chances of successful DX integration.

To evaluate the importance of CSFs, the study has conducted a ranking analysis. This analysis aids in assessing and prioritizing the factors that contribute to the adoption of DX by contractors in the construction industry. By assigning rankings to the CSFs, contractors can focus their attention and resources on the most

influential and critical elements, ensuring a more targeted and efficient implementation of DX strategies.

Furthermore, the study has employed a Fuzzy Cognitive Map (FCM) to delve into the interrelationships among the identified CSFs. This analysis provides a comprehensive understanding of how the different factors interact and influence one another within the DX implementation context. By visualizing the interconnections, contractors can gain insights into the complex dynamics and dependencies among CSFs, enabling them to make informed decisions and develop effective strategies to manage DX implementation.

The research findings have undergone verification by domain experts, ensuring the credibility and reliability of the outcomes. As a result, the insights and outcomes of this study are expected to make significant contributions to the DX journey of construction contractors. The knowledge and understanding acquired from the ranked CSFs, DX roadmap, and FCM analysis provide contractors with actionable guidance and a solid foundation for transforming their business strategies. This, in turn, facilitates the effective management of the DX implementation process, enabling contractors to embrace DX technologies and practices more successfully. Ultimately, the study's contributions are poised to advance the construction industry's digital transformation efforts and promote improved business outcomes for contractors in the rapidly evolving digital landscape.

9.3 Contributions

My research contribution encompasses two perspectives: theoretical perspective and practical perspective, each offering unique insights and implications.

From a theoretical perspective, the research aims to analyze the importance of the factors that contribute to the adoption of Digital Transformation (DX) by construction contractors. By delving into the underlying factors, the study seeks to provide a comprehensive understanding of the key drivers and determinants that

shape the successful implementation of DX in the construction industry. This analysis helps to shed light on the factors that influence contractors' decisions and strategies regarding DX adoption, offering valuable theoretical contributions to the field.

Furthermore, the research examines the interrelationship among Critical Success Factors (CSFs) for DX implementation in construction contractors. By exploring the complex network of relationships among CSFs, the study aims to uncover the interdependencies and synergies that exist between different factors. This analysis provides a deeper understanding of the critical interactions and dependencies between CSFs, offering theoretical insights into how these factors collectively influence the outcomes of DX implementation efforts.

From a practical perspective, the research contributes by proposing a new roadmap specifically designed for construction contractors to guide them in implementing DX effectively. This roadmap outlines the step-by-step process and strategic considerations that contractors need to address to embark on a successful DX journey. The proposed roadmap takes into account the unique challenges and characteristics of the construction industry, providing practical guidance and direction for contractors to navigate the complexities of DX implementation.

Additionally, the research offers practical CSFs associated with each step of the DX implementation roadmap. These CSFs are tailored to the specific needs and requirements of construction contractors, highlighting the key factors that need to be prioritized and addressed at each stage of the implementation process. By providing practical insights into the specific CSFs that have the most significant impact on successful DX implementation, the research equips contractors with valuable knowledge and recommendations to optimize their DX strategies and increase the likelihood of successful transformation.

Overall, the research contributes to both theoretical and practical perspectives in the domain of DX implementation in the construction industry. Theoretical insights provide a deeper understanding of the underlying factors and

their interrelationships, while practical contributions offer tangible guidance and CSFs for contractors to navigate their DX journey effectively. Through these perspectives, the research aims to advance knowledge and facilitate the successful adoption of DX in the construction sector, ultimately driving innovation, productivity, and competitiveness in the industry.

9.4 Limitations and future works

The development of Critical Success Factors (CSFs) for Digital Transformation (DX) implementation by construction contractors in this study is a significant contribution. However, it is important to acknowledge the limitations of the current research, as they can serve as stepping stones for future improvements in the CSFs system for DX implementation.

One limitation of the study is that it primarily focuses on the CSFs for DX implementation from the perspective of the contractor, without considering other project parties such as owners, designers, or consultants. To enhance the comprehensiveness of the CSFs system, future research should address this limitation by providing reference CSFs for DX adoption that encompass the perspectives of all project parties involved in the construction process. This broader perspective would enable a more holistic understanding of DX implementation and its implications across different construction project parties.

Another limitation arises from the early stage of DX implementation in the construction industry, particularly in developing countries like Vietnam. As a result, finding experienced DX experts with substantial knowledge and practical experience in the field becomes challenging. This limitation can be overcome in future works by actively seeking out DX experts from both construction companies and other industries that have successfully implemented DX. Involving a diverse range of experienced professionals will enhance the robustness and credibility of the CSFs for DX implementation system.

It is also worth noting that the research conducted in this study is specific to construction contractors in Vietnam. The findings may not directly apply to other countries with distinct characteristics in their construction industries. To address this limitation, future studies can explore the CSFs for DX implementation in construction firms across different countries, allowing for comprehensive comparisons and insights into the contextual differences that influence the effectiveness of DX strategies.

These limitations should be regarded as opportunities for future research and improvement. By addressing these shortcomings, future studies can refine the CSFs system for DX implementation, broaden its applicability to various project parties and countries, and contribute to a more comprehensive understanding of the factors influencing successful DX adoption in the construction industry.

APPENDIX A: IN-DEPTH INTERVIEW

DEVELOPING DIGITAL TRANSFORMATION ROADMAP

CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

Dear Sir/Madam,

I am Tan Thanh Trang, a PhD Candidate at the Chulalongkorn University in Thailand. I have been doing research about "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". This interview is used only for the purpose of writing the thesis, the personal information within the interview is confidential and will not be opened to the public. Your knowledge and contribution will be very important for the accuracy of the research. I highly appreciate your co-operation and contribution! Thank you so much.

The interview consists of three sections:

Section 1: Personal information

Section 2: DX roadmap

Section 3: Interview questions

Researcher Information

Tan Thanh Trang	PhD Candidate, Construction Engineering and Management, Chulalongkorn University, Thailand and Osaka University, Japan
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Email thanhtanxdbk@gmail.com

Please kindly answer the questions; the research would not be accomplished without your cooperation. Thank you so much for your kind support.

SECTION 1: PERSONAL INFORMATION

1) How long have you worked in the construction industry?

☐ < 3 years ☐ 3 - 5 years

☐ 5 - 10 years ☐ > 10 years

2) What kind of company are you working at?

☐ Contractors ☐ Owner ☐ Consultants ☐Other: .....

3) You are working at your company as a position:

☐ Directors ☐ Deputy Directors ☐ Project Managers

☐ Engineers ☐ Other: .....

4) Do you know about Digital Transformation (DX)?

☐ Known ☐ Unknown

☐ Heard of it ☐ Know very well

5) Do you know about roadmap?

☐ Known ☐ Unknown

☐ Heard of it ☐ Know very well

6) How is the status of DX implementation of your organization/ company?

.....

.....

.....

Contact Information

Name:

Email:

Mobile:

Name of your organization/ company:

SECTION 2: DX ROADMAP

I. DEFINITION OF DX ROADMAP

A roadmap is a visualization of a strategic plan (Aha! Labs Inc., 2022). In other definition, a roadmap is a strategic plan that defines a goal or desired outcome and includes the major steps or milestones needed to reach it (ProductPlan, 2022). It is a visual way to quickly communicate a plan or strategy (Roadmunk, 2021). Construction contractors need to have a complete and comprehensive roadmap to implement DX into their business in an efficient and effective way. Every firm has a limited budget and resources, to implement DX successfully, they have to allocate their resources wisely and suitably by setting the plan carefully.

The DX roadmap in this research is developed based on the knowledge of developing a business strategy (Bunce, 2022; Emmer, 2020; MacDonald, 2022; MasterClass, 2021). The level of roadmap is organizational level. It is used by different departments within contractors. A construction contractor has different departments such as design department, tender department, technical department, construction department, administration department, human resources department, finance & accounting department, IT department, etc.

II. DX ROADMAP

The roadmap has two stages which are “before DX implementation” and “during and after DX implementation”. It consists of six steps as shown in Figure 1. Six steps of DX roadmap are as follows:

(1) Step 1 - Current state of contractor and market

(2) Step 2 – Goals

(3) Step 3 – Plans

(4) Step 4 - DX implementation

(5) Step 5 - Measure the process

(6) Step 6 - Adjust the roadmap

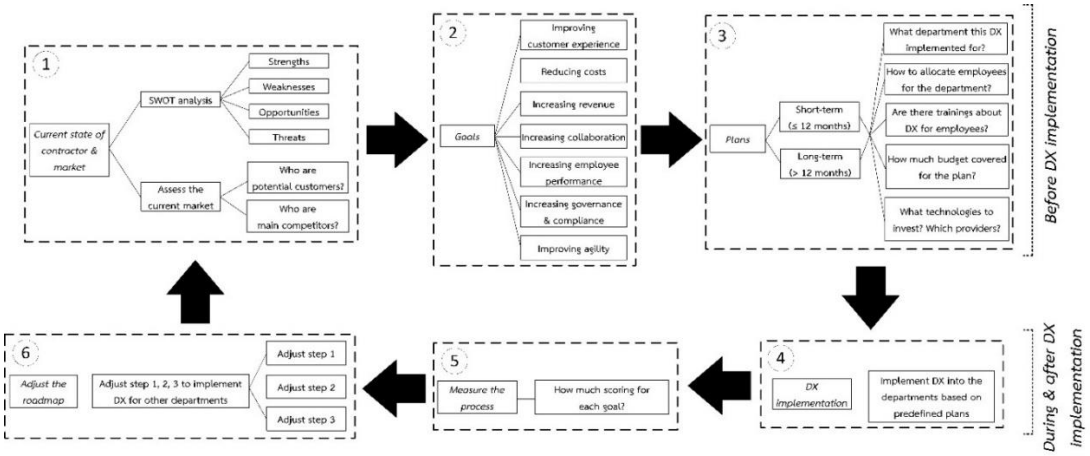

Figure 1. DX roadmap

III. INTERVIEW QUESTIONS

1) Are there any steps that need to be removed?

2) Are there any steps that need to be modified or renamed?

3) Are there any steps that need to be merged with others?

4) Do you want to add any other steps excluding the above six steps?

5) Do you have any other suggestions or comments?

APPENDIX B: IN-DEPTH INTERVIEWS

DEFINING FINAL CRITICAL SUCCESS FACTORS (CSFs) LIST

CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

Dear Sir/Madam,

I am Tan Thanh Trang, a PhD Candidate at the Chulalongkorn University in Thailand. I have been doing research about "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". This interview is used only for the purpose of writing the thesis, the personal information within the interview is confidential and will not be opened to the public. Your knowledge and contribution will be very important for the accuracy of the research. I highly appreciate your co-operation and contribution! Thank you so much.

The interview consists of four sections:

Section 1: Personal information

Section 2: CSFs regarding DX implementation for contractors

Section 3: CSFs linked with the steps of DX roadmap

Section 4: Interview questions

Researcher Information

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Please kindly answer the questions; the research would not be accomplished without your cooperation. Thank you so much for your kind support.

SECTION 1: PERSONAL INFORMATION

1) How long have you worked in the construction industry?

☐< 3 years ☐3 - 5 years

☐5 - 10 years ☐ > 10 years

2) What kind of company are you working at?

☐ Contractors ☐ Owner ☐ Consultants ☐ Other: .....

3) You are working at your company as a position:

☐ Directors ☐ Deputy Directors ☐ Project Managers

☐ Engineers ☐ Other: .....

4) Do you know about Digital Transformation (DX)?

☐Known ☐Unknown

☐Heard of it ☐Know very well

5) Do you know about Critical Success Factors (CSFs)?

☐Known ☐Unknown

☐Heard of it ☐Know very well

6) How is the status of DX implementation of your organization/ company?

.....

.....

.....

Contact Information

Name:

Email:

Mobile:

Name of your organization/ company:

SECTION 2: CSFs AFFECT DX IMPLEMENTATION FOR CONTRACTORS

I. DEFINITION

1. Digital Transformation (DX)

DX is the cultural, organizational and operational change of an organization, industry or ecosystem through a smart integration of digital technologies, processes and competencies across all levels and functions in a staged and strategic way (i-SCOOP, 2021b). In other words, DX is the integration of digital technology into all areas of a business, fundamentally changing how you operate and deliver value to customers (The Enterprisers Project, 2016).

2. Critical Success Factors (CSFs)

CSFs are indicators for opportunities, activities or conditions required to achieve an objective within a project or mission (Janse, 2019). Moreover, CSFs are specific elements or action areas a business, team or department must focus on and successfully implement to reach its strategic objectives (CMOE, 2021).

II. CSFs REGARDING DX IMPLEMENTATION FOR CONTRACTORS

From literature review, 69 preliminary CSFs are collected. After scanning, merging, combining and removing duplicated CSFs by researcher, 37 CSFs are achieved and presented in Table 1.

Table 1. CSFs regarding DX implementation for contractors

Code	CSFs	Description
C1	Determining digital strategy	The strategy describes the why, the what and the how, which are tied to specific, quantified business outcomes
C2	Effective monitoring of progress	Establishing clear metrics and targets around processes and monitoring the progress rigidly
C3	Awareness level of the industry	Familiarity of the industry and current level of DX implementation within the industry
C4	Effective leadership	Commitment and approach of the top management to facilitate DX within the organization
C5	Willingness of staffs to learn new technology	Enthusiasm of organizational staffs related DX learning and knowledge
C6	Organizational culture	Existence of an organizational culture to be prone to learning and implementing of innovative technology
C7	Availability of information and technology	Existence of necessary information and technology infrastructure within the organization for implementing DX
C8	Financial support from the government	Existence of incentive from government in terms of financial support to promote DX
C9	DX training programs	The use of training and seminars to equip staffs with useful information and skills to facilitate DX
C10	DX legislation	Existence of DX guidelines, standards, codes, rules, regulations and roadmaps within the

Code	CSFs	Description
		industry
C11	Organizational restructuring	Restructure the organization to support DX implementation
C12	Financial resources of organization	Ability of the organization to allocate sufficient budget for DX implementation
C13	Availability of qualified staff	Existence of competent personnel within the organization
C14	Relationships and knowledge sharing with other firms	Existence of a knowledge-sharing and collaborative platform within the industry
C15	Innovate by rapid experimentation	Learn to experiment continuously and effectively, getting real data and real customer feedback, continuously iterating and testing new ideas
C16	Turn data into assets	Develop the clear vision and the growing capability needed to put data to work in the service of innovation and value creation
C17	Competent technical support team within company	Existence of necessary technicians to deploy DX implementation
C18	Consulting	Receiving consultancy services from specialized firms
C19	Commitment of employees	Employees are fully engaged in the process of DX implementation

Code	CSFs	Description
C20	Harness customer networks	Learn to view customers differently, understanding the dynamic, networked ways in which they interact, both with businesses and with each other, helping them to access, engage, connect and even collaborate with the business
C21	Data security	The process of protecting data from unauthorized access and data corruption throughout its lifecycle including data encryption, hashing, tokenization and key management practices that protect data across all applications and platforms.
C22	Political stability	The low chance of government collapse either because of conflicts or rampant competition between various political parties
C23	Business model innovation	Capability to design new business models
C24	A growth mindset	Individuals who believe their abilities can be developed
C25	Determining transformed areas	Identifying areas of organizational business that need DX
C26	Coordination among project parties	Existence of a cooperative project environment between project parties to successfully implement DX
C27	Project size	The scale of the project in terms of its budget
C28	Client's attitude with DX	The willingness of clients to adopt DX or existence of a requirement specified or pressure exerted by the client

Code	CSFs	Description
C29	Maintenance and upgrade cost (software, hardware)	Organization strategic policies that favor allocation of sufficient budget toward DX system maintenance and upgrade
C30	Work environment	The surrounding conditions in which an employee operates or refers to the elements that comprise the setting in which employees work and impact workers
C31	Organizational flexibility or adaptability to market	The ability of organization to adapt the change of market
C32	Perceived benefits from DX	Notice or become aware of benefits and advantages from DX implementation
C33	Research and development capability of organization	The ability of organization to do research for innovation by themselves
C34	Pressure from competitors	The pressure to compete with other competitors within the industry
C35	Socioeconomic conditions	The social standing or class of an individual or group. It is often measured as a combination of education, income and occupation
C36	Technical support from software and hardware suppliers	The support in terms of technical problems from software and hardware suppliers
C37	Shared risks and rewards among	Risks and rewards are shared equally among team members

Code	CSFs	Description
	team members	

SECTION 3: CSFs LINKED WITH THE STEPS OF DX ROADMAP

Figure 1 shows the CSFs linked with the steps of DX roadmap.

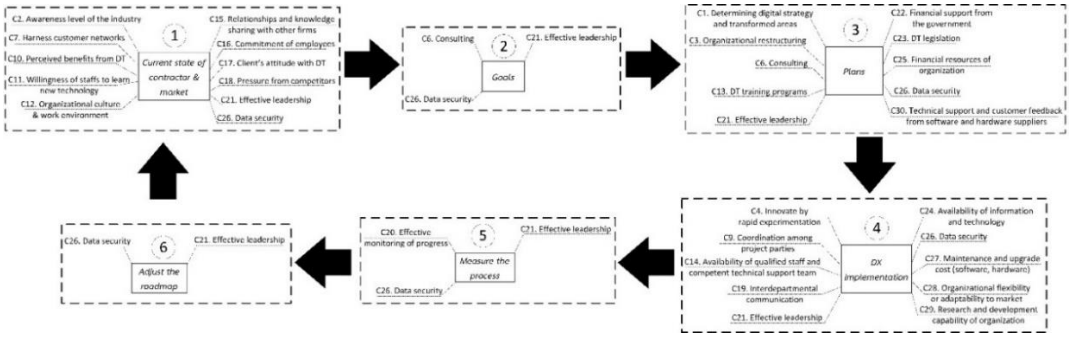

Figure 1. CSFs linked with steps of DX roadmap

SECTION 4: INTERVIEW QUESTIONS

Interview questions for section 2

1) Are there any factors that need to be removed?

2) Are there any factors that need to be modified or renamed?

3) Are there any factors that need to be merged with others?

4) Do you want to add any other factors excluding the above 37 factors?

5) Are there any descriptions of factors unclear or need to be revised?

Interview questions for section 3

1) Are there any CSFs that need to be removed from any steps of DX roadmap?

1) Are there any CSFs that need to be added to any steps of DX roadmap?

APPENDIX C: PILOT SURVEY

RANKING CSFs

CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

Dear Sir/Madam,

I am Tan Thanh Trang, a PhD Candidate at the Chulalongkorn University in Thailand. I have been doing research about "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". The below questionnaire survey is used only for the purpose of writing the thesis, the personal information within the survey is confidential and will not be opened to the public. Your knowledge and contribution will be very important for the accuracy of the research. I highly appreciate your co-operation and contribution! Thank you so much.

The survey consists of three sections:

Section 1: Personal information

Section 2: CSFs regarding DX implementation for contractors

Section 3: Ranking CSFs questionnaire survey

Ông (bà) thân mến,

Tôi tên là Trang Thanh Tân, hiện đang là nghiên cứu sinh bậc Tiến Sỹ tại trường Đại học Chulalongkorn ở Thái Lan. Tôi đang làm nghiên cứu về đề tài: "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". Bảng câu hỏi dưới đây chỉ dùng cho mục đích viết luận văn, tất cả các thông tin cá nhân trong khảo sát này đều được giữ bí mật. Những ý kiến và đóng góp

của ông (bà) rất quan trọng đối với độ chính xác của nghiên cứu này. Tôi chân thành cám ơn sự hợp tác và giúp đỡ từ ông (bà).

Bảng khảo sát gồm ba phần:

Phần 1: Thông tin cá nhân

Phần 2: Các nhân tố thành công then chốt (CSFs) liên quan tới việc áp dụng chuyển đổi số ở nhà thầu.

Phần 3: Bảng câu hỏi xếp hạng CSFs

Researcher Information/ Thông tin nghiên cứu sinh

Tan Thanh Trang	PhD Candidate, Construction Engineering and Management, Chulalongkorn University, Thailand and Osaka University, Japan
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Please kindly answer the questions. The research would not be accomplished without your cooperation. Thank you so much for your kind support. / Ông (bà) vui lòng trả lời các câu hỏi dưới đây, việc hỗ trợ của ông (bà) góp phần hoàn thành nghiên cứu này. Cám ơn ông (bà) rất nhiều.

SECTION 1: PERSONAL INFORMATION/ PHẦN 1: THÔNG TIN CÁ NHÂN

1) How long have you worked in the construction industry? / Ông (bà) đã làm việc trong ngành xây dựng được bao lâu?

☐< 3 years/ 3 năm ☐3 - 5 years/ 3 - 5 năm

☐5 - 10 years/ 5 - 10 năm ☐> 10 years/ 10 năm

2) What kind of company are you working at? / Ông (bà) đang làm việc cho công ty gì?

☐Contractors/ Nhà thầu ☐Owner/ Chủ đầu tư

☐Consultants/Tư vấn ☐Sub-contractors/ Nhà thầu phụ

☐Other/ Khác: .....

3) You are working at your company as a position/ Vị trí hiện tại của ông (bà) ở công ty là:

☐Directors/ Giám đốc ☐Deputy Directors/ Phó giám đốc

☐Site Managers/ Chỉ huy trưởng ☐Engineers/ Kỹ sư

☐Other/ Khác: .....

4) Total revenue of your company/ Tổng doanh thu hàng năm của công ty ông (bà):

☐< 100 billion VND/ 100 tỷ đồng ☐100 - 200 billion VND/ 100 - 200 tỷ đồng

☐> 200 billion VND/ 200 tỷ đồng

5) Number of employees in your company/ Số nhân sự ở công ty ông (bà):

☐<50 ☐50 – 200 ☐>200

6) Do you know about Digital Transformation (DX)? / Ông (bà) có biết về Chuyển Đổi Số (CĐS)?

☐Known/ Biết ☐Unknown/ Không biết

☐Heard of it/ Có nghe qua ☐Know very well/ Biết rất rõ

7) Do you know about Critical Success Factors (CSFs)? Ông (bà) có biết về yếu tố thành công then chốt (CSFs)?

☐Known/ Biết ☐Unknown/ Không biết

☐Heard of it/ Có nghe qua ☐Know very well/ Biết rất rõ

8) How is the status of DX implementation of your organization/ company? / Hiện trạng của việc áp dụng CĐS ở công ty ông (bà) là như thế nào?

.....

.....

.....

Contact Information/ Thông tin liên hệ

Name/ Tên:

Email:

Mobile/ SĐT:

Name of your company/ Tên công ty:

SECTION 2: CSFs AFFECT DX IMPLEMENTATION FOR CONTRACTORS/ PHẦN 2: CÁC YẾU TỐ THÀNH CÔNG THEN CHỐT (CSFs) ẢNH HƯỞNG TỚI VIỆC ÁP DỤNG CĐS Ở NHÀ THẦU

I. DEFINITION AND EXAMPLES/ ĐỊNH NGHĨA VÀ VÍ DỤ

1. Digital Transformation (DX)/ CHUYỂN ĐỔI SỐ (CĐS)

DX is the cultural, organizational and operational change of an organization, industry or ecosystem through a smart integration of digital technologies, processes and competencies across all levels and functions in a staged and strategic way (i-SCOOP, 2021b). In other words, DX is the integration of digital technology into all areas of a business, fundamentally changing how you operate and deliver value to customers (The Enterprisers Project, 2016)./ CĐS là sự thay đổi về văn hóa hoặc quá trình hoạt động của một tổ chức, một ngành công nghiệp hoặc hệ sinh thái thông qua việc kết hợp thông minh giữa các công nghệ mới và các quy trình ở mọi cấp độ và mọi chức năng theo một chiến lược bài bản. Nói cách khác, CĐS là sự hợp nhất các công nghệ số vào mọi lĩnh vực của doanh nghiệp và thay đổi cách doanh nghiệp vận hành hay mang tới giá trị cho khách hàng.

2. DX examples/ Ví dụ về CĐS

In this section, some concepts and technologies for DX implemenatation are given so the respondents have a clear perception of DX and to help them to answer the questionnaire more easily. Below concepts and technologies are adopted from Sawhney et al. (2020) and are categorized into three clusters: Smart Construction, Modeling and Simulation, Digitization and Virtualization./ Trong phần này, một số khái niệm và công nghệ liên quan việc áp dụng CĐS được đưa ra để người trả lời hiểu rõ hơn về CĐS và giúp họ trả lời bảng câu hỏi dễ dàng hơn. Các khái niệm và công nghệ dưới đây được phân thành ba nhóm: Xây dựng thông minh, Mô hình hóa và Mô phỏng, Số hóa và Ảo hóa.

Smart Construction/ Xây dựng thông minh	Cyber Physical System/ Hệ thống không gian mạng thực-ảo Interner of Things; Internet of Services/ Internet vạn vật Robotics & Automation/ Người máy và Tự động hóa Modularization; Prefabrication/ Mô-đun hóa; Tiền chế Embedded Sensors; RFID (Radio Frequency Identification) / Cảm biến nhúng; RFID (Nhận dạng qua tần số vô tuyến) .....
Modeling & Simulation/ Mô hình hóa và Mô phỏng	High Performance Computing/ Điện toán hiệu năng cao Deep Learning/ Học sâu Data Driven Generative Design/ Thiết kế tạo theo hướng dữ liệu Building Information Modelling (BIM)/ Mô hình thông tin xây dựng Energy; Construction Simulations/ Năng lượng; Mô phỏng xây dựng Virtual/Augmented Reality (AR; VR)/ Thực tế ảo; Thực tế ảo tăng cường 3D Laser Scanner/ Quét 3D laser Unmanned Aerial Vehicles (Drone)/ Máy bay không người lái .....
Digitization & Virtualization/ Số hóa và Ảo hóa	Cloud Computing/ Điện toán đám mây Big Data Analytics/ Phân tích dữ liệu lớn Adaptive Building Systems/ Hệ thống tòa nhà thích ứng Mobile Interfaces/ Giao diện di động Smart Home (AI Assistants)/ Nhà thông minh (Hỗ trợ trí tuệ nhân tạo) Product Life Cycle Management/ Quản lý vòng đời sản phẩm .....

3. Critical Success Factors (CSFs)

CSFs are indicators for opportunities, activities or conditions required to achieve an objective within a project or mission (Janse, 2019). Moreover, CSFs are

specific elements or action areas a business, team or department must focus on and successfully implement to reach its strategic objectives (CMOE, 2021)./ CSFs là các biểu thị cho các cơ hội, các hoạt động hoặc các điều kiện cần thiết cho việc đạt được một mục tiêu nào đó ở một dự án hoặc một nhiệm vụ. Ngoài ra, CSFs là các yếu tố đặc trưng để đạt được các mục tiêu chiến lược.

II. CSFs REGARDING DX IMPLEMENTATION FOR CONTRACTORS

Below table provides thirty-three CSFs regaring DX implemenation for contractors and their clear descriptions. These CSFs is grouped into four different categories: (1) Strategy & Vision, (2) People & Culture, (3) Process & Governance and (4) Technology & Capabilities. Please kindly read it carefully before doing the questionnaire survey.

Table 1. CSFs regarding DX implementation for contractors

Code	CSFs	Description
(1)	Strategy & Vision	
C1	Determining digital strategy and transformed areas/ Xác định chiến lược số và phạm vi chuyển đổi	The strategy describes the why, the what and the how, which are tied to specific, quantified business outcomes and identifying areas of organizational business that need DX/ Chiến lược mô tả lý do tại sao, cái gì và bằng cách nào, gắn liền với các kết quả kinh doanh được định lượng cụ thể và xác định cụ thể phạm vi kinh doanh của cơ quan cần CĐS
C2	Awareness level of the industry/ Mức độ nhận thức của ngành công nghiệp XD	Familiarity of the industry and current level of DX implementation within the industry/ Sự quen thuộc và mức độ thực hiện CĐS hiện tại trong ngành XD
C3	Organizational	Restructure the organization to support DX

Code	CSFs	Description
	restructuring/ Cơ cấu lại cơ quan	implementation/ Cơ cấu lại cơ quan để hỗ trợ thực hiện CĐS
C4	Innovate by rapid experimentation/ Đổi mới bằng thử nghiệm nhanh	Learn to experiment continuously and effectively, getting real data and real customer feedback, continuously iterating and testing new ideas/ Học cách thử nghiệm liên tục và hiệu quả, nhận dữ liệu và phản hồi của khách hàng theo thời gian thực, đồng thời liên tục lặp lại thử nghiệm các ý tưởng mới
C5	Turn data into assets/ Biến dữ liệu thành tài sản	Develop the clear vision and the growing capability needed to put data to work in the service of innovation and value creation/ Phát triển tầm nhìn rõ ràng và gia tăng các năng lực cần thiết cho việc đưa dữ liệu vào hoạt động phục vụ sự đổi mới và tạo ra các giá trị
C6	Consulting/ Tư vấn	Receiving consultancy services from specialized firms/ Nhận dịch vụ tư vấn từ các cơ quan có chuyên môn
C7	Harness customer networks/ Khai thác mạng lưới khách hàng	Learn to view customers differently, understanding the dynamic, networked ways in which they interact, both with businesses and with each other, helping them to access, engage, connect and even collaborate with the business/ Học cách nhìn nhận khách hàng khác đi, hiểu được sự tương tác giữa họ với nhau hoặc giữa họ với doanh nghiệp theo hướng năng động và có hệ thống, từ đó giúp họ tiếp cận, tương tác, kết nối và cộng tác với doanh nghiệp
C8	Business model	Capability to design new business models/ Khả

Code	CSFs	Description
	innovation/ Đổi mới mô hình kinh doanh	năng thiết kế hay xây dựng các mô hình kinh doanh mới
C9	Coordination among project parties/ Phối hợp giữa các bên của dự án	Existence of a cooperative project environment between project parties to successfully implement DX/ Sự sẵn có của một môi trường mang tính hợp tác giữa các bên của dự án để thực hiện CĐS thành công
C10	Perceived benefits from DX/ Lợi ích nhận được từ CĐS	Notice or become aware of benefits and advantages from DX implementation/ Nhận thức được lợi ích và lợi thế từ việc triển khai CĐS
(2)		People & Culture
C11	Willingness of staffs to learn new technology/ Việc sẵn sàng học hỏi công nghệ mới của nhân viên	Enthusiasm of organizational staffs realated DX learning and knowledge/ Sự hăng hái, nhiệt tình của nhân viên cơ quan trong việc học hỏi và trau dồi kiến thức về CĐS
C12	Organizational culture & work environment / Văn hóa cơ quan & môi trường làm việc	Existence of an organizational culture to be prone to learning and implementing of innovative technology and the surrounding conditions in which an employee operates or refers to the elements that comprise the setting in which employees work and impact workers/ Văn hóa cơ quan thiên về việc học hỏi và triển khai công nghệ đổi mới và các điều kiện tại nơi làm việc hoặc các yếu tố cấu thành nên môi trường làm việc của nhân viên và có ảnh hưởng trực tiếp tới nhân viên
C13	DX training programs/ Các chương trình đào	The use of training and seminars to equip staffs with useful information and skills to facilitate

Code	CSFs	Description
	tạo CĐS	DX/ Việc sử dụng các khóa đào tạo, hội thảo để trang bị cho nhân viên những thông tin và kỹ năng hữu ích cho việc CĐS
C14	Availability of qualified staff and competent technical support team within company/ Sự sẵn có của đội ngũ nhân viên có trình độ và các kỹ thuật viên	Existence of competent personnel and necessary technicians to deploy DX implementation within the organization/ Sự sẵn có của nhân sự có năng lực và các kỹ thuật viên cần thiết cho việc triển khai thực hiện CĐS trong cơ quan XD
C15	Relationships and knowledge sharing with other firms/ Mối quan hệ và chia sẻ kiến thức với các cơ quan khác	Existence of a knowledge-sharing and collaborative platform within the industry/ Sự tồn tại của một nền tảng hợp tác và chia sẻ kiến thức trong ngành XD
C16	Commitment of employees/ Cam kết của nhân viên	Employees are fully engaged in the process of DX implementation/ Nhân viên cam kết tuyệt đối tham gia vào quá trình thực hiện CĐS
C17	Client's attitude with DX/ Thái độ của khách hàng về CĐS	The willingness of clients to adopt DX or existence of a requirement specified or pressure exerted by the client/ Sự sẵn lòng của khách hàng để áp dụng CĐS hoặc sự sẵn có của yêu cầu được chỉ định bởi khách hàng
C18	Pressure from competitors/ Áp lực từ đối thủ cạnh tranh	The pressure to compete with other competitors within the industry/ Áp lực từ việc cạnh tranh với các đối thủ khác trong ngành XD
C19	Interdepartmental communication/ Liên lạc giữa các phòng ban	Communication and connection among different departments within organization/ Sự liên lạc và kết nối giữa các phòng ban khác nhau trong nội

Code	CSFs	Description
		bộ cơ quan
(3)		Process & Governance
C20	Effective monitoring of progress/ Giám sát hiệu quả tiến độ	Establishing clear metrics and targets around processes and monitoring the progress rigidly/ Thiết lập các chỉ số và mục tiêu rõ ràng cho các quy trình và giám sát tiến độ một cách chặt chẽ
C21	Effective leadership/ Lãnh đạo hiệu quả	Commitment and approach of the top management to facilitate DX within the organization/ Việc cam kết và cách tiếp cận của lãnh đạo cấp cao để tạo điều kiện cho CĐS trong cơ quan
C22	Financial support from the government/ Hỗ trợ tài chính từ Chính Phủ	Existence of incentive from government in terms of financial support to promote DX/ Sự khuyến khích và hỗ trợ của Chính Phủ về mặt tài chính để thúc đẩy CĐS
C23	DX legislation/ Luật CĐS	Existence of DX guidelines, standards, codes, rules, regulations and roadmaps within the industry/ Sự sẵn có của các hướng dẫn, tiêu chuẩn, quy chuẩn, quy tắc, quy định và lộ trình CĐS trong ngành XD
(4)		Technology & Capabilities
C24	Availability of information and technology/ Sự sẵn có của thông tin và công nghệ	Existence of necessary information and technology infrastructure within the organization for implementing DX/ Sự sẵn có của cơ sở hạ tầng công nghệ thông tin cần thiết trong nội bộ cơ quan cho việc triển khai CĐS
C25	Financial resources of organization/ Nguồn lực tài chính của cơ	Ability of the organization to allocate sufficient budget for DX implementation/ Khả năng của cơ quan để phân bổ đủ ngân sách cho việc thực

Code	CSFs	Description
	quan	hiện CĐS
C26	Data security/ Bảo mật dữ liệu	The process of protecting data from unauthorized access and data corruption throughout its lifecycle including data encryption, hashing, tokenization and key management practices that protect data across all applications and platforms/ Quy trình bảo vệ dữ liệu khỏi truy cập trái phép hay bị hư hỏng suốt vòng đời của nó bao gồm mã hóa dữ liệu, mã hóa kỹ thuật số và các phương pháp quản lý then chốt để bảo vệ dữ liệu trên tất cả các ứng dụng và nền tảng
C27	Maintenance and upgrade cost (software, hardware)/ Chi phí bảo trì và nâng cấp (phần mềm, phần cứng)	Organization strategic policies that favors allocation of sufficient budget toward DX system maintenance and upgrade/ Các chính sách chiến lược của cơ quan thiên về việc phân bổ đủ ngân sách cho việc bảo trì và nâng cấp hệ thống CĐS
C28	Organizational flexibility or adaptability to market/ Tính linh hoạt của cơ quan hoặc khả năng thích ứng với thị trường	The ability of organization to adapt the change of market/ Khả năng của cơ quan để thích ứng với sự thay đổi của thị trường
C29	Research and development capability of organization/ Khả năng nghiên cứu và phát triển của cơ quan	The ability of organization to do research for innovation by themselves/ Khả năng tự nghiên cứu độc lập của cơ quan cho việc đổi mới, cải tiến

Code	CSFs	Description
C30	Technical support and customer feedback from software and hardware suppliers/ Hỗ trợ kỹ thuật và nhận phản hồi khách hàng từ các nhà cung cấp phần mềm và phần cứng	The support in terms of technical problems and customer feedback service from software and hardware suppliers/ Sự hỗ trợ liên quan đến các vấn đề kỹ thuật và phản hồi của khách hàng từ các nhà cung cấp phần mềm và phần cứng

SECTION 3: RANKING CSFs QUESTIONNAIRE SURVEY/

PHẦN 3: BẢNG CÂU HỎI XẾP HẠNG CSFs

Please check on the checklist box ☑ based on your own opinion and experience.

1) Please kindly evaluate the importance of the below CSFs regarding the DX implementation for Vietnamese contractors. / Ông (Bà) hãy đánh giá mức độ quan trọng của những yếu tố thành công then chốt dưới đây trong ảnh hướng tới việc áp dụng Chuyển Đổi Số (CĐS) cho các Nhà thầu tại Việt Nam.

Very unimportant/ Rất không quan trọng	Unimportant/ Không quan trọng	Neutral/ Trung lập	Important/ Quan trọng	Very important/ Rất quan trọng
1	2	3	4	5

Code	Factors that influence the DX implementation of contractors	Level of importance				
		Very unimportant ----> Very important				
(1)	Strategy & Vision	1	2	3	4	5
C1	Determining digital strategy and transformed areas	☐	☐	☐	☐	☐
C2	Awareness level of the industry	☐	☐	☐	☐	☐
C3	Organizational restructuring	☐	☐	☐	☐	☐
C4	Innovate by rapid experimentation	☐	☐	☐	☐	☐
C5	Turn data into assets	☐	☐	☐	☐	☐
C6	Consulting	☐	☐	☐	☐	☐
C7	Harness customer networks	☐	☐	☐	☐	☐
C8	Business model innovation	☐	☐	☐	☐	☐
C9	Coordination among project parties	☐	☐	☐	☐	☐

Code	Factors that influence the DX implementation of contractors	Level of importance				
		Very unimportant ----> Very important				
C10	Perceived benefits from DX	☐	☐	☐	☐	☐
(2)	People & Culture	1	2	3	4	5
C11	Willingness of staffs to learn new technology	☐	☐	☐	☐	☐
C12	Organizational culture & work environment	☐	☐	☐	☐	☐
C13	DX training programs	☐	☐	☐	☐	☐
C14	Availability of qualified staff and competent technical support team within company	☐	☐	☐	☐	☐
C15	Relationships and knowledge sharing with other firms	☐	☐	☐	☐	☐
C16	Commitment of employees	☐	☐	☐	☐	☐
C17	Client's attitude with DX	☐	☐	☐	☐	☐
C18	Pressure from competitors	☐	☐	☐	☐	☐
C19	Interdepartmental communication	☐	☐	☐	☐	☐
(3)	Process & Governance	1	2	3	4	5
C20	Effective monitoring of progress	☐	☐	☐	☐	☐
C21	Effective leadership	☐	☐	☐	☐	☐
C22	Financial support from the government	☐	☐	☐	☐	☐
C23	DX legislation	☐	☐	☐	☐	☐
(4)	Technology & Capabilities	1	2	3	4	5
C24	Availability of information and technology	☐	☐	☐	☐	☐
C25	Financial resources of organization	☐	☐	☐	☐	☐
C26	Data security	☐	☐	☐	☐	☐

Code	Factors that influence the DX implementation of contractors	Level of importance				
		Very unimportant ----> Very important				
C27	Maintenance and upgrade cost (software, hardware)	☐	☐	☐	☐	☐
C28	Organizational flexibility or adaptability to market	☐	☐	☐	☐	☐
C29	Research and development capability of organization	☐	☐	☐	☐	☐
C30	Technical support and customer feedback from software and hardware suppliers	☐	☐	☐	☐	☐

2) Is the survey easy to understand? / Bảng khảo sát có dễ hiểu không?

☐Yes/ Có ☐No/ Không ☐Other/ Khác

3) Do you want to add, remove or merge any factors? *(if yes, please give details)*/ Ông (Bà) có muốn bổ sung, xóa hay gom các yếu tố nào lại với nhau không? *(nếu có, vui lòng nêu chi tiết)*

☐Yes/ Có ☐No/ Không

More details/ Chi tiết: .....

4) How would you rate the survey design? / Ông (Bà) đánh giá thiết kế của khảo sát này như thế nào?

☐Great/ Tốt ☐Not so great/ Không quá tốt ☐Average/ Trung bình

5) Other ideas or opinions/ Một số ý kiến bổ sung khác:

.....

APPENDIX D: LARGE-SCALE SURVEY

CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

Dear Sir/Madam,

I am Tan Thanh Trang, a PhD Candidate at the Chulalongkorn University in Thailand. I have been doing research about "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". The below questionnaire survey is used only for the purpose of writing the thesis, the personal information within the survey is confidential and will not be open to the public. Your knowledge and contribution will be very important for the accuracy of the research. I highly appreciate your co-operation and contribution! Thank you so much.

The survey consists of three sections:

Section 1: Personal information

Section 2: CSFs regarding DX implementation for contractors

Section 3: Questionnaires

Ông (bà) thân mến,

Tôi tên là Trang Thanh Tân, hiện đang là nghiên cứu sinh bậc Tiến Sỹ tại trường Đại học Chulalongkorn ở Thái Lan. Tôi đang làm nghiên cứu về đề tài: "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". Bảng câu hỏi dưới đây chỉ dùng cho mục đích viết luận văn, tất cả các thông tin cá nhân trong khảo sát này đều được giữ bí mật. Những ý kiến và đóng góp

của ông (bà) rất quan trọng đối với độ chính xác của nghiên cứu này. Tôi chân thành cám ơn sự hợp tác và giúp đỡ từ ông (bà).

Bảng khảo sát gồm ba phần:

Phần 1: Thông tin cá nhân

Phần 2: Các nhân tố thành công then chốt (CSFs) liên quan tới việc áp dụng chuyển đổi số ở nhà thầu.

Phần 3: Bảng câu hỏi

Researcher Information/ Thông tin nghiên cứu sinh

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Email	thanhtanxdbk@gmail.com

Please kindly answer the questions. The research would not be accomplished without your cooperation. Thank you so much for your kind support. / Ông (bà) vui lòng trả lời các câu hỏi dưới đây, việc hỗ trợ của ông (bà) góp phần hoàn thành nghiên cứu này. Cám ơn ông (bà) rất nhiều.

SECTION 1: PERSONAL INFORMATION/ PHẦN 1: THÔNG TIN CÁ NHÂN

1) How long have you worked in the construction industry? / Ông (bà) đã làm việc trong ngành xây dựng được bao lâu?

☐< 3 years/ 3 năm ☐3 - 5 years/ 3 - 5 năm

☐5 - 10 years/ 5 - 10 năm ☐> 10 years/ 10 năm

2) What kind of company are you working at? / Ông (bà) đang làm việc cho công ty gì?

☐Contractors/ Nhà thầu ☐Owner/ Chủ đầu tư

☐Consultants/Tư vấn ☐Sub-contractors/ Nhà thầu phụ

☐Other/ Khác: .....

3) You are working at your company as a position/ Vị trí hiện tại của ông (bà) ở công ty là:

☐Directors/ Giám đốc ☐Deputy Directors/ Phó giám đốc

☐Site Managers/ Chỉ huy trưởng ☐Engineers/ Kỹ sư

☐Other/ Khác: .....

4) Total revenue of your company/ Tổng doanh thu hàng năm của công ty ông (bà):

☐< 100 billion VND/ 100 tỷ đồng ☐100 - 200 billion VND/ 100 - 200 tỷ đồng

☐> 200 billion VND/ 200 tỷ đồng

5) Number of employees in your company/ Số nhân sự ở công ty ông (bà):

☐<50 ☐50 – 200 ☐>200

6) Do you know about Digital Transformation (DX)? / Ông (bà) có biết về Chuyển Đổi Số (CĐS)?

☐Known/ Biết ☐Unknown/ Không biết

☐Heard of it/ Có nghe qua ☐Know very well/ Biết rất rõ

7) Do you know about Critical Success Factors (CSFs)? Ông (bà) có biết về yếu tố thành công then chốt (CSFs)?

☐Known/ Biết ☐Unknown/ Không biết

☐Heard of it/ Có nghe qua ☐Know very well/ Biết rất rõ

8) How is the status of DX implementation of your organization/ company?/ Hiện trạng của việc áp dụng CĐS ở công ty ông (bà) là như thế nào?

.....

.....

Contact Information/ Thông tin liên hệ

Name/ Tên:

Email:

Mobile/ SĐT:

Name of your company/ Tên công ty:

SECTION 2: CSFs AFFECT DX IMPLEMENTATION OF CONTRACTORS/ PHẦN 2: CÁC YẾU TỐ THÀNH CÔNG THEN CHỐT (CSFs) ẢNH HƯỞNG TỚI VIỆC ÁP DỤNG CĐS Ở NHÀ THẦU

I. DEFINITION AND EXAMPLES

1. Digital Transformation (DX)

DX is the cultural, organizational and operational change of an organization, industry or ecosystem through a smart integration of digital technologies, processes and competencies across all levels and functions in a staged and strategic way (i-SCOOP, 2021b). In other words, DX is the integration of digital technology into all areas of a business, fundamentally changing how you operate and deliver value to customers (The Enterprisers Project, 2016)./ CĐS là sự thay đổi về văn hóa hoặc quá trình hoạt động của một tổ chức, một ngành công nghiệp hoặc hệ sinh thái thông qua việc kết hợp thông minh giữa các công nghệ mới và các quy trình ở mọi cấp độ và mọi chức năng theo một chiến lược bài bản. Nói cách khác, CĐS là sự hợp nhất các công nghệ số vào mọi lĩnh vực của doanh nghiệp và thay đổi cách doanh nghiệp vận hành hay mang tới giá trị cho khách hàng.

2. DX examples

In this section, some concepts and technologies for DX implemenatation are given so the respondents have a clear perception of DX and to help them to answer the questionnaire more easily. Below concepts and technologies are adopted from Sawhney et al. (2020) and are categorized into three clusters: Smart Construction, Modeling and Simulation, Digitization and Virtualization./ Trong phần này, một số khái niệm và công nghệ liên quan việc áp dụng CĐS được đưa ra để người trả lời hiểu rõ hơn về CĐS và giúp họ trả lời bảng câu hỏi dễ dàng hơn. Các khái niệm và công nghệ dưới đây được phân thành ba nhóm: Xây dựng thông minh, Mô hình hóa và Mô phỏng, Số hóa và Ảo hóa.

Smart Construction/ Xây dựng thông minh	Cyber Physical System/ Hệ thống không gian mạng thực-ảo Interner of Things; Internet of Services/ Internet vạn vật Robotics & Automation/ Người máy và Tự động hóa Modularization; Prefabrication/ Mô-đun hóa; Tiền chế Embedded Sensors; RFID (Radio Frequency Identification) / Cảm biến nhúng; RFID (Nhận dạng qua tần số vô tuyến) .....
Modeling & Simulation/ Mô hình hóa và Mô phỏng	High Performance Computing/ Điện toán hiệu năng cao Deep Learning/ Học sâu Data Driven Generative Design/ Thiết kế tạo theo hướng dữ liệu Building Information Modelling (BIM)/ Mô hình thông tin xây dựng Energy; Construction Simulations/ Năng lượng; Mô phỏng xây dựng Virtual/Augmented Reality (AR; VR)/ Thực tế ảo; Thực tế ảo tăng cường 3D Laser Scanner/ Quét 3D laser Unmanned Aerial Vehicles (Drone)/ Máy bay không người lái .....
Digitization & Virtualization/ Số hóa và Ảo hóa	Cloud Computing/ Điện toán đám mây Big Data Analytics/ Phân tích dữ liệu lớn Adaptive Building Systems/ Hệ thống tòa nhà thích ứng Mobile Interfaces/ Giao diện di động Smart Home (AI Assistants)/ Nhà thông minh (Hỗ trợ trí tuệ nhân tạo) Product Life Cycle Management/ Quản lý vòng đời sản phẩm

	.....

3. Critical Success Factors (CSFs)

CSFs are indicators for opportunities, activities or conditions required to achieve an objective within a project or mission (Janse, 2019). Moreover, CSFs are specific elements or action areas a business, team or department must focus on and successfully implement to reach its strategic objectives (CMOE, 2021)./ CSFs là các biểu thị cho các cơ hội, các hoạt động hoặc các điều kiện cần thiết cho việc đạt được một mục tiêu nào đó ở một dự án hoặc một nhiệm vụ. Ngoài ra, CSFs là các yếu tố đặc trưng để đạt được các mục tiêu chiến lược.

II. CSFs REGARDING DX IMPLEMENTATION FOR CONTRACTORS

Table 9-1. CSFs regarding DX implementation for contractors

Code	CSFs	Description
(1)	Strategy & Vision	
C1	Determining digital strategy and transformed areas/ Xác định chiến lược số và phạm vi chuyển đổi	The strategy describes the why, the what and the how, which are tied to specific, quantified business outcomes and identifying areas of organizational business that need DX/ Chiến lược mô tả lý do tại sao, cái gì và bằng cách nào, gắn liền với các kết quả kinh doanh được định lượng cụ thể và xác định cụ thể phạm vi kinh doanh của cơ quan cần CĐS
C2	Awareness level of the industry/ Mức độ nhận thức của ngành công nghiệp XD	Familiarity of the industry and current level of DX implementation within the industry/ Sự quen thuộc và mức độ thực hiện CĐS hiện tại trong ngành XD
C3	Organizational restructuring/ Cơ cấu lại cơ quan	Restructure the organization to support DX implementation/ Cơ cấu lại cơ quan để hỗ trợ thực hiện CĐS

Code	CSFs	Description
C4	Innovate by rapid experimentation/ Đổi mới bằng thử nghiệm nhanh	Learn to experiment continuously and effectively, getting real data and real customer feedback, continuously iterating and testing new ideas/ Học cách thử nghiệm liên tục và hiệu quả, nhận dữ liệu và phản hồi của khách hàng theo thời gian thực, đồng thời liên tục lặp lại thử nghiệm các ý tưởng mới
C5	Turn data into assets/ Biến dữ liệu thành tài sản	Develop the clear vision and the growing capability needed to put data to work in the service of innovation and value creation/ Phát triển tầm nhìn rõ ràng và gia tăng các năng lực cần thiết cho việc đưa dữ liệu vào hoạt động phục vụ sự đổi mới và tạo ra các giá trị
C6	Consulting/ Tư vấn	Receiving consultancy services from specialized firms/ Nhận dịch vụ tư vấn từ các cơ quan có chuyên môn
C7	Harness customer networks/ Khai thác mạng lưới khách hàng	Learn to view customers differently, understanding the dynamic, networked ways in which they interact, both with businesses and with each other, helping them to access, engage, connect and even collaborate with the business/ Học cách nhìn nhận khách hàng khác đi, hiểu được sự tương tác giữa họ với nhau hoặc giữa họ với doanh nghiệp theo hướng năng động và có hệ thống, từ đó giúp họ tiếp cận, tương tác, kết nối và cộng tác với doanh nghiệp
C8	Business model innovation/ Đổi mới mô hình kinh doanh	Capability to design new business models/ Khả năng thiết kế hay xây dựng các mô hình kinh doanh mới
C9	Coordination	Existence of a cooperative project environment

Code	CSFs	Description
	among project parties/ Phối hợp giữa các bên của dự án	between project parties to successfully implement DX/ Sự sẵn có của một môi trường mang tính hợp tác giữa các bên của dự án để thực hiện CĐS thành công
C10	Perceived benefits from DX/ Nhận thức được lợi ích từ CĐS	Notice or become aware of benefits and advantages from DX implementation/ Nhận thức được lợi ích và lợi thế từ việc triển khai CĐS
(2)		People & Culture
C11	Willingness of staffs to learn new technology/ Việc sẵn sàng học hỏi công nghệ mới của nhân viên	Enthusiasm of organizational staffs realated DX learning and knowledge/ Sự hăng hái, nhiệt tình của nhân viên cơ quan trong việc học hỏi và trau dồi kiến thức về CĐS
C12	Organizational culture & work environment / Văn hóa cơ quan & môi trường làm việc	Existence of an organizational culture to be prone to learning and implementing of innovative technology and the surrounding conditions in which an employee operates or refers to the elements that comprise the setting in which employees work and impact workers/ Văn hóa cơ quan thiên về việc học hỏi và triển khai công nghệ đổi mới và các điều kiện tại nơi làm việc hoặc các yếu tố cấu thành nên môi trường làm việc của nhân viên và có ảnh hưởng trực tiếp tới nhân viên
C13	DX training programs/ Các chương trình đào tạo CĐS	The use of training and seminars to equip staffs with useful information and skills to facilitate DX/ Việc sử dụng các khóa đào tạo, hội thảo để trang bị cho nhân viên những thông tin và kỹ năng hữu ích cho

Code	CSFs	Description
		việc CĐS
C14	Availability of qualified staff and competent technical support team within company/ Sự sẵn có của đội ngũ nhân viên có trình độ và các kỹ thuật viên	Existence of competent personnel and necessary technicians to deploy DX implementation within the organization/ Sự sẵn có của nhân sự có năng lực và các kỹ thuật viên cần thiết cho việc triển khai thực hiện CĐS trong cơ quan XD
C15	Relationships and knowledge sharing with other firms/ Mối quan hệ và chia sẻ kiến thức với các cơ quan khác	Existence of a knowledge-sharing and collaborative platform within the industry/ Sự tồn tại của một nền tảng hợp tác và chia sẻ kiến thức trong ngành XD
C16	Commitment of employees/ Cam kết của nhân viên	Employees are fully engaged in the process of DX implementation/ Nhân viên cam kết tuyệt đối tham gia vào quá trình thực hiện CĐS
C17	Client's attitude with DX/ Thái độ của khách hàng về CĐS	The willingness of clients to adopt DX or existence of a requirement specified or pressure exerted by the client/ Sự sẵn lòng của khách hàng để áp dụng CĐS hoặc sự sẵn có của yêu cầu được chỉ định bởi khách hàng
C18	Pressure from competitors/ Áp lực từ đối thủ cạnh	The pressure to compete with other competitors within the industry/ Áp lực từ việc cạnh tranh với các đối thủ khác trong ngành XD

Code	CSFs	Description
	tranh	
C19	Interdepartmental communication/ Liên lạc giữa các phòng ban	Communication and connection among different departments within organization/ Sự liên lạc và kết nối giữa các phòng ban khác nhau trong nội bộ cơ quan
(3)		Process & Governance
C20	Effective monitoring of progress/ Giám sát hiệu quả tiến độ	Establishing clear metrics and targets around processes and monitoring the progress rigidly/ Thiết lập các chỉ số và mục tiêu rõ ràng cho các quy trình và giám sát tiến độ một cách chặt chẽ
C21	Effective leadership/ Lãnh đạo hiệu quả	Commitment and approach of the top management to facilitate DX within the organization/ Việc cam kết và cách tiếp cận của lãnh đạo cấp cao để tạo điều kiện cho CĐS trong cơ quan
C22	Financial support from the government/ Hỗ trợ tài chính từ Chính Phủ	Existence of incentive from government in terms of financial support to promote DX/ Sự khuyến khích và hỗ trợ của Chính Phủ về mặt tài chính để thúc đẩy CĐS
C23	DX legislation/ Luật CĐS	Existence of DX guidelines, standards, codes, rules, regulations and roadmaps within the industry/ Sự sẵn có của các hướng dẫn, tiêu chuẩn, quy chuẩn, quy tắc, quy định và lộ trình CĐS trong ngành XD
(4)		Technology & Capabilities
C24	Availability of information and technology/ Sự sẵn có của thông tin và công nghệ	Existence of necessary information and technology infrastructure within the organization for implementing DX/ Sự sẵn có của cơ sở hạ tầng công nghệ thông tin cần thiết trong nội bộ cơ quan cho việc triển khai CĐS

Code	CSFs	Description
C25	Financial resources of organization/ Nguồn lực tài chính của cơ quan	Ability of the organization to allocate sufficient budget for DX implementation/ Khả năng của cơ quan để phân bổ đủ ngân sách cho việc thực hiện CĐS
C26	Data security/ Bảo mật dữ liệu	The process of protecting data from unauthorized access and data corruption throughout its lifecycle including data encryption, hashing, tokenization and key management practices that protect data across all applications and platforms/ Quy trình bảo vệ dữ liệu khỏi truy cập trái phép hay bị hư hỏng suốt vòng đời của nó bao gồm mã hóa dữ liệu, mã hóa kỹ thuật số và các phương pháp quản lý then chốt để bảo vệ dữ liệu trên tất cả các ứng dụng và nền tảng
C27	Maintenance and upgrade cost (software, hardware)/ Chi phí bảo trì và nâng cấp (phần mềm, phần cứng)	Organization strategic policies that favors allocation of sufficient budget toward DX system maintenance and upgrade/ Các chính sách chiến lược của cơ quan thiên về việc phân bổ đủ ngân sách cho việc bảo trì và nâng cấp hệ thống CĐS
C28	Organizational flexibility or adaptability to market/ Tính linh hoạt của cơ quan hoặc khả năng thích ứng với thị trường	The ability of organization to adapt the change of market/ Khả năng của cơ quan để thích ứng với sự thay đổi của thị trường
C29	Research and	The ability of organization to do research for

Code	CSFs	Description
	development capability of organization/ Khả năng nghiên cứu và phát triển của cơ quan	innovation by themselves/ Khả năng tự nghiên cứu độc lập của cơ quan cho việc đổi mới, cải tiến
C30	Technical support and customer feedback from software and hardware suppliers/ Hỗ trợ kỹ thuật và nhận phản hồi khách hàng từ các nhà cung cấp phần mềm và phần cứng	The support in terms of technical problems and customer feedback service from software and hardware suppliers/ Sự hỗ trợ liên quan đến các vấn đề kỹ thuật và phản hồi của khách hàng từ các nhà cung cấp phần mềm và phần cứng

SECTION 3: RANKING CSFs QUESTIONNAIRE SURVEY/

PHẦN 3: BẢNG CÂU HỎI XẾP HẠNG CSFs

Please check on the checklist box ☑ based on your own opinion and experience.

1) Please kindly evaluate the importance of the below CSFs regarding the DX implementation for Vietnamese contractors. / Ông (Bà) hãy đánh giá mức độ quan trọng của những yếu tố thành công then chốt dưới đây trong ảnh hướng tới việc áp dụng Chuyển Đổi Số (CĐS) cho các Nhà thầu tại Việt Nam.

Very unimportant/ Rất không quan trọng	Unimportant/ Không quan trọng	Neutral/ Trung lập	Important/ Quan trọng	Very important/ Rất quan trọng
1	2	3	4	5

Code	Factors that influence the DX implementation of contractors	Level of importance				
		Very unimportant ----> Very important				
(1)	Strategy & Vision	1	2	3	4	5
C1	Determining digital strategy and transformed areas	☐	☐	☐	☐	☐
C2	Awareness level of the industry	☐	☐	☐	☐	☐
C3	Organizational restructuring	☐	☐	☐	☐	☐
C4	Innovate by rapid experimentation	☐	☐	☐	☐	☐
C5	Turn data into assets	☐	☐	☐	☐	☐
C6	Consulting	☐	☐	☐	☐	☐
C7	Harness customer networks	☐	☐	☐	☐	☐
C8	Business model innovation	☐	☐	☐	☐	☐
C9	Coordination among project parties	☐	☐	☐	☐	☐

Code	Factors that influence the DX implementation of contractors	Level of importance				
		Very unimportant ----> Very important				
C10	Perceived benefits from DX	☐	☐	☐	☐	☐
(2)	People & Culture	1	2	3	4	5
C11	Willingness of staffs to learn new technology	☐	☐	☐	☐	☐
C12	Organizational culture & work environment	☐	☐	☐	☐	☐
C13	DX training programs	☐	☐	☐	☐	☐
C14	Availability of qualified staff and competent technical support team within company	☐	☐	☐	☐	☐
C15	Relationships and knowledge sharing with other firms	☐	☐	☐	☐	☐
C16	Commitment of employees	☐	☐	☐	☐	☐
C17	Client's attitude with DX	☐	☐	☐	☐	☐
C18	Pressure from competitors	☐	☐	☐	☐	☐
C19	Interdepartmental communication	☐	☐	☐	☐	☐
(3)	Process & Governance	1	2	3	4	5
C20	Effective monitoring of progress	☐	☐	☐	☐	☐
C21	Effective leadership	☐	☐	☐	☐	☐
C22	Financial support from the government	☐	☐	☐	☐	☐
C23	DX legislation	☐	☐	☐	☐	☐
(4)	Technology & Capabilities	1	2	3	4	5
C24	Availability of information and technology	☐	☐	☐	☐	☐
C25	Financial resources of organization	☐	☐	☐	☐	☐
C26	Data security	☐	☐	☐	☐	☐

Code	Factors that influence the DX implementation of contractors	Level of importance				
		Very unimportant ----> Very important				
C27	Maintenance and upgrade cost (software, hardware)	☐	☐	☐	☐	☐
C28	Organizational flexibility or adaptability to market	☐	☐	☐	☐	☐
C29	Research and development capability of organization	☐	☐	☐	☐	☐
C30	Technical support and customer feedback from software and hardware suppliers	☐	☐	☐	☐	☐

2) Other ideas or opinions/ Một số ý kiến khác: .....

APPENDIX E: IN-DEPTH INTERVIEW

ANALYZING RELATIONSHIP AMONG CSFs

CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

Dear Sir/Madam,

I am Tan Thanh Trang, a PhD Candidate at the Chulalongkorn University in Thailand. I have been doing research about "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map (FCM) And Ranking Analysis Approach". This interview is used only for the purpose of writing the thesis, the personal information within the interview is confidential and will not be opened to the public. Your knowledge and contribution will be very important for the accuracy of the research. I highly appreciate your co-operation and contribution! Thank you so much.

The interview consists of three sections:

Section 1: Personal information

Section 2: CSFs of DX implementation and evaluation scale for FCM

Section 3: Interview questions

Researcher Information

Tan Thanh Trang	PhD Candidate, Construction Engineering and Management, Chulalongkorn University, Thailand and Osaka University, Japan
Address	107/99 Soi Man Sin 4, Rama VI Road, Khwaeng Thung Phaya Thai, Khet Ratchathewi, Bangkok 10400, Thailand

Mobile (+66) 94.260.5093

Email thanhtanxdbk@gmail.com

Please kindly answer the questions; the research would not be accomplished without your cooperation. Thank you so much for your kind support.

SECTION 1: PERSONAL INFORMATION

1) How long have you worked in the construction industry?

☐< 3 years ☐3 - 5 years

☐5 - 10 years ☐> 10 years

2) What kind of company are you working at?

☐ Contractors ☐ Owner ☐ Consultants ☐ Other: .....

3) You are working at your company as a position:

☐ Directors ☐ Deputy Directors ☐ Project Managers

☐ Engineers ☐ Other: .....

4) Do you know about Digital Transformation (DX)?

☐Known ☐Unknown

☐Heard of it ☐Know very well

5) Do you know about Critical Success Factors (CSFs)?

☐Known ☐Unknown

☐Heard of it ☐Know very well

6) How is the status of DX implementation of your organization/ company?

.....

Contact Information

Name:

Email:

Mobile:

Name of your organization/ company:

SECTION 2: CSFs OF DX IMPLEMENTATION AND EVALUATION SCALE FOR FUZZY COGNITIVE MAP

I. DEFINITION

1. Digital Transformation (DX)

DX is the cultural, organizational and operational change of an organization, industry or ecosystem through a smart integration of digital technologies, processes and competencies across all levels and functions in a staged and strategic way (i-SCOOP, 2021b). In other words, DX is the integration of digital technology into all areas of a business, fundamentally changing how you operate and deliver value to customers (The Enterprisers Project, 2016).

2. Critical Success Factors (CSFs)

CSFs are indicators for opportunities, activities or conditions required to achieve an objective within a project or mission (Janse, 2019). Moreover, CSFs are specific elements or action areas a business, team or department must focus on and successfully implement to reach its strategic objectives (CMOE, 2021).

II. CSFs REGARDING DX IMPLEMENTATION FOR CONTRACTORS

Table 1. CSFs regarding DX implementation for contractors

Code	CSFs Categories
Group 1	Strategy & Vision
C1	Determining digital strategy and transformed areas
C2	Awareness level of the industry
C3	Organizational restructuring
C4	Innovate by rapid experimentation
C5	Turn data into assets
C6	Consulting
C7	Harness customer networks
C8	Business model innovation
C9	Coordination among project parties

Code	CSFs Categories
C10	Perceived benefits from DX
(2)	People & Culture
C11	Willingness of staffs to learn new technology
C12	Organizational culture & work environment
C13	DX training programs
C14	Availability of qualified staff and competent technical support team within company
C15	Relationships and knowledge sharing with other firms
C16	Commitment of employees
C17	Client's attitude with DX
C18	Pressure from competitors
C19	Interdepartmental communication
(3)	Process & Governance
C20	Effective monitoring of progress
C21	Effective leadership
C22	Financial support from the government
C23	DX legislation
(4)	Technology & Capabilities
C24	Availability of information and technology
C25	Financial resources of organization
C26	Data security
C27	Maintenance and upgrade cost (software, hardware)
C28	Organizational flexibility or adaptability to market
C29	Research and development capability of organization
C30	Technical support and customer feedback from software and hardware suppliers

III. EVALUATION SCALE FOR FCM

Table 2. Linguistic term scale with nine linguistic variables

Linguistic terms	TFNs	Code
Very high positive relation	(1.00, 1.00, 0.75)	VHP (4)
High positive relation	(1.00, 0.75, 0.50)	HP (3)
Medium positive relation	(0.75, 0.50, 0.25)	MP (2)
Low positive relation	(0.50, 0.25, 0.00)	LP (1)
No relation, zero	(0.25, 0.00, -0.25)	Z (0)
Low negative relation	(0.00, -0.25, -0.50)	LN (-1)
Medium negative relation	(-0.25, -0.50, -0.75)	MN (-2)
High negative relation	(-0.50, -0.75, -1.00)	HN (-3)
Very high negative relation	(-0.75, -1.00, -1.00)	VHN (-4)

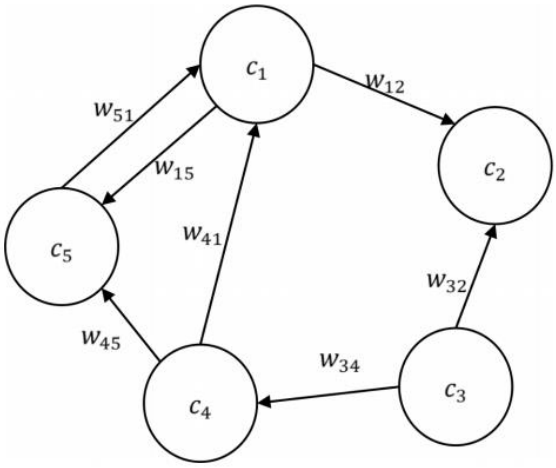

Figure 1. The basic concept of FCM (Kosko, 1986; Mei et al., 2013)

Evaluate the relationship between the factors:

- If wij > 0: positive causality between concepts Ci and Cj, if Ci increases (decreases), then Cj increases (decreases).
- If wij < 0: negative causality between concepts Ci and Cj, if Ci increases (decreases), then Cj decreases (increases).
- If wij = 0, no relationship between concepts Ci and Cj.

SECTION 3: INTERVIEW QUESTIONS

Please use the linguistic term scale provided in Table 2 to evaluate the relationship between each pair of CSFs in Table 3.

Table 3. FCM matrice

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C1	-																													
C2		-																												
C3			-																											
C4				-																										
C5					-																									
C6						-																								
C7							-																							
C8								-																						
C9									-																					
C10										-																				
C11											-																			
C12												-																		
C13													-																	
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C26																										-				
C27																											-			
C28																												-		
C29																													-	
C30																														-

APPENDIX F: QUESTIONNAIRE SURVEY

VERIFYING THE RESEARCH RESULTS

CRITICAL SUCCESS FACTORS FOR DIGITAL TRANSFORMATION IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY: AN INTEGRATED FUZZY COGNITIVE MAP AND RANKING ANALYSIS APPROACH

Dear Sir/Madam,

I am Tan Thanh Trang, a PhD Candidate at the Chulalongkorn University in Thailand. I have been doing research about "Critical Success Factors (CSFs) For Digital Transformation (DX) Implementation In The Construction Industry: An Integrated Fuzzy Cognitive Map And Ranking Analysis Approach". This questionnaire survey is used only for the purpose of writing the thesis, the personal information within the survey is confidential and will not be opened to the public. Your knowledge and contribution will be very important for the accuracy of the research. I highly appreciate your co-operation and contribution! Thank you so much.

The questionnaire survey consists of three sections:

Section 1: Personal information

Section 2: Research results

Section 3: Questionnaires

Researcher Information

Tan Thanh Trang	PhD Candidate, Construction Engineering and Management, Chulalongkorn University, Thailand and Osaka University, Japan
Address	107/99 Soi Man Sin 4, Rama VI Road, Khwaeng Thung Phaya Thai, Khet Ratchathewi, Bangkok 10400, Thailand

Mobile (+66) 94.260.5093

Email thanhtanxdbk@gmail.com

Please kindly answer the questions; the research would not be accomplished without your cooperation. Thank you so much for your kind support.

SECTION 1: PERSONAL INFORMATION

Contact Information

Name:.....

Email:.....

Mobile:.....

Name of your organization/ company:.....

SECTION 2: RESEARCH RESULTS

I. DX ROADMAP

Figure 1 shows the DX roadmap.

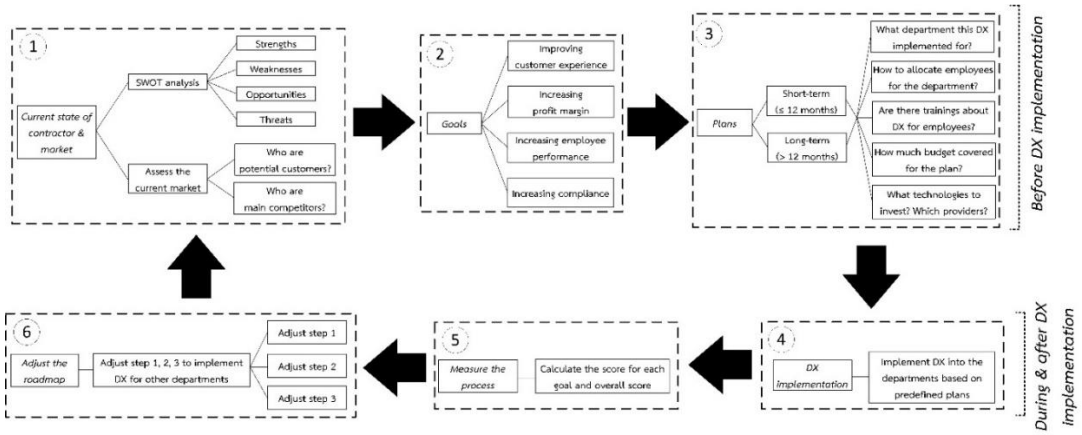

Figure 1. DX roadmap

I. FINAL CSF list

The final thirty CSF list is presented in Table 1.

Table 1. Final thirty CSFs

Code	CSFs Categories
Group 1	Strategy & Vision
C1	Determining digital strategy and transformed areas
C2	Awareness level of the industry
C3	Organizational restructuring
C4	Innovate by rapid experimentation
C5	Turn data into assets
C6	Consulting
C7	Harness customer networks
C8	Business model innovation
C9	Coordination among project parties
C10	Perceived benefits from DX

Code	CSFs Categories
(2)	People & Culture
C11	Willingness of staffs to learn new technology
C12	Organizational culture & work environment
C13	DX training programs
C14	Availability of qualified staff and competent technical support team within company
C15	Relationships and knowledge sharing with other firms
C16	Commitment of employees
C17	Client's attitude with DX
C18	Pressure from competitors
C19	Interdepartmental communication
(3)	Process & Governance
C20	Effective monitoring of progress
C21	Effective leadership
C22	Financial support from the government
C23	DX legislation
(4)	Technology & Capabilities
C24	Availability of information and technology
C25	Financial resources of organization
C26	Data security
C27	Maintenance and upgrade cost (software, hardware)
C28	Organizational flexibility or adaptability to market
C29	Research and development capability of organization
C30	Technical support and customer feedback from software and hardware suppliers

Figure 2 illustrates the CSFs linked with steps of DX roadmap.

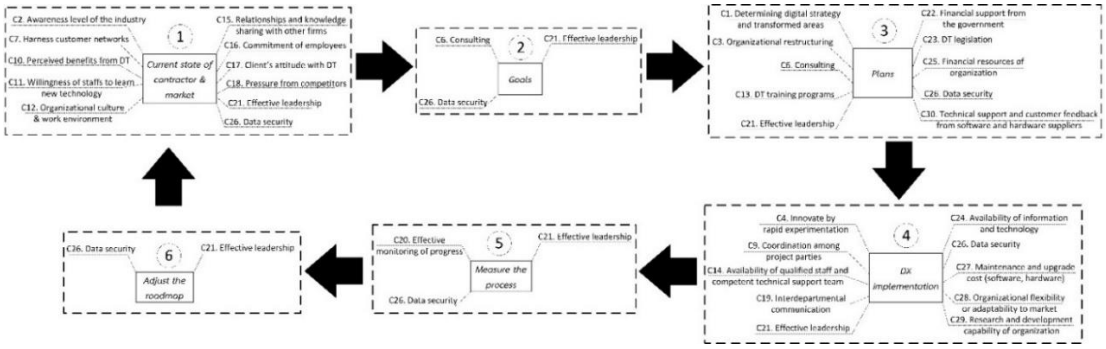

Figure 2. CSFs linked with steps of DX roadmap

Table 2 summaries the CSFs linked with steps of DX roadmap

Table 2. CSFs linked with steps of DX roadmap

Steps	Description	CSFs
Step 1	Current state of contractor & market	C2, C7, C10, C11, C12, C15, C16, C17, C18, C21, C26
Step 2	Goals	C6, C21, C26
Step 3	Plans	C1, C3, C6, C13, C21, C22, C23, C25, C26, C30
Step 4	DX implementation	C4, C9, C14, C19, C21, C24, C26, C27, C28, C29
Step 5	Measure the process	C20, C21, C26
Step 6	Adjust the roadmap	C21, C26

II. CSFs RANKING ANALYSIS

The output from SPSS software after analyzing the data from the large-scale survey is presented in Table 3.

Table 3. SPSS output of the large-scale survey

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
C21	75	2	5	4.45	0.759
C5	75	3	5	4.35	0.668
C26	75	2	5	4.33	0.759
C11	75	1	5	4.28	0.847
C25	75	2	5	4.27	0.759
C24	75	3	5	4.27	0.759
C1	75	3	5	4.25	0.737
C29	75	3	5	4.20	0.637
C20	75	2	5	4.20	0.771
C12	75	1	5	4.19	0.865
C19	75	1	5	4.19	0.940
C13	75	2	5	4.19	0.748
C10	75	2	5	4.16	0.717
C30	75	1	5	4.12	0.838
C28	75	3	5	4.11	0.669
C7	75	2	5	4.08	0.731
C14	75	2	5	4.04	0.829
C4	75	2	5	4.04	0.813
C6	75	2	5	4.01	0.893
C23	75	2	5	4.00	0.885
C18	75	1	5	3.99	0.979
C3	75	2	5	3.99	0.862
C27	75	2	5	3.99	0.762
C8	75	2	5	3.95	0.853
C16	75	1	5	3.91	0.932
C9	75	2	5	3.89	0.764
C17	75	1	5	3.85	0.896
C22	75	1	5	3.80	1.027
C15	75	2	5	3.71	0.818
C2	75	2	5	3.67	0.905

II. ANALYZING RELATIONSHIPS AMONG CSFs

Constructed FCM for the CSFs of DX implementation for contractors is indicated in Figure 3.

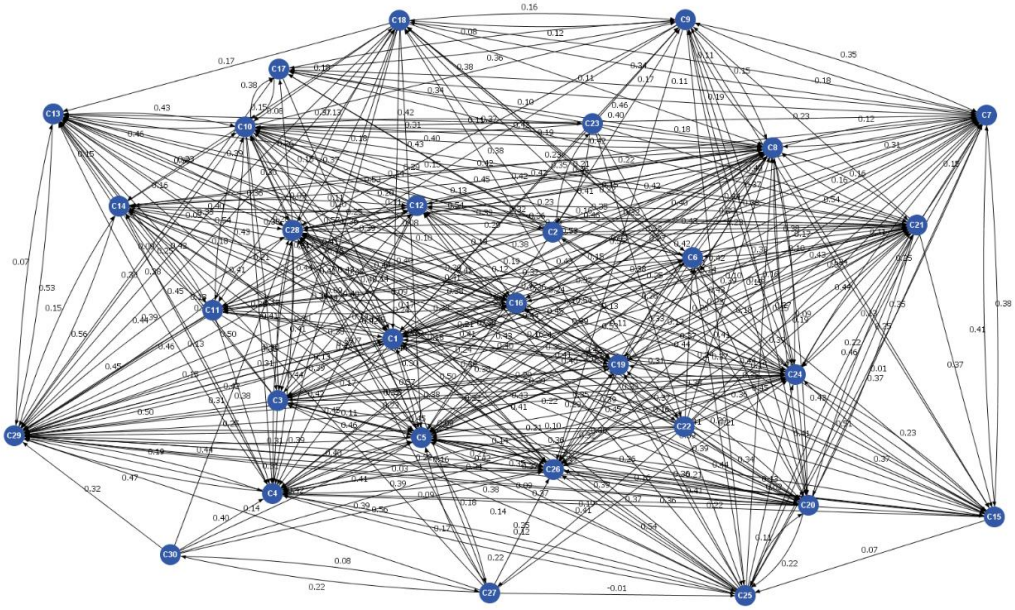

Figure 3. Constructed FCM for the CSFs of DX implementation

Outdegree, indegree and centrality values for each factor are shown in Table 4.

Table 4. Graph index values

Criteria	Indegree	Outdegree	Total degree
C1	4.59	6.61	11.20
C2	1.15	2.65	3.80
C3	3.36	3.68	7.04
C4	6.87	1.91	8.78
C5	7.79	4.82	12.61
C6	2.64	4.61	7.25
C7	5.38	2.82	8.20
C8	6.47	3.73	10.20
C9	2.71	2.95	5.66
C10	5.02	6.81	11.83
C11	3.88	3.87	7.75

Criteria	Indegree	Outdegree	Total degree
C12	3.47	3.76	7.23
C13	6.04	2.14	8.18
C14	2.84	4.31	7.15
C15	3.65	3.28	6.93
C16	2.90	5.48	8.38
C17	3.10	0.54	3.64
C18	0.83	2.31	3.14
C19	4.15	3.36	7.51
C20	4.90	4.74	9.64
C21	5.02	8.65	13.67
C22	0.90	4.22	5.12
C23	0.77	3.47	4.24
C24	4.10	5.68	9.78
C25	1.47	5.63	7.10
C26	4.89	2.47	7.36
C27	0.45	1.44	1.89
C28	8.18	5.19	13.37
C29	9.18	3.34	12.52
C30	0.22	2.45	2.67

The calculated values for each factors are ranked in descending order for outdegree, indegree and total degree to show the factors that influence other factors the most (outdegree value), the factors that are influenced the most (indegree value) and the most important factors (centrality values). All calculated values are illustrated in Table 5 and Table 6.

Table 5. Ranked graph index values

Ranked Order	Criteria	Indegree	Criteria	Outdegree	Criteria	Total Degree
1	C29	9.18	C21	8.65	C21	13.67
2	C28	8.18	C10	6.81	C28	13.37
3	C5	7.79	C1	6.61	C5	12.61

Ranked Order	Criteria	Indegree	Criteria	Outdegree	Criteria	Total Degree
4	C4	6.87	C24	5.68	C29	12.52
5	C8	6.47	C25	5.63	C10	11.83
6	C13	6.04	C16	5.48	C1	11.20
7	C7	5.38	C28	5.19	C8	10.20
8	C10	5.02	C5	4.82	C24	9.78
9	C21	5.02	C20	4.74	C20	9.64
10	C20	4.9	C6	4.61	C4	8.78
11	C26	4.89	C14	4.31	C16	8.38
12	C1	4.59	C22	4.22	C7	8.20
13	C19	4.15	C11	3.87	C13	8.18
14	C24	4.1	C12	3.76	C11	7.75
15	C11	3.88	C8	3.73	C19	7.51
16	C15	3.65	C3	3.68	C26	7.36
17	C12	3.47	C23	3.47	C6	7.25
18	C3	3.36	C19	3.36	C12	7.23
19	C17	3.1	C29	3.34	C14	7.15
20	C16	2.9	C15	3.28	C25	7.10
21	C14	2.84	C9	2.95	C3	7.04
22	C9	2.71	C7	2.82	C15	6.93
23	C6	2.64	C2	2.65	C9	5.66
24	C25	1.47	C26	2.47	C22	5.12
25	C2	1.15	C30	2.45	C23	4.24
26	C22	0.9	C18	2.31	C2	3.80
27	C18	0.83	C13	2.14	C17	3.64
28	C23	0.77	C4	1.91	C18	3.14
29	C27	0.45	C27	1.44	C30	2.67
30	C30	0.22	C17	0.54	C27	1.89

SECTION 3: QUESTIONNAIRES

(1: Very unsatisfied ---> 2: Unsatisfied ---> 3: Neutral ---> 4: Satisfied ---> 5: Very satisfied)

1) Are you satisfied with the DX roadmap?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

2) Are you satisfied with the final CSF list?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3) Are you satisfied with the result of CSFs linked with steps of DX roadmap?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

4) Are you satisfied with the results of CSFs ranking?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

5) Are you satisfied with the results of relationships among CSFs?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

6) Do you have any comments or suggestions about the DX roadmap?

.....

.....

7) Do you have any comments or suggestions about the final CSF list?

.....

.....

8) Do you have any comments or suggestions about the CSFs linked with steps of DX roadmap?

.....

.....

9) Do you have any comments or suggestions about the results of CSFs ranking?

.....

.....

10) Do you have any comments or suggestions about the results of relationship among CSFs?

.....

.....

APPENDIX G: ONE-WAY ANOVA TEST

Table 1. Summary of one-way ANOVA test for thirty CSFs – Type of construction firms

CSFs	Sig. value (Levene test)	Sig. value (ANOVA test)	Sig. value (Robust test)	Hypothesis
C1	.257	.043	-	H_1
C2	.044	-	.062	H_0
C3	.369	.082	-	H_0
C4	.388	.174	-	H_0
C5	.510	.252	-	H_0
C6	.772	.166	-	H_0
C7	.557	.575	-	H_0
C8	.585	.040	-	H_1
C9	.449	.227	-	H_0
C10	.418	.120	-	H_0
C11	.584	.733	-	H_0
C12	.914	.302	-	H_0
C13	.931	.420	-	H_0
C14	.619	.107	-	H_0
C15	.272	.207	-	H_0
C16	.043	-	<.001	H_1
C17	.001	-	.	H_1
C18	.645	.578	-	H_0
C19	.163	.188	-	H_0
C20	.107	.179	-	H_0
C21	.003	-	.025	H_1
C22	.148	.160	-	H_0
C23	.827	.940	-	H_0
C24	.316	.413	-	H_0
C25	.241	.133	-	H_0

CSFs	Sig. value (Levene test)	Sig. value (ANOVA test)	Sig. value (Robust test)	Hypothesis
C26	.153	.738	-	H_0
C27	.680	.046	-	H_1
C28	.076	.014	-	H_1
C29	.168	.151	-	H_0
C30	.105	.045	-	H_1

Table 2. Summary of one-way ANOVA test for thirty CSFs – Size of construction firms

CSFs	Sig. value (Levene test)	Sig. value (ANOVA test)	Sig. value (Robust test)	Hypothesis
C1	.234	.563	-	H_0
C2	.039	-	.416	H_0
C3	.261	.951	-	H_0
C4	.190	.125	-	H_0
C5	.356	.812	-	H_0
C6	.005	-	.288	H_0
C7	.041	-	.259	H_0
C8	.063	.108	-	H_0
C9	.267	.725	-	H_0
C10	.310	.298	-	H_0
C11	.439	.574	-	H_0
C12	.219	.773	-	H_0
C13	.669	.986	-	H_0
C14	.189	.413	-	H_0
C15	.557	.648	-	H_0
C16	.217	.854	-	H_0
C17	.315	.613	-	H_0
C18	.181	.247	-	H_0

CSFs	Sig. value (Levene test)	Sig. value (ANOVA test)	Sig. value (Robust test)	Hypothesis
C19	.421	.213	-	H_0
C20	.059	.658	-	H_0
C21	.099	.862	-	H_0
C22	.239	.044	-	H_1
C23	.946	.870	-	H_0
C24	.308	.754	-	H_0
C25	.292	.666	-	H_0
C26	.589	.520	-	H_0
C27	.665	.186	-	H_0
C28	.254	.445	-	H_0
C29	.004	-	.003	H_1
C30	.840	.060	-	H_0

APPENDIX H: WEIGHT OF FCM

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C1	0.00	0.00	0.17	0.45	0.57	0.42	0.43	0.53	0.42	0.47	0.00	0.00	0.54	0.00	0.41	0.38	0.00	0.00	0.40	0.45	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.44	0.31	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.40	0.39	0.00	0.00	0.43	0.00	0.43	0.11	0.00	0.00	0.23	0.11	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	0.13	0.00	0.00	0.31	0.11	0.00	0.00	0.19	0.00	0.00	0.00	0.09	0.25	0.13	0.00	0.00	0.00	0.00	0.50	0.36	0.54	0.00	0.00	0.20	0.09	0.11	0.00	0.17	0.50	0.00
C4	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.03	0.00	0.35	0.47	0.00
C5	0.00	0.00	0.00	0.41	0.00	0.24	0.43	0.32	0.43	0.34	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.43	0.26	0.33	0.00	0.00	0.00	0.00	0.14	0.18	0.43	0.44	0.00
C6	0.45	0.00	0.38	0.38	0.40	0.00	0.16	0.44	0.00	0.54	0.41	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.38	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00
C7	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.31	0.18	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.46	0.11	0.00	0.00	0.00	0.00	0.00	0.25	0.01	0.27	0.00	0.42	0.00	0.00
C8	0.15	0.00	0.36	0.16	0.13	0.00	0.12	0.00	0.19	0.38	0.00	0.22	0.31	0.13	0.25	0.27	0.00	0.00	0.14	0.09	0.16	0.00	0.00	0.10	0.00	0.17	0.00	0.23	0.17	0.00
C9	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.36	0.12	0.00	0.38	0.00	0.00	0.00	0.37	0.22	0.03	0.00	0.37	0.36	0.00
C10	0.57	0.29	0.21	0.38	0.43	0.45	0.40	0.42	0.38	0.00	0.43	0.00	0.46	0.00	0.00	0.11	0.38	0.00	0.00	0.00	0.00	0.41	0.42	0.38	0.00	0.09	0.00	0.30	0.30	0.00
C11	0.30	0.00	0.00	0.38	0.39	0.00	0.35	0.00	0.00	0.40	0.00	0.41	0.41	0.38	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00
C12	0.00	0.00	0.14	0.37	0.00	0.00	0.00	0.21	0.00	0.37	0.41	0.00	0.39	0.28	0.24	0.13	0.00	0.00	0.32	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
C13	0.00	0.00	0.00	0.45	0.41	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.53	0.00
C14	0.00	0.00	0.00	0.13	0.41	0.00	0.23	0.15	0.00	0.38	0.42	0.36	0.15	0.00	0.00	0.41	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.33	0.56	0.00
C15	0.00	0.45	0.00	0.37	0.41	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.37	0.07	0.02	0.00	0.39	0.38	0.00
C16	0.41	0.00	0.23	0.28	0.39	0.00	0.33	0.32	0.00	0.39	0.45	0.39	0.38	0.44	0.00	0.00	0.00	0.00	0.39	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.31	0.00
C17	0.11	0.00	0.00	0.00	0.00	0.00	0.17	0.10	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C18	0.14	0.00	0.20	0.16	0.08	0.19	0.11	0.11	0.16	0.18	0.15	0.00	0.17	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.18	0.18	0.00
C19	0.00	0.00	0.00	0.09	0.00	0.00	0.17	0.42	0.00	0.00	0.35	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.21	0.19	0.00	0.00	0.37	0.00	0.30	0.00	0.38	0.42	0.00
C20	0.32	0.00	0.37	0.37	0.39	0.00	0.35	0.39	0.10	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.39	0.00	0.46	0.00	0.00	0.00	0.22	0.36	0.00	0.39	0.39	0.00
C21	0.25	0.00	0.53	0.36	0.44	0.43	0.15	0.54	0.23	0.46	0.43	0.52	0.42	0.32	0.37	0.42	0.42	0.00	0.15	0.37	0.00	0.00	0.00	0.13	0.51	0.44	0.00	0.55	0.21	0.00
C22	0.00	0.00	0.00	0.27	0.10	0.37	0.37	0.39	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.34	0.00	0.00	0.00	0.34	0.19	0.00	0.00	0.36	0.22	0.00	0.19	0.38	0.46	0.00
C23	0.29	0.41	0.00	0.00	0.00	0.00	0.00	0.18	0.34	0.40	0.00	0.00	0.37	0.00	0.00	0.00	0.34	0.00	0.00	0.36	0.40	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24	0.42	0.00	0.22	0.21	0.39	0.18	0.11	0.16	0.20	0.00	0.43	0.00	0.10	0.00	0.23	0.00	0.36	0.16	0.38	0.41	0.44	0.00	0.00	0.00	0.00	0.39	0.00	0.44	0.45	0.00
C25	0.32	0.00	0.14	0.22	0.41	0.29	0.22	0.15	0.00	0.00	0.00	0.35	0.44	0.38	0.00	0.00	0.00	0.17	0.36	0.11	0.43	0.00	0.00	0.13	0.00	0.54	0.00	0.41	0.56	0.00

C26	0.00	0.00	0.00	0.09	0.24	0.00	0.18	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.21	0.41	0.00	0.00	0.16	0.00	0.00	0.00	0.30	0.31	0.00
C27	0.16	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	-0.01	0.25	0.00	0.23	0.14	0.22
C28	0.42	0.00	0.41	0.44	0.42	0.00	0.22	0.42	0.00	0.00	0.00	0.25	0.16	0.00	0.31	0.00	0.26	0.13	0.00	0.41	0.46	0.00	0.00	0.24	0.00	0.18	0.00	0.00	0.46	0.00
C29	0.15	0.00	0.00	0.19	0.25	0.07	0.12	0.14	0.00	0.00	0.00	0.38	0.07	0.15	0.35	0.00	0.09	0.02	0.00	0.22	0.00	0.00	0.00	0.31	0.00	0.39	0.00	0.44	0.00	0.00
C30	0.00	0.00	0.00	0.40	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.39	0.08	0.42	0.32	0.00

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