Complex Systems Informatics and Modeling Quarterly (CSIMQ)
eISSN: 2255-9922
Published online by RTU Press, https://csimq-journals.rtu.lv
Article 203, Issue 37, December 2023/January 2024, Pages 22–53
https://doi.org/10.7250/csimq.2023-37.02

Determining Critical Success Factors of the Digital Transformation Using a Force-Directed Network Graph

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Abstract. Conducting a digital transformation is one of the major challenges for today's companies as it is usually associated with a high risk. The reasons for this are manifold. Technologies are still evolving and there is no coherent standard for digital platforms enabling digitalization. Furthermore, it is not only about introducing new technology but also requires a fundamental change in an organization and its culture. Consequently, planning a digital transformation project (or program) requires a careful analysis of the company's current situation and the envisioned objectives. This article investigates critical success factors for preparing and executing such a transformation. The success factors are identified by conducting a structured literature analysis. 13 scientific papers are identified and then analyzed quantitatively and qualitatively. The quantitative analysis is conducted by using force-directed network graphs. Both methods are then compared and discussed. The result shows that most critical success factors are related to the business change rather than to introducing technology. Leadership, strategy, vision, corporate culture, and customer centricity play a stronger role than a digital platform.

Keywords: Digital Transformation, Critical Success Factors.

1 Introduction

1.1 Motivation

Digital transformation (DT) affects all sectors of society, particularly economies. Besides various challenges, digitalization creates new networking possibilities and enables cooperation among companies that exchange data and initiate new processes [1]. As part of this digitalization process across economies, digital transformation investigates the effects and necessary adjustments to corporate structures, processes, functions, and business models [2]. In this context, information and communication technologies, often referred to as digital technologies, are one of the main drivers forcing companies to engage in digital transformation [3], [4]. Some prominent examples emphasize the relevance of DT for today's companies. Netflix utilized digital technologies to create

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Reference: G. Pasqual, J. Jung, and B. Fraunholz, "Determining Critical Success Factors of the Digital Transformation Using a Force-Directed Network Grap", Complex Systems Informatics and Modeling Quarterly, CSIMQ, no. 37, pp. 22–53, 2023. Available: https://doi.org/10.7250/csimq.2023-37.02

Additional information. Author's ORCID iD: J. Jung – https://orcid.org/0000-0002-8649-4827. PII S225599222300203X. Received: 18 August 2023. Accepted: 18 December 2023. Available online: 30 December 2023.

a new business model that revolutionized how movies are consumed [5], [6]. By investigating how customers consume content, the company expanded its business model from a streaming provider to a movie production company [7]. While Netflix's story is a positive example of applying digital technologies, many traditional and established companies face new challenges because of these technologies.

In practice, such an endeavor is extremely difficult for established companies, as 90% of all digital transformation projects fail [8]. In addition, of the $1.3 trillion that was spent on DT in 2018, it was estimated that $900 billion went to waste [9]. General Electric (GE) is a prominent example of an exhausting digital transformation journey from a traditional company. At the beginning of the 21st century, General Electric, an industrial conglomerate, was one of the most valuable companies in the world [10]. In early 2010, GE planned to shape the digital future of the Internet of Things and become one of the ten largest software companies by 2020 [11]. To accomplish this transformation, GE introduced a new business unit, GE Digital, and hired thousands of software developers to gain expertise in big data analytics and machine learning [12]. Despite the enormous amount of capital GE made available for its digital transformation into a software company, the company has not been able to establish itself in the new market [13], [10]. Expressed by a 90% failure rate, with some practitioners referring to a failure rate of 86% [14], companies in other industries are experiencing similar issues. Walmart and Staples in the retail industry [15], various companies from the manufacturing industry [16], but also software companies like Sears and Zynga [15], are companies that struggled with digital transformation. These examples show that a digital transformation is not only a matter of technology but also requires changing the organization and people [17], [18], [19]. This adds some significant complexity and requires strict risk awareness and change management [20]. Hence, companies must be aware of critical success factors (CSF) to perform such an endeavor successfully.

Therefore, research on critical success factors for digital transformation holds significant importance in academia and practice as it enables a deeper understanding of the competitive advantages specific to DT strategy, its impact on institutional management and performance, and the development of empirical insights through comparative studies [21], [22]. Incorporating CSFs, such as developing a digital strategy, creating a digital culture, and establishing a digital ecosystem, is crucial for successful DT implementation [23]. The dynamic nature of DT necessitates interdisciplinary research to gain a comprehensive understanding and facilitate effective decision-making by practitioners [24]. Furthermore, a holistic approach to DT implementation is essential to ensure improved performance and sustainable growth [24]. However, current research on DT implementation requires further exploration to enhance its holistic perspective and incorporate diverse research methods for data collection [25]. The holistic approach is underlined by multiple scholars who emphasize the importance of expanding our understanding of DT and its successful implementation [26], and broadening the research methods used for data collection [25]. By conducting interdisciplinary research and employing diverse data collection methods, researchers can develop a more holistic understanding of DT and its critical success factors, enabling practitioners to make informed strategic decisions and drive successful digital transformations.

1.2 Research Objectives

The primary objective of this study is to establish a comprehensive understanding of the critical success factors (CSFs) for digital transformation. By conducting a cross-industry investigation of CSFs, drawing upon existing scholarly research [27], [28], [29], and utilizing a qualitative content analysis method, this study aims to provide a holistic view of digital transformation and facilitate effective decision-making in this context [24]. The research seeks to identify commonalities and differences among CSFs, validating the final result by discussing the findings derived from qualitative and quantitative approaches.

Besides cross-study aggregation and evaluation of the CSFs, this study illustrates relationships between the factors, as suggested by [30]. The network graph employed in this study disregards variations in wording, focusing solely on the interconnections and prominence of factors. This approach allows for a more abstract representation. It facilitates a higher-level analysis and interpretation of the relationships between factors independent of specific terminologies or linguistic nuances. By disregarding varying wording, the graph emphasizes the underlying conceptual connections. It provides a clear visualization of the overall structure and significance of the factors involved in the digital transformation context. This visual representation aids in identifying key relationships and prioritizing actions for effective digital transformation strategies.

The article is organized as follows. Related research is analyzed in Section 2. Research design is described in Section 3, the results are presented in Section 4 and discussed in Section 5. Conclusions and ideas for further research are provided in Section 6.

2 Related Research

This study builds upon prior scholarly research on digital transformation's critical success factors (CSFs). While numerous studies have examined the prevalence of CSFs in specific sectors, such as manufacturing [26], logistics [31], aviation [32], and with a particular emphasis on the retail industry [30], the current study takes a comprehensive and overarching approach. It investigates the CSFs of digital transformation across industries, drawing upon the works of [25], [33], [34]. The primary objective is to establish a cross-case comparison that not only enhances our understanding but also facilitates effective decision-making in the context of digital transformation by providing a holistic view of DT [24]. In addition to quantitative evaluation, this study incorporates a qualitative evaluation employing a qualitative content analysis method proposed by [35] to determine the criticality levels [36] of identified factors. This combined approach provides a more comprehensive understanding of the CSFs and their impact on digital transformation.

2.1 Digital Transformation

Digital transformation has long been dismissed as a buzzword but proves to be a strategic advantage when implemented correctly. With ubiquitous computing, cloud technologies, social media, data analytics, the Internet of Things (IoT), and many other technological developments, companies are facing massive changes [17]. As digital transformation encompasses profound changes in society and industries through digital technologies [37], DT affects all types of companies in all industries.

With 2015 there has been an exponential increase of research regarding digital transformation and the research field has broadened, as shown in Section 3.1. While [19], [38], [33] investigate challenges of digital transformation in banking and automotive industries, [39] identify strategic, organizational, and cultural stakes as the biggest challenges that require the dedication of the entire company, especially of management. Another central area of research is the study of frameworks to guide the successful implementation of DT in companies [40], [41], [42], [43]. Further research on digital maturity seeks to optimize processes and encourages efficient behavior that, in turn, reduces risks and increases DT success [44], [45].

Companies seek to create new market opportunities through digital transformation, drive product innovations through technologies, make their business processes more flexible, and generally increase efficiency [6]. The difficulty is not the procurement and implementation of new technologies but their efficient, large-scale, and purpose-related use [46].

Although research on digital transformation has increased exponentially since 2017, the concept lacks a universally valid definition [47], [48]. Table 1 shows a rough overview of the literature's most frequently referenced definitions of digital transformation.

Table 1. Definitions of Digital Transformation

Definitions of Digital Transformation	
Reference	Definition
Kane 2017 [49]	"The best understanding of digital transformation is adopting business processes and practices to help the organization compete effectively in an increasingly digital world."
Fitzgerald et al. 2014 [17]	"We define [DT] as the use of new digital technologies (social media, mobile, analytics or embedded devices) to enable major business improvements (such as enhancing customer experience, streamlining operations or creating new business models)."
Westerman et al. 2011 [50]	"Digital transformation (DT) – the use of technology to radically improve performance or reach of enterprises – is becoming a hot topic for companies across the globe. Executives in all industries are using digital advances such as analytics, mobility, social media and smart embedded devices – and improving their use of traditional 52 technologies such as ERP – to change customer relationships, internal processes, and value propositions."
Stolterman and Fors 2004 [51]	"The digital transformation can be understood as the changes that the digital technology causes or influences in all aspects of human life."
Davenport and Westerman 2018 [15]	"Digital transformation is an ongoing process of changing the way you do business. It requires foundational investments in skills, projects, infrastructure, and, often, in cleaning up IT systems. It requires mixing people, machines, and business processes, with all of the messiness that entails. It also requires continuous monitoring and intervention, from the top, to ensure that both digital leaders and non-digital leaders are making good decisions about their transformation efforts."
Leyh et al. 2021 [46]	"DT refers to the fundamental transformation of society as well as the economy using digital technologies. DT not only has social, cultural, legal, and political implications but also consequences for all corporate structures and value chains. For companies to master DT successfully, new business models, strategies, organisational forms, and processes are necessary, as well as a strong customer-centricity."

Although the definitions provided in Table 1 differ, in scope and detail, they all describe fundamental organizational changes possible or imposed by digital technologies. Thus, four of the six authors explicitly mention technologies in their definitions [17], [50], [51], [46], as well as the adaptation of business processes [49], [50], [15], [46]. Based on the shared conceptualization of DT in literature, for this research, we define digital transformation as follows: *Digital transformation describes an evolutionary process of realigning corporate structures, culture, and strategies to enhance companies' responsiveness to compete in a dynamic, customer-centric environment, driven by digital technologies*. The definition strongly emphasizes ongoing change, while "evolutionary" refers to continuous ubiquitous development. Companies must adapt their business processes as long as technologies, consumer behavior, and customer demands change [2].

2.2 Critical Success Factors

The concept of "success factors" was first introduced by Daniel D Ronald in 1961 and gained momentum through [52]. Since managers have limited time, management should focus exclusively on the few factors critical to the company's success [53]. In recent decades, the identification of critical success factors has extended from a management domain to a broader business context, focussing on their attributes [36] and structures [54]. Based on Little's framework of causality [55], Williams and Ramaprasad describe four levels of "criticality". While (a)-factors linked to success by a known causal mechanism are extremely difficult to determine in a complex business environment, (b.1)-factors necessary and sufficient for success and (b.2)-factors necessary for success are easier to determine. A company can name sufficient and necessary factors but simultaneously, cannot explicitly explain which events they are based on [36]. The weakest factor is (c), a factor associated with success that cannot be identified as necessary or sufficient for success. CSFs act as a starting point for a company's success; therefore, inhibiting and enhancing factors should be captured and conducted equally.

3 Research Design

This research is conducted as a meta-study based on academic publications to examine the critical success factors of digital transformation [56], [57]. Figure 1 depicts the three phases of the research project: structured literature review, qualitative content analysis, and quantitative content analysis based on the force-directed network graph, and final aggregation of both analyses, resulting in the critical success factors of digital transformation.

Initially, the APIs of scientific libraries were queried. Instead of a manual search or using their web interfaces, a Python script was implemented to gather all publications at once. Afterward, the data were reduced to specific attributes and filtered by keywords. 13 studies were identified as relevant to this research after filtering. A rating was calculated for each CSF (when applicable), resulting in an individual rating interval for each publication. These intervals were transformed into a common standard interval for comparison. Simultaneously, all factors were roughly categorized for a gross overview. A force-directed network graph was generated from the previous categorization, description of the individual factors, and contextual information. Based on its clusters and the standardized ratings, the qualitative and quantitative analyses were weighted against each other to determine the CSFs of digital transformation.

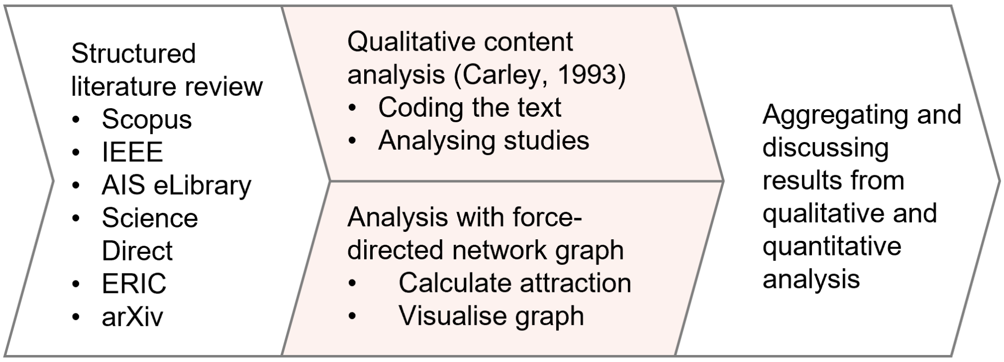

Figure 1. Research method overview

3.1 Structured Literature Review

During systematic literature research [58], [59], various publications from different libraries were collected. To collect the necessary data, we queried the APIs of various sources including Scopus, IEEE, AIS eLibrary, Science Direct, ERIC, and arXiv. Their respective APIs returned data in JSON, XML, HTML, and PubMed format for each publication, which were reduced to only a few relevant attributes during data preprocessing. Additionally, all the publications were converted into the same format, JSON. It should be noted that initially, we only searched for publications that had the phrase "digital transformation" in their titles. Furthermore, not all APIs allowed filtering based on keywords and abstracts, but on titles. Lastly, having "digital transformation" in the title of a paper does not guarantee that it would also be included in the keywords. By sticking to the title during initial data collection returned more potentially relevant results. The retrieval period was not limited, and only papers written in English were considered. A total of 4145 papers were returned in the results from the respective libraries in January 2022[3].

[3] This is a summary of a larger study that was conducted in early 2022

After selecting relevant data, data preprocessing was conducted. The paper's metadata was reduced to the title, library, year, and abstract. If the library's endpoint provided an abstract, it was included. However, if the papers remained relevant and an abstract was not provided, it was collected manually in a later step. Records that did not specify a publication date were removed. Duplicates within and across the six datasets were removed as well, resulting in 3260 remaining records. Figure 2 shows the published research on digital transformation per year. The graph includes all publications from the six libraries mentioned above. Particularly striking is the period from 2015 to 2021, with publications on digital transformation increasing almost exponentially.

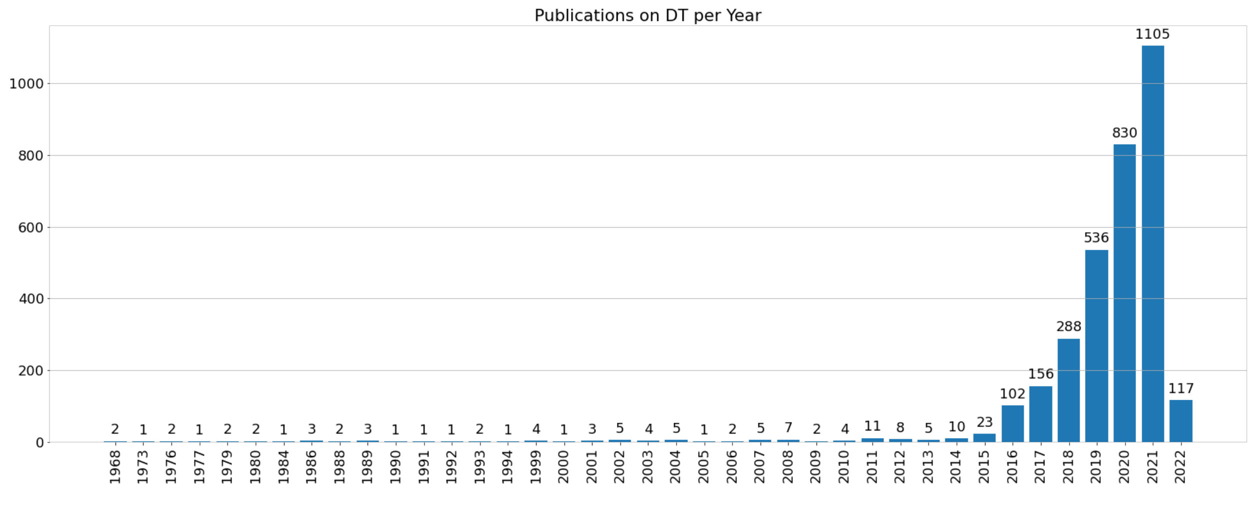

Figure 2. Publications on digital transformation by year across all libraries

Although the chart does not differentiate between libraries, an increase occurred across all investigated libraries. Regarding data distribution across the libraries, Scopus contained 2272, IEEE 446, AIS eLibrary 269, Science Direct 223, ERIC 35, and arXiv 15 records. Since this work focuses on capturing critical success factors of digital transformation, publications of interest had to refer to the discussion on success factors for DT. The remaining 3260 datasets were further filtered for explicitly containing one of the following keywords: "success", "key", "critical", "crucial", "factors", or "lessons" in their title. Of the remaining 153 studies, the title and abstract were screened manually, resulting in 43 potentially relevant studies. Great care was taken during further manual examination of the entire publications to ensure a needed level of quality. Papers considered for the final sample size had to clearly and in detail describe their research method and structure, ensuring reproducibility. After a thorough review, the total sample size resulted in 13 studies. The list of studies is available in Table A1 in the Appendix.

3.2 Coding the Content Analysis

As a research method, qualitative content analysis was chosen [35], [60]. By defining translation rules, the qualitative content analysis provides a predefined structure consisting of several steps that enhance reproducibility and ensure consistency during the coding process. Parameters are defined that determine the scope of further analysis within the first four steps. Translation rules are formulated, and how to deal with irrelevant information is defined in the subsequent two steps. Steps 7-8 deal with coding and analyzing the studies based on the rules and scope defined in the previous steps. The method has already been applied in digital transformation research [30], data governance activities [61], and other research areas, such as enterprise resource planning [62].

One of the most critical parts of content analysis is the creation of translation rules to ensure consistency and internal validity when coding specific concepts into more general ones [62]. The most critical information from the 13 studies is captured with six translation rules. At first, each study was read line by line. Contextual information was highlighted, and relevant information, such as title, year, region, research method, industry, and dataset size, was extracted. Based on contextual information, such as dimension, description and subfactors, each CSF will be transferred into a matrix. To group two factors, they must be identical or assignable without doubt by their contextual information. If possible, a rating will be calculated for each factor. A factor's rating represents the importance of a factor by a numeric value and enables cross-study comparison by mapping the different ratings into a common interval. A common interval is necessary, as ratings of the CSFs can vary significantly from paper to paper.

However, a rating can only be calculated if a study specifies the total number of datasets (n) and the respective rating for each CSF, see [46], [30]. Alternatively, a study has to provide the total number of datasets and the frequency of each CSF (Figure 3), see [26]. Suppose the study already provides a rating expressed by either a Likert scale [63] or a similar metric; in that case, the two highest scores (4-High influence and 5-Very high influence) are considered for the calculation. If no rating can be calculated, 0.5 will be entered in the corresponding matrix field.

Example 1	Example 2
Leyh et al. 2021 investigate the results of an online survey with n=97 participants. The CSF „Software" was rated *4-High influence* and *5-Very high influence* 40 and 50 times, respectfully. Thus, the rating is calculated as follows: $\frac{(40+50)}{97} = 0.928$	Vogelsang et al. 2018 evaluate n=614 statements of a semi-structured interview. The CSF „Pilot projects" was mentioned in 64 statements. Thus, the rating is calculated as follows: $\frac{64}{614} = 0.104$

Figure 3. CSF rating calculation

Figure 3 shows the CSFs "Software" and "Pilot projects" calculations as examples. As stated previously, the values vary significantly from each other, even though both display the highest rating of the respective study. To eliminate this discrepancy, the papers' ratings are mapped to a uniform scale which allows for comparison. The mapping formula is displayed in Figure A1, listed in the Appendix. After all success factors have been evaluated, and a rating has been entered in the corresponding matrix field, final categorization takes place. The generated matrix is provided in Figure A3–Figure A6 in the Appendix.

3.3 Analysis Using a Force-Directed Network Graph

While the qualitative content analysis provides first insights into the success factors of digital transformation, a precise categorization is needed. As CSFs overlap and contain one another, it is challenging to reflect the complexity in a tabular listing. In addition, some factors are hard to grasp as they are formulated more abstractly, e.g., "prepare for future" [46]. If no collective term for a cluster could be derived from the papers, a new term was defined to summarise factors that describe the same thing. These include "digital corporate culture" and "innovation structures". In addition, the CDO was identified as a critical success factor, despite being explicitly mentioned, as it was often given as contextual information [31], [64], [47], [27].

To stay abreast of this complexity, the factors are transferred into a network graph. Thus, the network graph representation enables a more transparent categorization of critical success factors. Simultaneously it illustrates interrelationships and dependencies between the individual CSFs.

The open platform Gephi[4] is used for visualizing the graph. Gephi is open-source software for analyzing networks and graphs [65]. Within Gephi, the algorithm used for visualization is

[4] https://gephi.org/

Force Atlas. Force Atlas is a force-directed algorithm to "[...] spatialise Small-World / Scale-free networks"[5]. Force Atlas is designed for quality to enable the most accurate interpretation of the graph. The focus is on minimizing deviations and maximizing readability. The algorithm increases the attraction between highly connected nodes while repulsing unrelated nodes [66]. Repulsion focuses on dissimilarities, describing how strongly nodes reject each other, while attraction points out similarities [67].

Consequently, the algorithm pushes the most connected/dominant nodes away from each other while aligning the nodes connected to the hubs in a cluster around them. As ratings of the CSFs are only partially available, edges are displayed without weighting. The graph displays success factors as nodes, and their size represents the number of associated nodes. The larger a node, the more connections it has and the larger the cluster surrounding it. Edges connect the respective nodes. If edges are thick (e.g., between "digital corporate culture" and "customer centricity"), the attraction of the two nodes is strong as the CSFs are mentioned together frequently. The edge length does not imply a specific interpretation, but only its thickness. To avoid overlaps and increase readability, the individual nodes are slightly relocated without affecting the spatial arrangement. The colored circles in the background of the clusters were added manually to highlight clusters and limit further analysis to the nodes inside a cluster.

The entire network graph can be seen in Figure A2 (Appendix). In Figure A2 edge duplicates are already merged and represented by thicker edges. The graph shows three additional clusters that are more detached from the central cluster, as they could not be associated with any other nodes. For a detailed view of the Gephi settings, see Figure A8 (Appendix).

4 Results

4.1 Force-Directed Network Graph

The qualitative content analysis identified 185 critical success factors from 13 studies. Half of the factors, 51% = (94), provided an additional description, while the remaining 49% of CSFs gave no further description. With the help of contextual information (e.g., description, dimension, and subfactors), the final network graph represents 146 factors, comprising 79%. Factors not represented in the graph were either too general ("usability" and "autonomy"), too vague, ("know the type of triggers", "know the type of inducers", and "customization"), or too specific ("paperless production" and "systematic analysis of errors and scrap"). Thus, the graph excludes 39 of the identified 185 factors. The final network graph consists of 149 nodes connected by 213 edges that display the 146 success factors[6]. Figure 4–Figure 7 displays some parts of this network graph.

The CSF "digital corporate culture" (Figure 4) is the most frequently cited and one of the most complex ones [32], [31], [68], [46], [25], [29], [47], [27], [26]. The most prominent node within this cluster is the application of agile methods. The main goal is not to apply the methods taken from software development one-to-one to the rest of the company but to benefit from their basic principles, approaches, and ideology. These principles include learning from mistakes, a short and regular reflection on working methods, and quick trial and error [33]. "Leadership" and "unified digital corporate strategy/vision" are complementary and closely related [32], [46], [30], [26], see Figure 5.

[5] https://gephi.org/tutorials/gephi-tutorial-layouts.pdf

[6] Due to digital corporate culture, innovation structures, and the role of the CDO, see Section 3.3

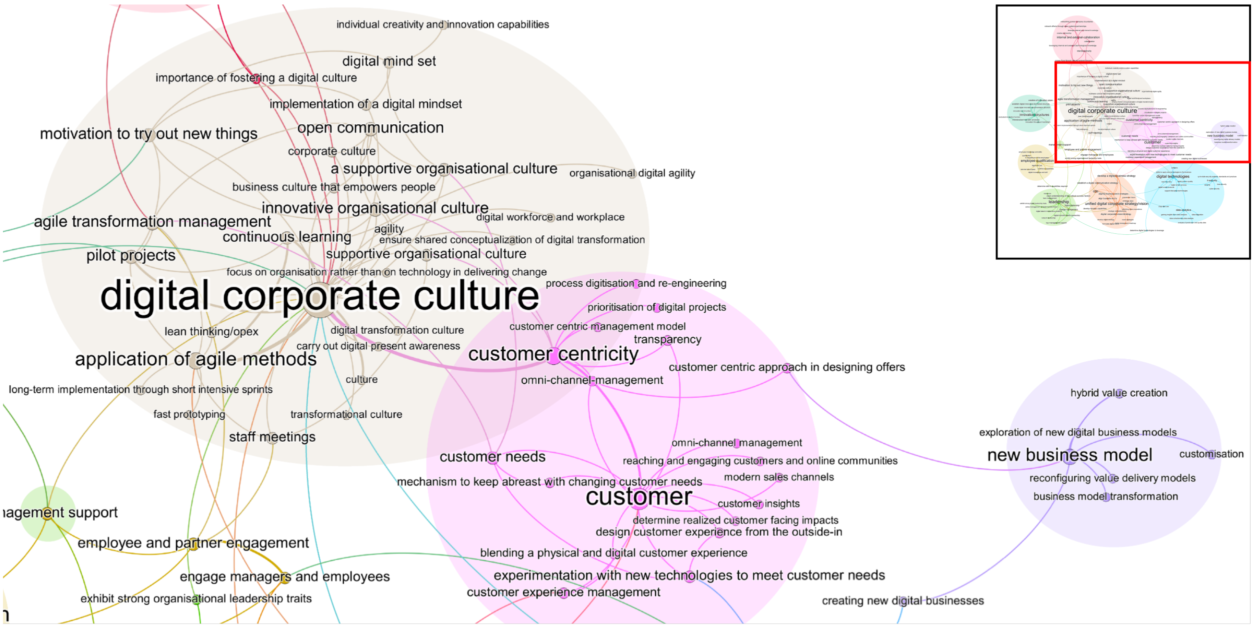

Figure 4. Digital corporate culture, customer and new business model clusters

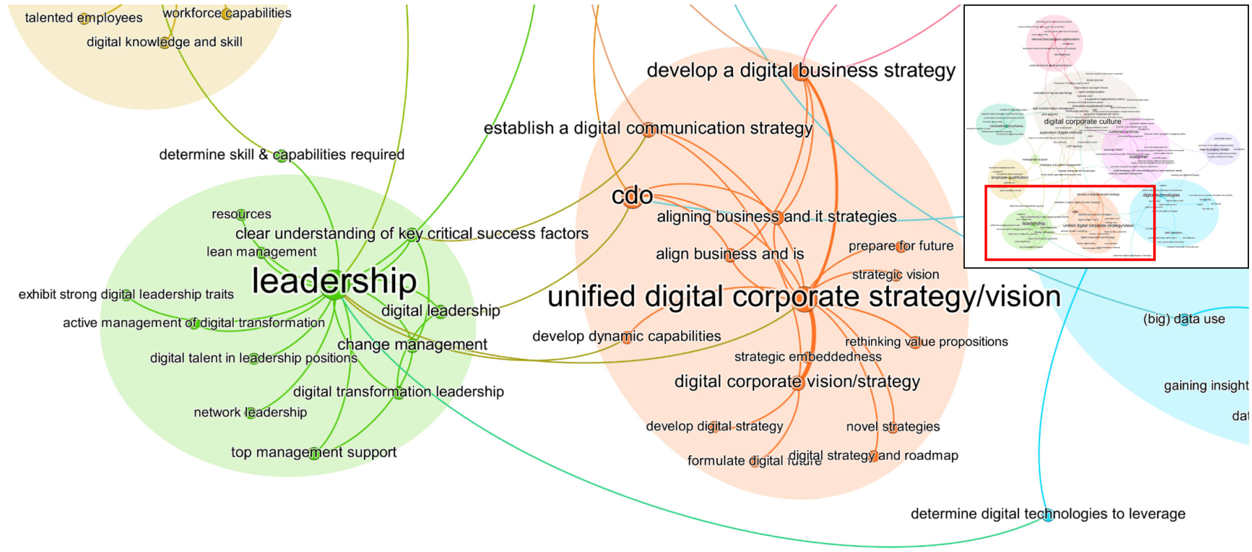

Figure 5. Leadership and unified digital corporate strategy/vision clusters

Management must align corporate strategy with upcoming changes and actively monitor market conditions to identify opportunities [31]. At the same time, leaders must be open-minded and need the right soft skills to communicate decisions effectively [68]. Especially the role of the Chief Digital Officer (CDO), who is responsible for "[…] the strategic exploitation of rapidly evolving technological opportunities, and the implementation of digital innovations […]" [64], is gaining momentum in DT literature [31], [47], [27].

In addition to the previous success factors, the role of the customer is vital in the digital transformation process [32], [25], [30], [26]. With rapidly changing customer demands on products and services, companies must implement structures that allow for fast adaptations. Customer needs are more important than ever, which is why corporate culture [46], [29], and digital strategy/vision must be aligned to meet customers' expectations [47]. As shown in Figure 4, customer satisfaction goes hand in hand with adapting the business model [25], [29], [26]. When planning to enhance an existing business model or create a new one, it is essential to determine which aspects have to be changed, how innovation will support the business model, and when business model innovation is considered successful [69]. Besides, business model innovation often accompanies technological improvements and smart products and services.

When using digital technologies, not only customer and product data are of interest as IT security and data analytics play an essential role [32], [46], [25], [34]. These two fields ensure that the company secures personal information and can draw the correct conclusions on investments from the data. Information Technology (IT) is getting more complex with applications deployed across multiple servers, distributed access rights, and steady controls [26]. Without IT security and strong governance practices, companies risk creating an IT that has not been authorized, a so-called shadow IT [29]. Only with the right expertise of employees, new technologies can be used to digitize existing analogue products and optimize internal processes [28].

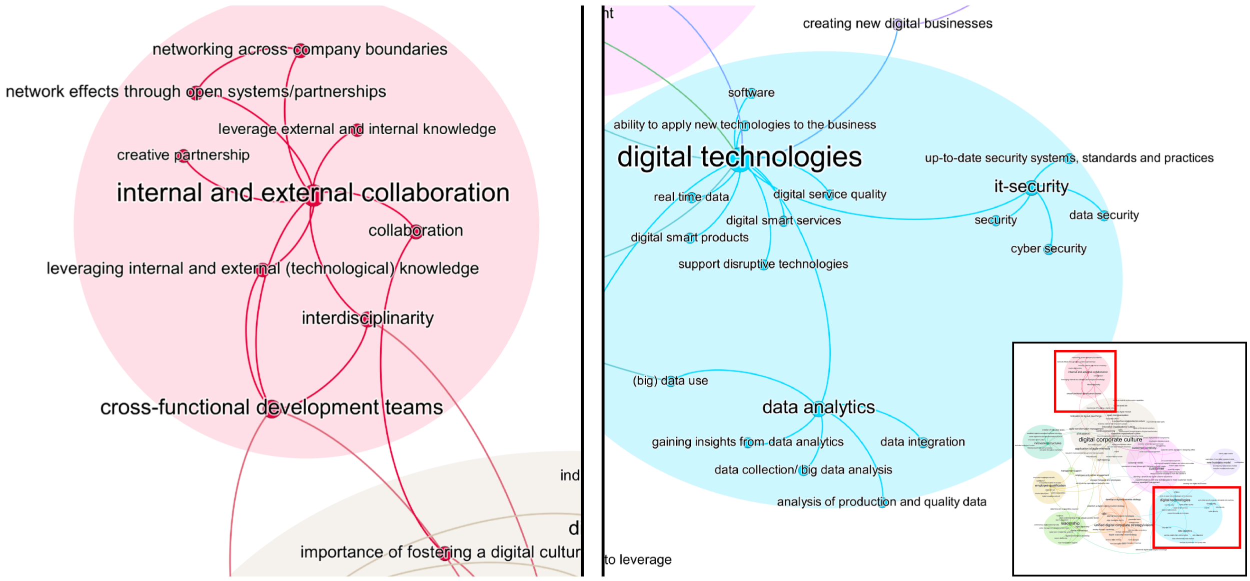

Figure 6. Digital technologies and internal and external collaboration clusters

Although the critical success factor of internal and external collaboration primarily addresses cross-functional collaboration within a company, it furthermore deals with cross-company collaboration [29], [47], [33]. As the complexity of tasks increases, a collaborative work environment that extends beyond company boundaries is beneficial [26]. Collaboration helps to rethink the company's position in the market and the network of customers and suppliers and improve its knowledge and technological capabilities [31]. The focus must be on fostering collaboration between employees to develop solutions to problems regardless of their roles and department [27].

The last two clusters are "innovation structures" and "employee qualification", shown in Figure 7. The first factor is closely linked to activities and factors of "digital corporate culture" [29], [30], [34], [26]. As for corporate culture, management must provide resources and space in which employees can implement ideas and utilize new technologies [33]. The structures do not need to be physical spaces. Instead, innovation can be achieved by systematic processes aligned with the individual and organizational settings, imposing structural value profiles [27]. Innovation can also be adapting systems and technologies within the company, reducing costs, increasing efficiency, and saving resources. If a company does not innovate independently, it will sooner or later be forced into action by new market players [33].

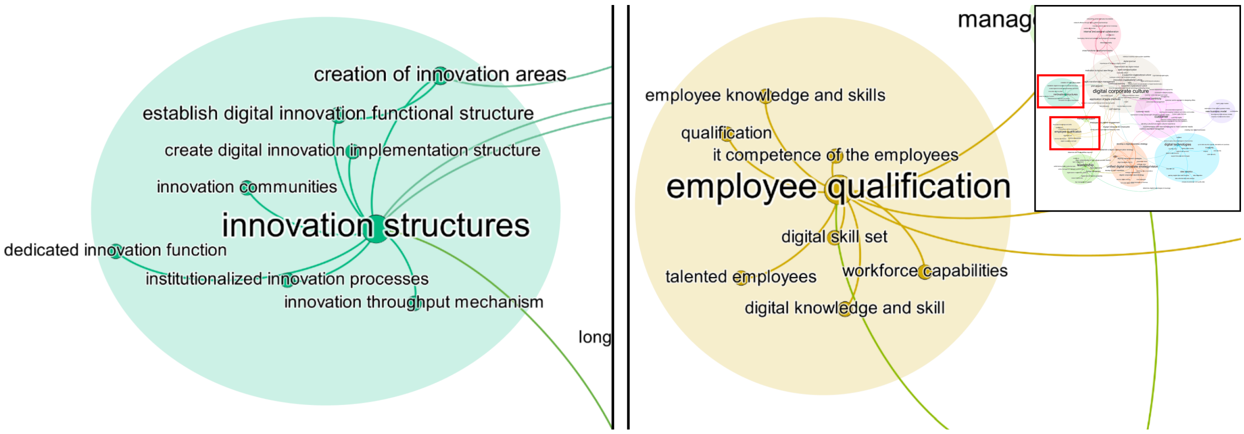

Figure 7. Innovation structures and employee qualification clusters

To persist in so-called VUCA[7] environments, employees must have the necessary competencies. Competencies make it easier for them to adapt to new situations and further develop their skills. Therefore, the success factor of employee qualification plays an essential role in the digital transformation process [32], [68], [28], [46], [34]. Employees can engage in digital transformation if they are trained and have the necessary skills [31]. Training provides workers with the required knowledge and reinforces their willingness to try new things as part of DT [26]. In addition to training employees, developing management competencies is equally important. For this purpose, portfolios with different programs can be used to conduct competence management [31].

4.2 Quantitative and Qualitative Analysis

The quantitative analysis determines how frequently a success factor is mentioned based on the identified clusters in the network graph. A cluster refers to the success factors located inside a color-coded circle. Each factor was examined for its corresponding paper to determine how many unique papers a cluster includes. A contribution is considered only once, even if several success factors of the same contribution are in one cluster. The results are depicted in Table 2. The numbers of the column "Papers referencing the Factor" refer to the bibliographical information given in the Appendix in Table A1. Similar to their visual representation, the most prominent nodes are also referenced most frequently. The top four factors in Table 2 are mentioned in more than 75% of the studies and can be seen as the first group of factors. The second group, starting with digital technologies, are factors mentioned in more than 50% of the investigated studies. The least frequently referenced success factors are "innovation structures" and "new business models". Only five to seven papers mention these as critical success factors of digital transformation. Selecting a 75% threshold is a methodological decision that ensures a factor is not merely common but dominant, appearing in a significant majority of studies to be considered critical. This conservative approach enhances the robustness of the research findings by minimizing the probability of false positives. Moreover, the 75% threshold provides a consistent metric that facilitates the comparison of results across different studies and contexts. Lastly, this threshold strikes a balance between practicality and rigor, being high enough to ensure significance but not so high as to preclude any factor from meeting the criteria, thereby ensuring the feasibility of the research process.

While the quantitative analysis determines how frequently a cluster is referenced, the qualitative analysis evaluates a cluster's rating. The success factors are divided into rated (rF) and non-rated factors (nrF). The relation of rated to non-rated factors expresses the percentage of rated factors inside a cluster. The evaluation considers only rated factors and omits non-rated factors with a

[7] The acronym VUCA reflects typical issues in today's IT management: volatility, uncertainty, complexity, and ambiguity

Table 2. Frequency of unique papers inside a cluster (bibliographical information for each reference is provided in the Appendix in Table A1)

Information on the Frequency of Occurrence			
Cluster	Papers referencing the Factor	Sum of References	Percentage by n=13
digital corporate culture	1,2,3,4,5,6,7,8,9,11,12,13	12	92%
leadership	1,2,3,4,5,8,9,10,11,12,13	11	85%
customer	1,2,3,4,5,6,7,8,10,12	10	77%
unified digital corporate strategy/vision	1,2,3,4,5,7,8,11,12,13	10	77%
digital technologies	2,3,5,6,8,10,11,13	8	62%
internal and external collaboration	2,3,4,6,7,8,9,12	8	62%
employee qualification	2,3,4,5,10,11,13	7	54%
innovation structures	1,3,6,9,10,12	6	46%
new business model	3,5,6,8,13	5	38%

value of 0.5; (cf. Section 3.2). On closer inspection of the cluster leadership, there is a discrepancy between the number of nodes inside the cluster, 14, and the number of "total Factors" in Table 3 (16 factors in total). This inconsistency only affects the visual representation, as duplicates were already merged; (cf. Section 3.3). The mean is not affected.

Table 3. Cluster ratings

Information on Cluster Ratings				
Cluster	rated Factors	total Factors	Relation of rF to nrF in %	Mean
digital technologies	13	17	76%	0.553
customer	13	17	76%	0.513
digital corporate culture	12	20	60%	0.494
leadership	10	16	63%	0.575
unified digital corporate strategy/vision	7	12	58%	0.558
internal and external collaboration	7	9	78%	0.482
innovation structures	5	8	63%	0.485
employee qualification	4	7	57%	0.536
new business model	3	6	50%	0.507

While the relation of rated to non-rated factors is mostly at or above 50%, "digital corporate culture" and "unified digital corporate strategy/vision" are two exceptions. Even though the cluster rating fluctuates, the means are relatively close. No outlier is positioned at the target interval's upper (0.7) or lower (0.3) end. Table A2, in combination with Figure A7 in the Appendix, can be consulted for a detailed distribution of the values.

4.3 Determining the CSF of DT

To be considered a critical success factor, a factor should be measurable, controllable, small in number, have a hierarchy, and apply to companies with similar goals and strategies [54]. The success factors identified via the cluster are measurable and controllable through digital maturity models [70], [71]. They contribute to achieving overall corporate goals and objectives and are "those few things that must go well" [72] to achieve the desired state. However, they have not yet been arranged hierarchically. To fill this gap and determine the level of "criticality", the qualitative and quantitative analyses are weighed against each other.

Since there is no explicit threshold in CSF literature separating a success factor from a critical success factor, this study defines 75% as the threshold. The threshold adjusts to the examined sample size (n=13). Factors below this threshold are not considered critical success factors. Applied to the results of the quantitative analysis, we identify four critical success factors: "digital corporate culture", "leadership", "customer" and "unified digital corporate strategy/vision". The mean value of the qualitative analysis determines their hierarchy. The five remaining factors that did not exceed the 75% threshold are sorted by the mean value of the qualitative analysis as well. Mentioned in less than three-quarters of the studies, they are considered "possible" critical success factors. Figure 8 lists both types of success factors in their respective order.

With the below listing, the hierarchical aspect of critical success factors, according to [54], is taken into account. The listing should be seen as a starting point and instead, serve the orientation. One success factor alone cannot lead to success. The network graph shows that the factors are mutually dependent or complementary and form a complex network of dependencies.

Critical success factors of DT	Possibly critical success factors of DT
1. Leadership 2. Unified digital corporate strategy/vision 3. Emphasize customer centricity and customer needs 4. Digital corporate culture	5. Utilise digital technologies 6. Support employee qualification 7. Embrace internal and external collaboration 8. Leverage new business models 9. Provide innovation structures

Figure 8. Critical success factors of the digital transformation

Regarding the level of criticality by [36], the identified critical success factors range within the "criticality"-level (b.2). B.2. factors are only necessary but not sufficient for success. As this research investigates the factors holistically, it cannot be concluded whether the identified critical success factors are sufficient for a successful digital transformation. It can only show that a factor is necessary and that its absence harms a company's success. The results of this research further emphasize the observations of [9], [73], [74]. Technologies should not be used to apply them to concrete business problems but to complement existing structures.

When looking at the investigated papers that were not biased towards any industry, they have identified contrasting numbers of critical success factors. Factors considered critical success ranged from 6 [28] to 18 [34], and even 25 [46], depending on the publication. Additionally, these factors were categorized in different ways, such as dimensions, critical success factors, subfactors, measures, and structural forces, revealing different elements and amounts of factors considered the most critical for success. Through our study, we have aggregated, categorized, and evaluated the findings to identify four critical success factors that are essential for any organization, regardless of their industry, providing a more structured and holistic approach to understanding and identifying critical success factors of DT.

5 Discussion

5.1 Critical Reflection on the Research Methods

This research is based on literature to examine critical success factors of digital transformation. Such a meta-study on existing publications is particularly well suited for reducing methodological bias and balancing dominant factors, such as particular industries or regions. The views of several experts are combined and weighed against each other [57] to make digital transformation more tangible as a holistic construct. As underlying literature only provides limited insight into the original data, this study inherits a certain information loss level and is never entirely exempt from personal and methodical bias [57]. Due to this bias, the general validity of secondary literature research can only be given to a certain extent [56]. Depending on the strength of bias in the investigated studies, this can be counteracted with a sufficiently large dataset [56]. Moreover, bias refers primarily to the evaluated datasets (interviews, case studies) and less to the conclusions of experts. By selecting high-quality sources, this bias is considerably minimized through the academic publication process. Using sources from renowned magazines and conferences ensures the quality of the selected literature. Finally, the processing of literature is efficient in covering a topic in its entirety. If case studies had to be evaluated in advance, a significant overhead would have been added to this research.

In contrast to the previously mentioned methods, qualitative content analysis provides a procedure. This is a predefined structure consisting of several steps which further enhance reproducibility. The steps precisely describe how to deal with irrelevant information and what context is chosen for which reason. Even though the main focus is on identifying concepts, this approach is not to be confused with the concept-driven (deductive) development of categories. Since the concepts already exist, they do not need to be derived from a theory or the literature. Therefore, the approach of data-driven (inductive) development of categories, according to [75], is followed. The categories are subdivided and merged step by step when applying the inductive methodology. In order to avoid confusion, the term concept will be used as defined by [35].

Concerning ratings, one can argue that the calculated rating only considers the relative evaluation of the paper but does not consider the papers' relativity to each other. This means that paper A could identify seven success factors with one value each. Paper A's values $[x_{min}; x_{max}]$ are between 0.9 and 0.7. Paper B identifies 18 success factors with values between 0.6 and 0.1. Using the formula from Figure A1 given in the Appendix, both papers' maximum values, 0.9 and 0.6, can be mapped to the target intervals' maximum value $y_{max} = 0.7$. However, after mapping the maximum values to $y_{max} = 0.7$, the minimum value from paper A, $x_{min} = 0.7$, cannot be mapped to 0.3. The minimum value of paper B, $x_{min} = 0.1$, is reserved for this position. This is not because x_{min} of paper A is greater than x_{min} of paper B but because of the difference in length relative to the centre (x_{ci}). The interval of paper A, $[0.9; 0.7]$, has a relative length of $x_{ci} = 0.1$, while the interval of paper B, $[0.6; 0.1]$, has a relative length of $x_{ci} = 0.25$. The papers could be set in relation by identifying the greatest length of all papers relative to the center in advance of the calculation. However, this method would distort the values and therefore was rejected. Due to different research methods based on different assumptions, such a relation cannot be established. Thus, the research method could not be extended any further for this study. The described relation could be established for other studies with equal research methods as a basis. By identifying the greatest length of all papers in advance, the papers' relativity to each other can be considered. While coding the content analysis, inconsistencies across the factors occurred. These inconsistencies came from similar success factors being described differently among the papers. The distinction between "customer centricity" and "customer needs", "leadership" and "(top) management support", and "digital mindset" and "agility" can be challenged. The question arises whether "customer centricity" and "customer needs" should be combined into a customer or whether this would distort the classification. "Agility" is a special case since it refers to the application of agile methods and the general agility of a company and its processes. A reverse procedure to combining customer-related factors to "customer" could be applied to "agility". The opposite approach would divide "agility" into organization-related and process-related agility, as well as the application of agile methods and iterative approaches.

5.2 Critical Reflection on the Results

In contrast to many other approaches, this work opted to represent the critical success factors in a force-directed network graph. This representation transparently displays the complexity of the research field and makes the interrelationships visible. However, the spatial representation is not always correct, like the factor "management support" shown in Figure 9. This factor is essential for providing resources and structures for developing digital corporate culture, innovation structures, and employee qualification and engagement. "Management support" was misplaced right next to the cluster "employee qualification" even though, just as "top management support", it belongs to "leadership". If edge weighting had been used, management support could have been artificially drawn to the Leadership cluster. Instead, the outlier was color-coded correctly for later analysis. However, too much edge weighting can distort the graph. Depending on repulsion strength, it would either pull "leadership" further to the center or cause the other clusters to be pulled closer together.

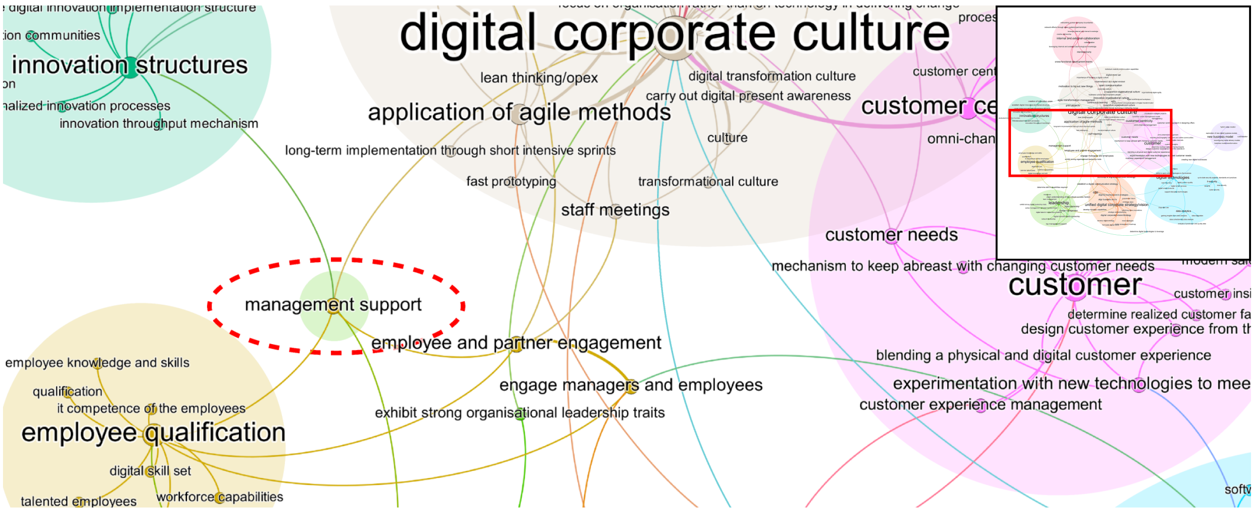

Figure 9. Management support and employee engagement nodes

Besides assigning factors to clusters, the network graph has some implications regarding the data it can display. Visualization via a network graph is not ideal if many factors are identical, such as leadership, change management, and infrastructure. The network graph strongly emphasizes connections and ignores nodes' frequency. If the data consists of many identical connections, solely edge thickness will increase but not node size. It seriously affects visualization as nodes with bold edges are pulled close to each other. If the edges are too thick, repulsion cannot place them far from each other, ultimately illustrating them as the same cluster. If there are no identical connections, but a factor is mentioned frequently, it will not be displayed in the graph. Without context, a factor cannot be associated with any other factor, resulting in an isolated node. As Force Atlas ignores isolated nodes, it does not matter how frequently a factor is mentioned. Another interesting aspect of the graph is "employee engagement", shown in Figure 9. The factor was rarely mentioned and is not prominent enough to serve as a critical success factor in the overall consideration of digital transformation. It illustrates the interrelations between "leadership", "unified digital strategy/vision", "employee qualification", "digital corporate culture" and "digital technologies". "Employee engagement" acts as the glue between the clusters, pulling them closer.

The CDO needs enough influence to motivate employees to embrace the changes associated with digital transformation [31]. In addition, leaders must consider employees as an active part of the transformation and address their concerns and issues. Furthermore, hiring and retaining employees with the necessary skills and talents is essential for a healthy corporate culture [31].

Another important aspect is the identified critical and possibly critical success factors. As depicted by the graphical representation, one success factor alone cannot lead to success. In addition, applying the critical success factors is no guarantee of becoming an industry's market leader. Such a development is only possible for "the first movers and super-fast followers" [31]. Limited by fundamental market conditions, few companies can only accomplish such a position. Of greater importance is that not applying those factors will result in a competitive disadvantage culminating in competitive failure [54]. Therefore, it is crucial not to consider the critical success factors, as well as the possibly critical success factors, isolated. By detaching the corporate strategy from technological developments, the competitive advantage of technology-enhanced products and services fades [4]. An insufficiently weighted corporate strategy also leads to short-, medium-, and long-term digitalization goals showing deficiencies [3]. Whereas an insufficient consideration of digital corporate culture, leadership, and digital corporate strategy/vision results in internal inefficiencies, the lack of customer-focused decisions is directly related to the profitability and survivability of an organization [76]. With the lack of data on customers, a company will be unable to perform analytics to better understand and predict customer behaviors, changing customer demands and market trends [77].

Finally, attention should be drawn to qualitative and quantitative analysis. While the quantitative analysis is reasonably accurate, the qualitative analysis should be seen as an indication instead. The quantitative analysis refers to all critical success factors depicted in the graph, representing 80% of the identified success factors. Qualitative analysis, on the other hand, only refers to rated factors inside a cluster. For the "internal and external collaboration" cluster, the average value of 0.482 will, in all likelihood, change only slightly, as roughly 80% of the factors have been assessed. In the case of the "digital corporate culture" cluster, the score may still change upwards or downwards, as only 43% of the factors were assessed. Due to these fluctuations, the results of the qualitative analysis should serve as an orientation. Furthermore, qualitative analysis entails the risk of biased ratings. A bias is possible if several cluster factors originate from the same paper. With the "digital technologies" cluster, three values originate from [32]: "data integration" (0.593), "data analytics" (0.611), and "cyber security" (0.4). The cluster's mean value includes all three values. To mitigate this distortion, a paper's success factors, located in the same cluster, could be averaged before calculation to reduce this distortion.

5.3 Practical Relevance

As digital transformation is still a challenging task, companies need guidance for planning and conducting the transition (cf. [78]). The critical success factors identified within this article provide basic guidelines for corporate decision-makers in order to avoid typical pitfalls. First of all, the results derived from the publications listed in Section 4.3 show that a digital transformation is clearly not just an IT project but a business change. The management, therefore, has to prepare the organization for change rather than getting obsessed with technology. It has to provide clear leadership, a strategy, and a vision as the first preparatory step. Leadership and vision are common aspects of any change project and both need to be maintained throughout its duration (cf. [79]). In addition to that, a digital transformation will have to consider customer needs as it is rather about improving a company's situation on the market rather than just increasing efficiency. This does not exclude efficiency gains from a digital transformation but puts a focus on the customer. Management also has to establish a corporate digital culture. Simply providing training or allowing employees to bring their own devices is not sufficient. Such a digital corporate structure also implies a significant cultural change so that innovation will be rewarded and failures not punished. It is not a simple task and will require a long period during the digital transformation.

6 Conclusion and Further Research

This study presents a novel approach to understanding the critical success factors (CSFs) of digital transformation (DT), offering a unique perspective through a force-directed network graph. The methodology enhances transparency and allows for a comprehensive categorization of factors, revealing the complexity and interrelationships of DT's CSFs.

Four critical and five potential CSFs were identified. Notably, digital corporate culture and customer focus demonstrated numerous and strong connections, indicating their well-understood correlations. However, a divergence was observed between these two CSFs and two other highly relevant CSFs: leadership and unified digital corporate strategy/vision. Future research could investigate whether these latter factors need to be further integrated, which might yield valuable insights into the optimal configuration of CSFs in DT. The study highlighted disconnected areas in DT research, such as infrastructure, data governance, and integrated systems approach. Future research could explore these topics to determine whether they should be incorporated into prevalent areas or considered noise. To improve this study, future research can focus on evaluating a more extensive dataset and consolidating or complementing the classification of critical and possible success factors. Having as little duplication as possible is crucial, as the network graph considers unique values only. With only 2% duplication in this study, duplication did not affect the result. With a larger dataset, the coverage of qualitative analysis can be increased, and the threshold of quantitative analyses to determine a success factor as critical can be adjusted further upwards.

Besides, future research should investigate whether the identified CSFs satisfy the "criticality"-level b.1 by [36]. While this study showed that the four factors are necessary for success, "criticality"-level b.2, future studies could investigate whether the factors are sufficient for success. Suppose the four factors are insufficient for success, the question arises whether some of the possibly critical success factors could complement the list to satisfy "criticality"-level b.1. As a research method, we recommend interviews or questionnaires. Through these methods, a common understanding of the individual factors can be conveyed in a targeted manner. A common understanding is beneficial considering the nomenclature, which differed from study to study. The study of critical success factors can be completed by examining hindering factors. [36] argue that it is crucial to consider both facilitating and hindering factors equally to avoid disbalance.

Finally, the proposed methodology is ideal for overcoming language bias, where the same concept or factor may be described differently across multiple studies and not confined to digital transformation (DT). While DT is a growing research area, we see significant potential in this approach for other less explored research areas due to its ability to make them more tangible as a holistic concept.

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Appendix

Table A1. Selected literature

Selected Literature						
ID	Study	Year	Region	Industry	Research Method	n
1	Morakanyane et al. [30]	2020	International	Biased towards the retail industry	Case Study	16
2	Leyh et al. [46]	2021	Germany	Balanced	Online Survey	97
3	Vogelsang et al. [26]	2018	Germany	Manufacturing industry	Semi-structured Interviews	20
4	Cichosz, Wallenburg, and Knemeyer [31]	2020	International	Logistics industry	Case Study	9
5	Büyüköpzkan, Feyzioglu, and Havle [32]	2019	n/a	Aviation industry	FCM-Technique	n/a
6	Mhlungu, Chen, and Alkema [29]	2019	South Africa	Business-to-Consumer (LEs)	Questionnaire	95
7	Osmundsen, Iden, and Bygstad [47]	2018	Norway	n/a	Systematic Literature Review	21
8	Loonam et al. [25]	2018	n/a	Balanced	Case Study	10
9	Wolf, Semm, and Erfurth [33]	2018	n/a	Balanced	Exploratory Case Study	n/a
10	Stich et al. [34]	2020	Germany	Balanced	Case Study	30
11	Kokolek, Jakovic, and Curlin [28]	2019	Croatia	Balanced	Online Survey	387
12	Rueckel, Muehlburger, and Koch [27]	2020	n/a	Balanced	Structured Literature Review	36
13	Florek-Paszkowska, Ujwary-Gil, and Godlewska-Dziobon [68]	2021	International	Balanced	Narrative Literature Review	n/a

Let $[x_{min}; x_{max}]$ be an interval of an arbitrary publication, ranging from the smallest rating x_{min} to the largest rating x_{max}. x_i represents a CSFs rating of a particular publication. To compare the publications, their individual intervals are mapped into a uniform interval $[y_{min}; y_{max}]$. Therefore, F is a mapping that assigns each rating x_i of an arbitrary publication a matching rating $F(x_i)$ inside the uniform interval $[y_{min}; y_{max}]$.

$$F : [x_{min}; x_{max}] \rightarrow [y_{min}; y_{max}] \quad (1)$$

For each $x_i \in [x_{min}; x_{max}]$ a mapping is defined through

$$F(x_i) = x_{ci} * (y_{max} - y_{min}) + \frac{y_{max} + y_{min}}{2} \quad (2)$$

where x_{ci} is defined as the relative distance of x_i to the center of its interval

$$x_{ci} := \frac{x_i - \frac{x_{min}+x_{max}}{2}}{x_{max} - x_{min}} \quad (3)$$

Figure A1. Formula to map the papers' ratings into a uniform interval

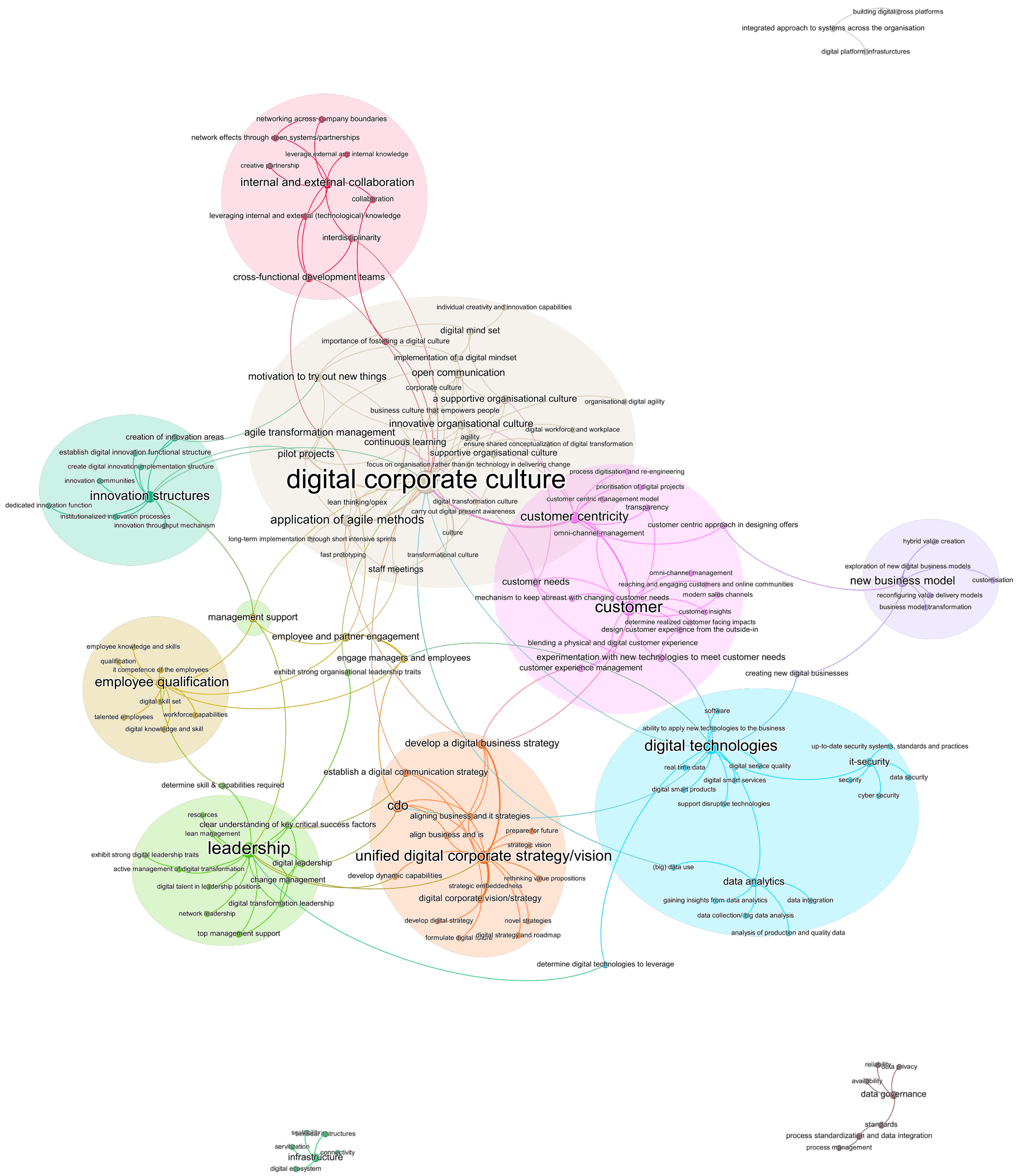

Figure A2. Entire network graph

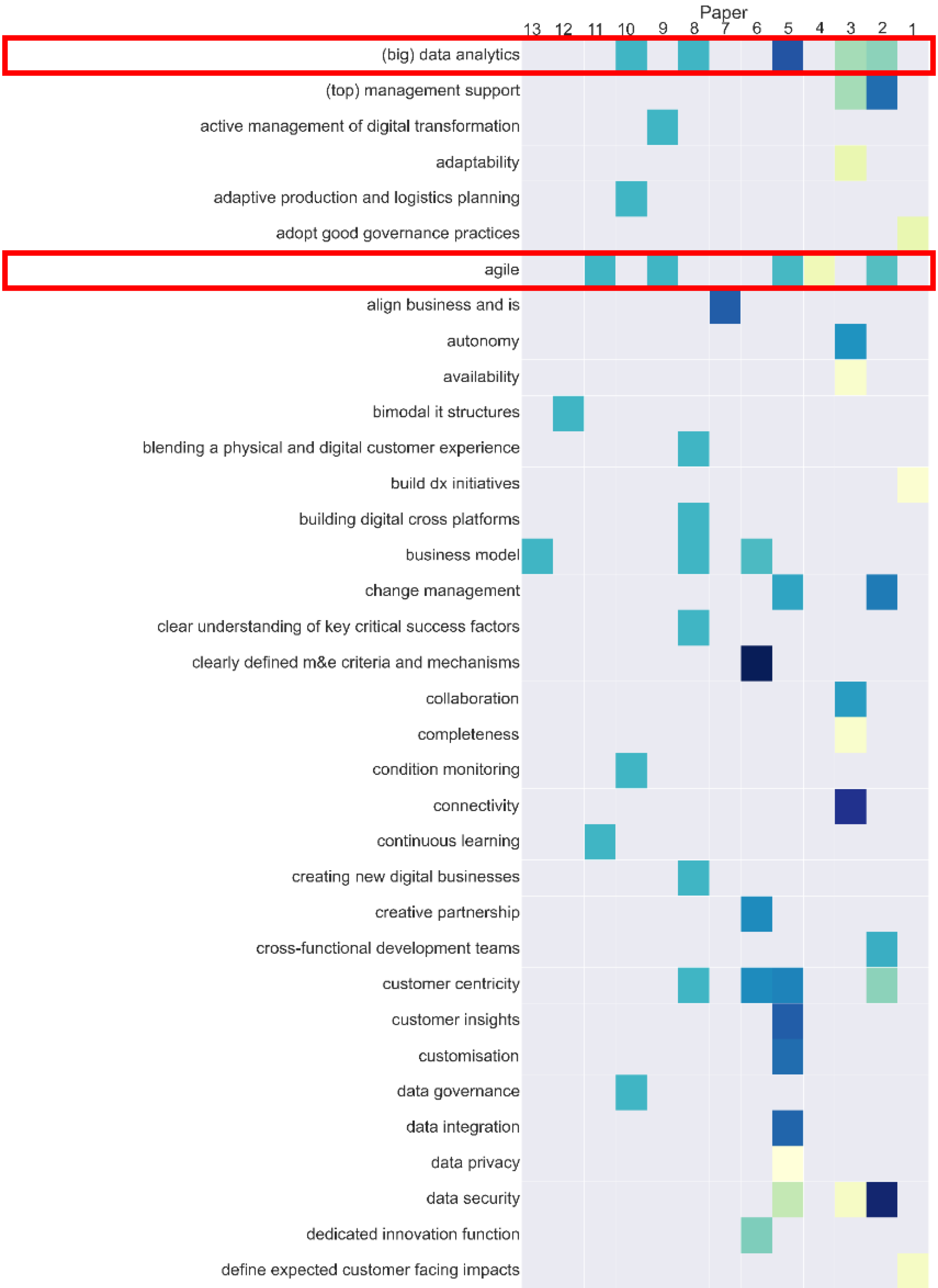

Figure A3. Critical success factor matrix (1 of 4)

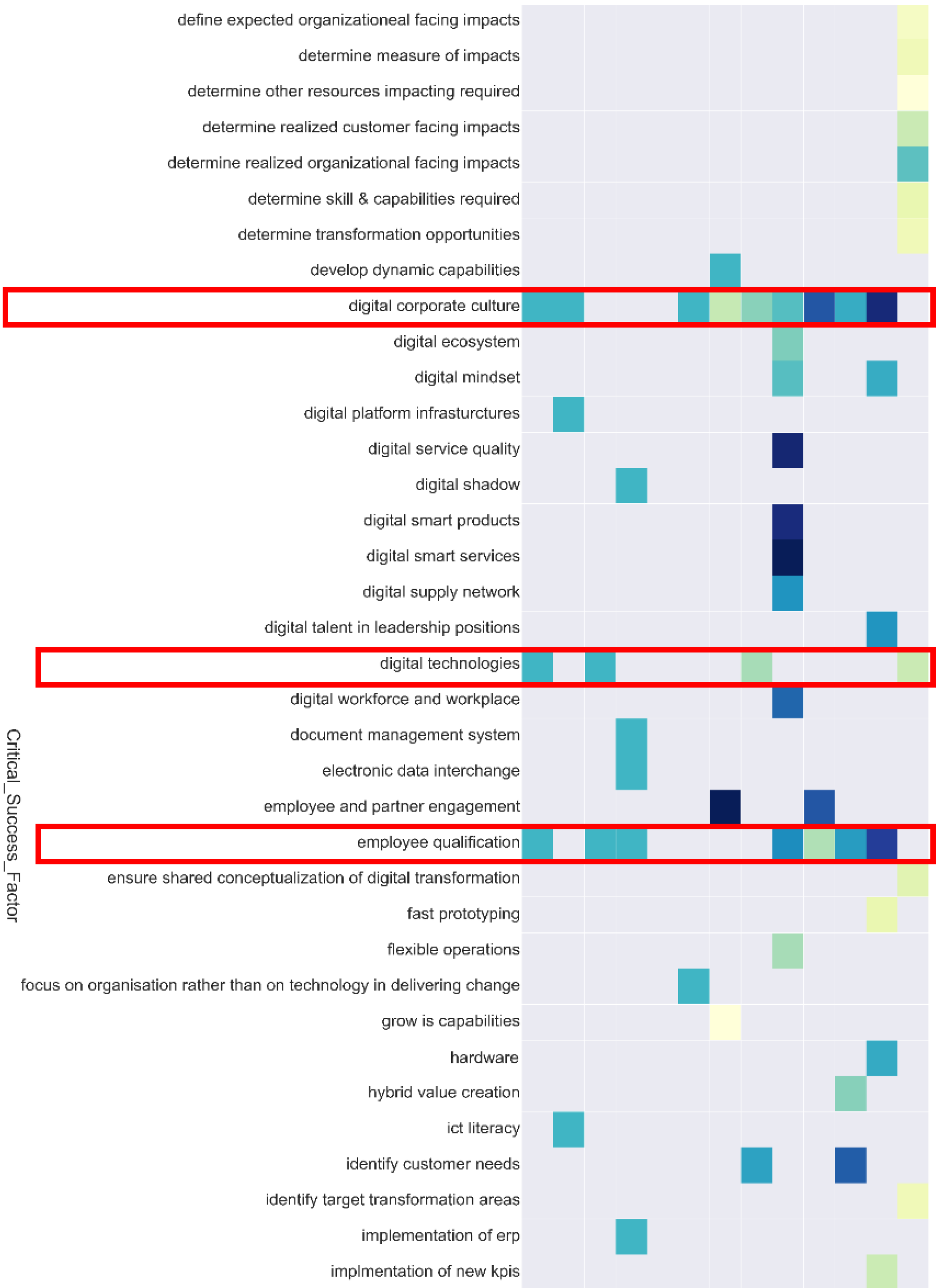

Figure A4. Critical success factor matrix (2 of 4)

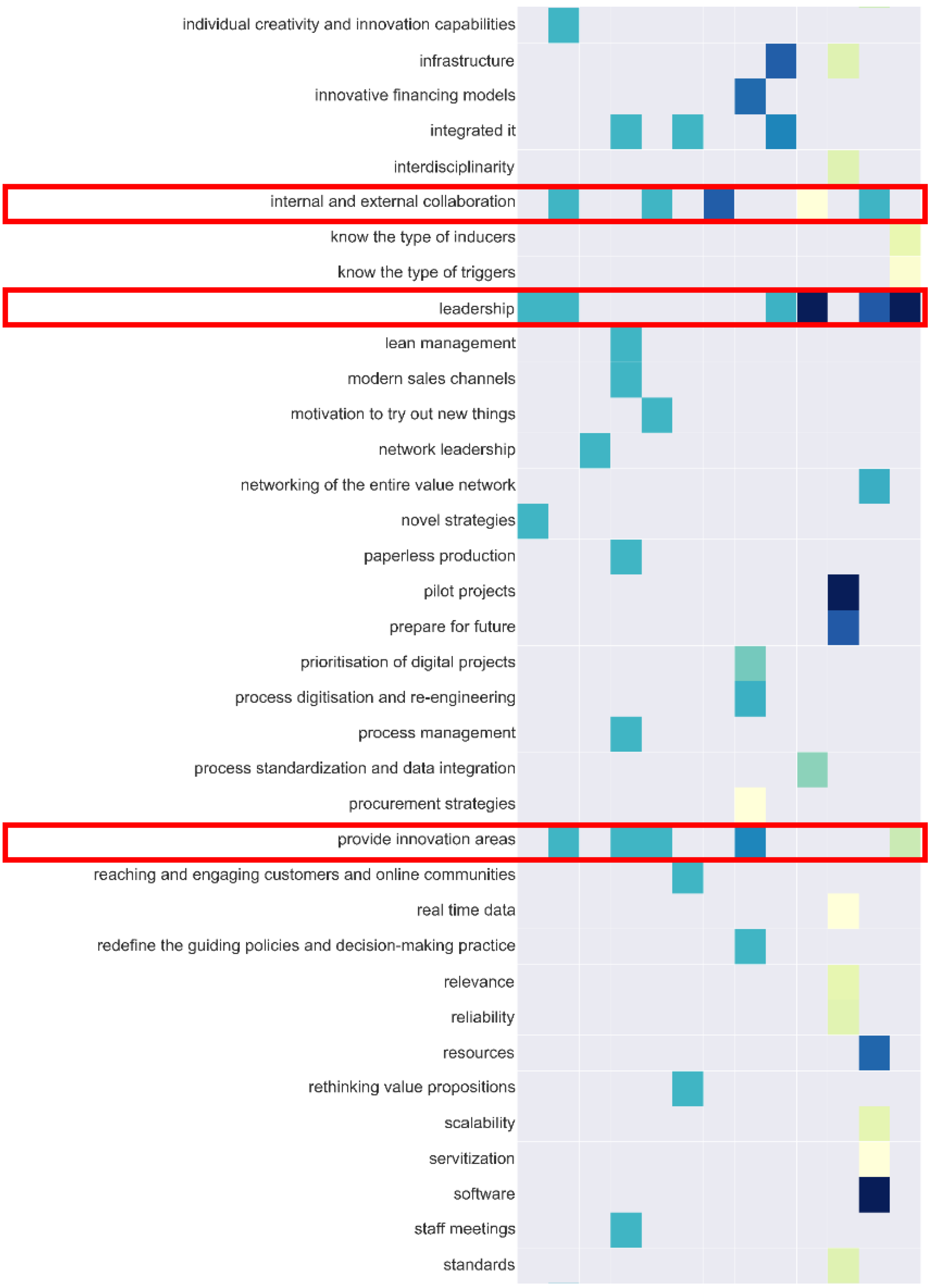

Figure A5. Critical success factor matrix (3 of 4)

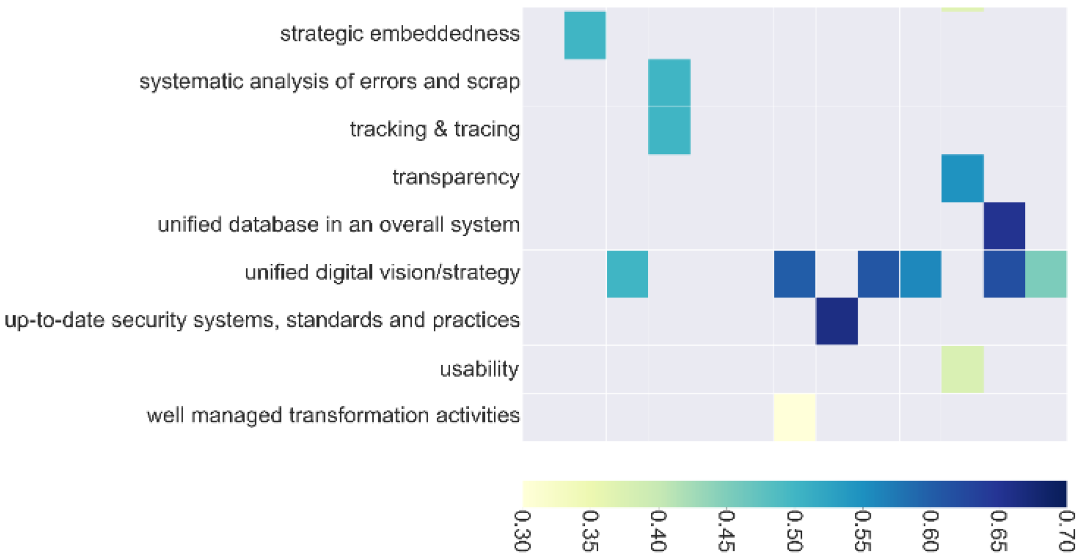

Figure A6. Critical success factor matrix (4 of 4)

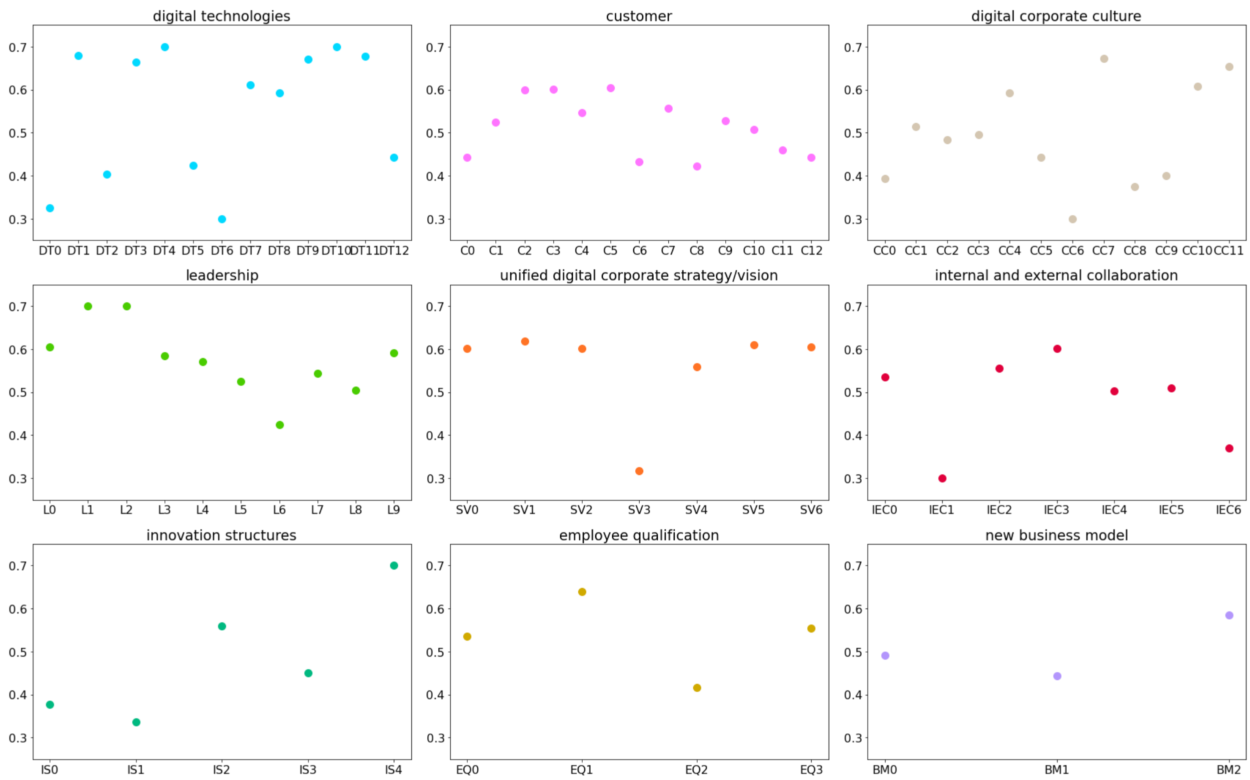

Figure A7. Rated factors scatter plot

Table A2. Mapping of Critical Success Factors to Codes

Mapping of Critical Success Factors to Codes (1 of 3).		
Critical Success Factor	Code	Rating
customer	C	
omni-channel-management	C0	0.442
customer experience management	C1	0.524
customer insights	C2	0.6
customer needs	C3	0.601
transparency	C4	0.547
omni-channel management	C5	0.604
determine realized customer facing impacts	C6	0.433
customer centric approach in designing offers	C7	0.556
experimentation with new technologies to meet customer needs	C8	0.423
mechanism to keep abreast with changing customer needs	C9	0.528
process digitisation and re-engineering	C10	0.508
prioritisation of digital projects	C11	0.459
customer centric management model	C12	0.442
digital corporate culture	CC	
ensure shared conceptualization of digital transformation	CC0	0.393
culture	CC1	0.514
digital transformation culture	CC2	0.484
organisational digital agility	CC3	0.496
digital workforce and workplace	CC4	0.592
transformational culture	CC5	0.443
carry out digital present awareness	CC6	0.3
corporate culture	CC7	0.673
lean thinking/opex	CC8	0.374
a supportive organisational culture	CC9	0.401
supportive organisational culture	CC10	0.608
implementation of a digital mindset	CC11	0.653

Mapping of Critical Success Factors to Codes. Continued (2 of 3).		
Critical Success Factor	Code	Rating
leadership	L	
leadership	L0	0.605
leadership	L1	0.7
exhibit strong digital leadership traits	L2	0.7
top management support	L3	0.585
change management	L4	0.571
change management	L5	0.524
management support	L6	0.424
digital talent in leadership positions	L7	0.544
digital transformation leadership	L8	0.505
resources	L9	0.591
unified digital corporate strategy/vision	SV	
develop a digital business strategy	SV0	0.601
unified digital corporate strategy/vision	SV1	0.618
align business and is	SV2	0.601
develop digital strategy	SV3	0.317
aligning business and it strategies	SV4	0.558
digital strategy and roadmap	SV5	0.609
prepare for future	SV6	0.605
employee qualification	EQ	
employee qualification	EQ0	0.535
qualification	EQ1	0.639
employee knowledge and skills	EQ2	0.417
digital skill set	EQ3	0.554
innovation structures	IS	
establish digital innovation functional structure	IS0	0.377
create digital innovation implementation structure	IS1	0.337
innovation throughput mechanism	IS2	0.56
dedicated innovation function	IS3	0.45
pilot projects	IS4	0.7

Mapping of Critical Success Factors to Codes. Continued (3 of 3).

Critical Success Factor	Code	Rating
digital technologies	DT	
security	DT0	0.325
data security	DT1	0.68
cyber security	DT2	0.403
up-to-date security systems, standards and practices	DT3	0.664
software	DT4	0.7
(big) data use	DT5	0.424
real time data	DT6	0.3
data analytics	DT7	0.611
data integration	DT8	0.593
digital smart products	DT9	0.67
digital smart services	DT10	0.7
digital service quality	DT11	0.678
data collection/ big data analysis	DT12	0.442
new business model	BM	
exploration of new digital business models	BM0	0.491
hybrid value creation	BM1	0.444
customisation	BM2	0.585
internal and external collaboration	IEC	
collaboration	IEC0	0.535
leveraging internal and external (technological) knowledge	IEC1	0.3
creative partnership	IEC2	0.555
leverage external and internal knowledge	IEC3	0.601
network effects through open systems/partnerships	IEC4	0.503
cross-functional development teams	IEC5	0.51
interdisciplinarity	IEC6	0.37

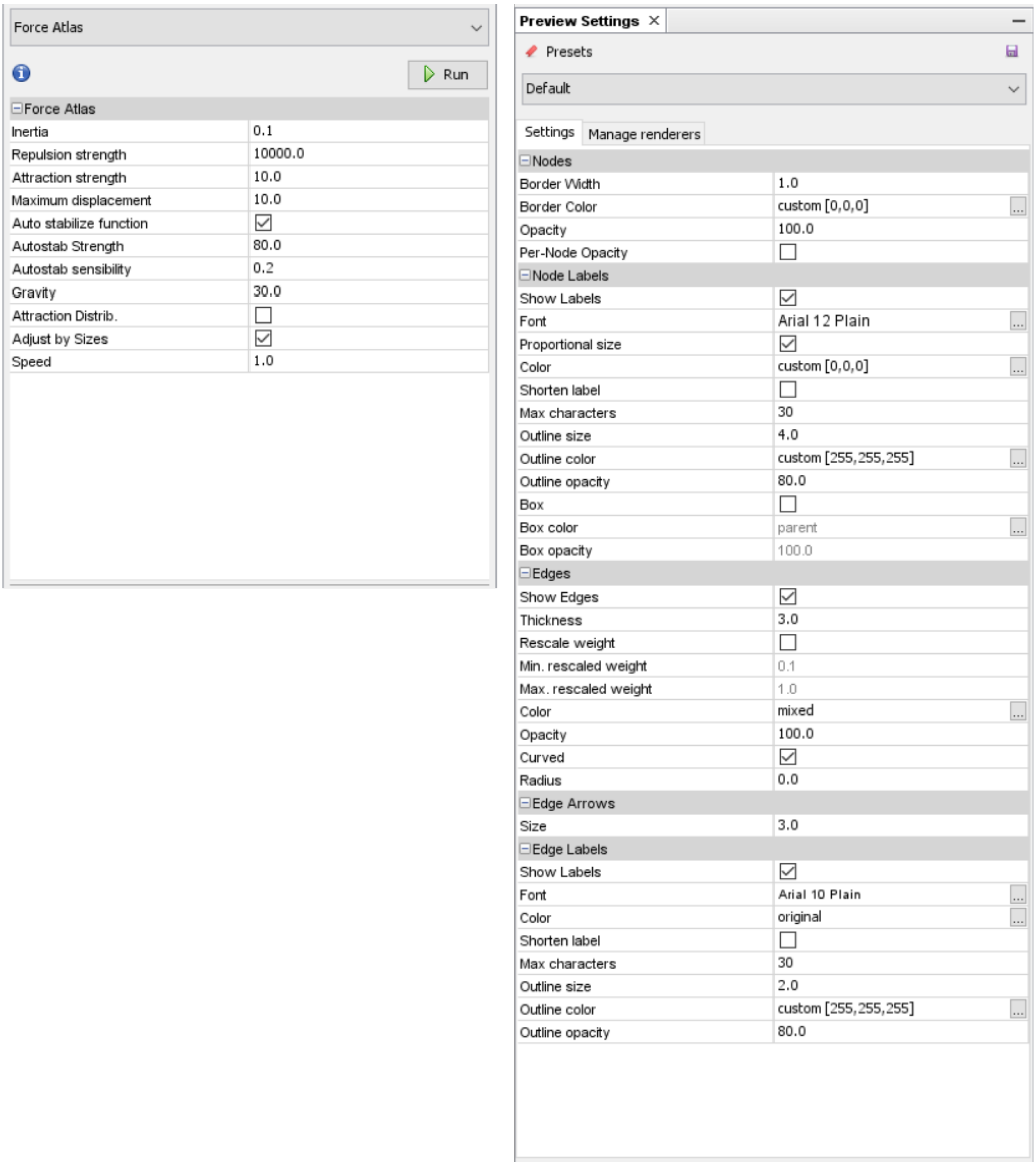

Figure A8. Force Atlas and Preview settings of the generated network in Gephi