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Dynamic Capabilities for the Twin Transformation Climb: A Capability Maturity Model

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Abstract
Digital transformation and sustainability transformation are at the top of organizations' agendas to remain competitive. While guidance on both transformations exists separately, even more research on integrating digital and sustainability transformation, namely twin transformation, is required. Specifically, deeper knowledge about relevant twin transformation capabilities and progress is needed for effective implementation. To enhance the understanding and provide corresponding guidance, we developed a twin transformation capability maturity model focusing on dynamic capabilities required to realize twin transformation based on a structured literature review and interviews with 13 experts. Further, we demonstrated its use with a technology service provider. Our contribution is twofold: First, accounting for organizations' twin transformation starting points in terms of their digitalization and sustainability experience and expertise, we reveal three pathways to becoming a twin transformer. Second, our work provides an overview of 45 relevant twin transformation capabilities structured along six capability dimensions and four maturity stages. Our work also provides relevant practical implications supporting organizations in assessing their twin transformation maturity building the foundation for targeted capability development.

Keywords Digital transformation · Sustainability transformation · Maturity model · Design science research · Twin transformation · Dynamic capabilities

1 Introduction

Digitalization and sustainability depict catalysts of change. As digital and climate challenges, such as cyber-attacks or extreme weather events, have ever more severe consequences, digital transformation (DT) and sustainability transformation (ST) are inevitable for almost all types of organizations. The organizational transformation in terms of digitalization and sustainability cannot be postponed as organizations want to reach global sustainable development goals and remain competitive (Veit & Thatcher, 2023). Hence, organizations are forced to adapt via DT and ST to the changing environment (Zimmer & Järveläinen, 2022). Both transformations bring individual advantages for organizations. While DT enables organizations to enhance existing or create new digital processes, products, services, and business models, potentially implying a new organizational identity (Setzke et al., 2023; Vial, 2019; Wessel et al., 2021), ST fundamentally changes organizational processes toward sustainability in all its dimensions, i.e., environmental, social, and economic sustainability (Dorninger et al., 2020), which is the foundation for future resilience (Boh et al., 2023). Thus, ST is a change process that encompasses the environmental, social, and economic dimensions.

Transformations are risky and time-consuming undertakings with often unclear results. DT still challenges organizations to date, resulting in high failure rates (Bonnet, 2022).

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Additionally, ST aims for long-term, mostly non-economic goals, making effective ST all the more challenging (Dyllick & Muff, 2016). To increase both transformations' effectiveness, research proposes integrating the two single transformations (e.g., Christmann et al., 2024; Graf-Drasch et al., 2023; Pappas et al., 2023; Zimmer & Järveläinen, 2022). In this regard, first studies and practice reports have shown the benefits of tackling DT and ST in an integrated way on equal footing – namely, pursuing a twin transformation (Crome et al., 2023b; Ollagnier et al., 2021). Twin transformation has been defined as *"a value-adding interplay between digital and sustainability transformation efforts that improve an organization by leveraging digital technologies for enabling sustainability and leveraging sustainability for guiding digital progress*" (Christmann et al., 2024, p. 7). By realizing twin transformation, organizations can simultaneously reach social, economic, and environmental sustainability objectives while enhancing the effectiveness of their DT initiatives. Combining and realizing the benefits of DT and ST, twin transformation enables societal change and long-term competitive advantage (Ollagnier et al., 2021).

While the twin transformation idea is conceptually convincing, its realization is not trivial. As for every transformation, organizations need dynamic capabilities to change their existing mode of doing business to address rapidly changing environments and ensure long-term growth and survival (Teece et al., 1997; Teece, 2014). Thus, to effectively master twin transformation, integrated dynamic capabilities need to be understood, developed, sustained, and continuously monitored to assess twin transformation progress and to leverage DTs' and STs' mutual benefits within a twin transformation. Researchers have already investigated and structured the capabilities required to master DT using maturity models (e.g., Aguiar et al., 2019; Ellström et al., 2022; Gökalp & Martinez, 2021). In addition, a growing number of researchers are examining capabilities required for ST (e.g., Amui et al., 2017; Shang et al., 2020; van de Wetering et al., 2017) and roadmaps toward sustainability maturity (e.g., Uhrenholt et al., 2022; Vásquez et al., 2021). While maturity models are already used to investigate the standalone view of DT or ST capabilities, research and practice lack a structured overview of integrated dynamic capabilities. For organizations to realize twin transformations, it is not enough to think of DT and ST separately and refer to the single maturity models. The integrated view leverages efficiencies between both transformations by saving time and resources. To develop integrated dynamic capabilities, namely twin transformation capabilities, organizations require straightforward guidance to use their experiences and current expertise effectively as DT and ST capabilities are the basis for integrated capability development. Further, especially multi-dimensional maturity models cover a holistic picture of organizations, which is advantageous in the given context as twin transformation affects "all organizational layers inside and outside an organization" (Graf-Drasch et al., 2023, p. 11).

We focus on the structured development of dynamic capabilities for twin transformation to enable organizations to assess their twin transformation maturity and to ensure sustainable long-term relevance. This leads to our research question: *What are twin transformation maturity stages and corresponding dynamic capabilities?* To address our research question, we developed, evaluated, and demonstrated the twin transformation capability maturity model (TTCMM), following Becker et al.'s (2009) procedure model for maturity model development under the design science research (DSR) methodology provided by Peffers et al. (2007). Our methodological steps comprised a structured literature review (Leidner, 2018; vom Brocke et al., 2015), 13 expert interviews (following Myers & Newman, 2007), and a case demonstration with a subsidiary of a DAX 40 company, which is one of the 40 largest German stock corporations. As for theoretical contributions, we structure the twin transformation maturity journey with the help of different capability dimensions and twin transformation maturity stages, revealing three twin transformation pathways to pave the way for realizing twin transformation. The pathways, namely *(1) twin transformation newcomers* integrating both transformations from scratch, *(2) DT experts* making DT sustainable, or *(3) ST experts* making ST digital, are designed to help organizations leverage their existing knowledge in the complex twin transformation endeavor. Moreover, we uncover which dynamic capabilities organizations need to master different stages of twin transformation by expanding existing DT and ST capability research. As for practical implications, the TTCMM supports organizations (from small and medium enterprises (SMEs) to large corporations) in the assessment of their twin transformation journey and paves the way to develop their missing capabilities, considering their prior transformation experience and expertise.

The remainder of this paper is structured as follows: In Section 2, we elaborate on the theoretical background of DT, ST, capability development, and maturity models. In Section 3, we outline our research method. In Sections 4 and 5, we introduce and show the demonstration of the TTCMM. In Sect. 6, we discuss the TTCMM, delving into its managerial and theoretical implications. Finally, we conclude by delineating the limitations of our study and offering directions for future research.

2 Theoretical Background

2.1 Integrating Digital and Sustainability Transformation Perspectives

DT has been on the minds of practitioners and researchers for a long time. During a DT, organizations undergo significant changes to improve their entity by adopting digital technologies (Vial, 2019). Bharadwaj et al. (2013) and Vial (2019) describe digital technologies as an 'umbrella term' for information, computing, communication, and connectivity technologies, which can be categorized based on purpose, for example, by the role the digital technology plays or by defining how the user is involved (Baier et al., 2023). Vial (2019) describes how the use of digital technologies fuels the three types of disruptions, i.e., consumer behavior and expectations, competitive landscape, and the availability of data, which trigger strategic responses by organizations and hence drive DT. Similarly, Wessel et al. (2021) see technological change, which includes the use of emergent digital technologies, as a driver of DT. Hanelt et al. (2021) draw upon these findings when elaborating a comprehensive overview of contextual conditions that trigger and shape DT. Inside the organization, Hanelt et al. (2021) find DT drivers such as the organizational strategy and legacy and the DT awareness of the top management team. Outside the organization, material-related DT drivers such as the emergence and diffusion of digital technologies and applications, digital properties, and data availability as well as environmental DT drivers such as legal and infrastructural conditions, technology-driven industry dynamics, and digital customer demand can impact contextual conditions (Hanelt et al., 2021). Overall, various intraorganizational and environmental sources as drivers for DT have been identified (e.g., Hanelt et al., 2021; Vial, 2019; Wessel et al., 2021), which foster organizations' DTs. If done effectively, DTs are continuous and have fundamental impacts, such as shaping innovations in changing surroundings (Nasiri et al., 2023), implementing agile structures (Hanelt et al., 2021), or redefining value propositions (Setzke et al., 2023), resulting in new organizational identities (Wessel et al., 2021).

Simultaneously, organizations face sustainability pressures of society in general and stakeholders in particular, for instance, business partners, regulations, and employees, which enhance the need to accelerate their ST (Alsayegh et al., 2020; Dyllick & Muff, 2016). Regulations such as the European Green Deal compel organizations in the European Union to decouple economic growth from resource use (European Commission, 2019). The different sustainability pressures act as ST drivers. Consequently, organizations have started to adopt ST measures to enhance stakeholder orientation and maximize the social value of their business model (Mirvis et al., 2016; Zeiss et al., 2021). During an ST, organizations interrupt previous path dependencies and pass large-scale non-linear changes toward more desirable social and environmental system states for the whole organizational ecosystem (Dorninger et al., 2020). Hence, an ST is multilayered and complex, encompassing environmental, societal, governmental, regulatory, and individual factors (Seidel et al., 2014).

Over the past few years, different Information Systems (IS) research endeavors such as "Digital Social Innovation" (e.g., Bonina et al., 2021; Kohli & Melville, 2019), "Responsible Digital Transformation" (e.g., Dennehy et al., 2023; Pappas et al., 2023), "Green Information Technology (IT)" (e.g., Henkel & Kranz, 2018; Loeser, 2013), "Green IS" (e.g., Melville, 2010; vom Brocke et al., 2013), or "Circular Economy" (e.g., Crome et al., 2023a; Ortega-Gras et al., 2021; Zeiss et al., 2021) already combined digitalization research with sustainability aspects. Experts from practice (Crome et al., 2023b; Ollagnier et al., 2021) and recent scientific publications (e.g., Christmann et al., 2024; Graf-Drasch et al., 2023) encourage our understanding of integrating DT and ST on eye level as twin transformation. Applying the typology of DT for sustainability by Zimmer and Järveläinen (2022), twin transformation has a high environmental and social emphasis, leading to its categorization as digital-sustainable co-transformation. The twin transformation interplay is twofold. First, DT, especially using digital technologies, enables organizations to achieve their sustainability goals, acting as a facilitator by automating processes and creating transparency, e.g., through data processing (Guandalini, 2022; Singh & El-Kassar, 2019). Nevertheless, it is important to acknowledge that the use of digital technologies always comes at a price in terms of sustainability and is not without consequences. More specifically, rare natural resources are often required in the production of digital technologies (e.g., Itten et al., 2020), and energy consumption typically increases when using emerging digital technologies such as large language models (e.g., Andersen et al., 2021). Further, data collectors may share sustainability-related data with various ulterior motives, for instance, to be able to control which data reaches the public (e.g., Monteiro & Parmiggiani, 2019). Second, ST represents an opportunity for DT by guiding DT through a purpose and goals beyond economic concerns, i.e., profitability or efficiency, thereby redesigning DT (Graf-Drasch et al., 2023; Isensee et al., 2020; Veit & Thatcher, 2023). Twin transformation supports organizations in simultaneously and effectively addressing changes in the environment regarding digitalization and sustainability (e.g., Graf-Drasch et al., 2023). By doing so, organizations can facilitate societal change, by creating both, business and social value (Veit & Thatcher, 2023). Building on this domain

background of DT and ST literature acknowledging existing hybrid concepts, our work aims to uncover and structure relevant dynamic capabilities organizations need to mature in twin transformation.

2.2 Capability Development and Maturity Models

Capabilities are repeatable patterns of actions using assets to create, produce, and offer products or services to a market (O'Reilly & Tushman, 2008). They can be operational or dynamic (Pavlou and El Sawy 2011). While operational capabilities facilitate organizations' daily processes and routines, dynamic capabilities support organizations in adapting and reconfiguring processes in fast-changing environments (Teece et al., 1997). Dynamic capabilities in the IS domain relate to three different capacities, which support organizations in adapting and reconfiguring their processes to external environments. These capacities encompass opportunity recognition (sensing), opportunity implementation (seizing), and continuous adoption (transforming) (Steininger et al., 2022; Teece, 2007, 2014). Thus, developing dynamic capabilities is crucial in implementing DT and ST as they are required to accomplish the necessary changes. Exemplary capabilities for DT are the "ability of employees to learn quickly" (Soluk & Kammerlander, 2021), or "reconfiguring routines by decomposing DT into specified projects" (Ellström et al., 2022). Exemplary capabilities for ST are "knowledge management activities of sustainability-related knowledge within the organization" and "corporate citizenship efforts" (Yazici, 2020).

Table 1 Comparison of Existing Maturity Models in the Realm of DT and ST

Focus	Relevant maturity models in the realm of DT and ST
DT	Maturity models exist for **various focus areas** and **target groups** of DT: - Data science: Gökalp et al., 2022 - Data management: Zitoun et al., 2021 - Digital business ecosystems: Ehrensperger et al., 2023 - Human resources: Zaoui & Souissi, 2022 - For public organizations: Nerima & Ralyté, 2021 - For business-to-business organizations: Hortovanyi et al., 2023 - For specific industries: Gollhardt et al., 2020; Goumeh & Barforoush, 2021; Nebati et al., 2023 - Focusing on capability development: Aguiar et al., 2019; Gökalp & Martinez, 2022; Kırmızı & Kocaoglu, 2022 - Industry 4.0: Amaral & Peças, 2021; Colli et al., 2018; Santos & Martinho, 2020
ST	Maturity models exist for **limited focus areas** for ST: - Business process management: Sohns et al., 2023 - Circular economy process: Uhrenholt et al., 2022 - Environmental sustainability for micro, small, and medium-sized enterprises: Vásquez et al., 2021
DT and ST	Models similar to maturity models with **one-sided views** exist at the interface of DT and ST: - Readiness and maturity of SMEs for circular economy and Industry 4.0: Kayikci et al., 2022 - Self-assessment framework for environmental sustainability in the era of digitalization: Eisner et al., 2022

Maturity models are managerial tools to structure the step-wise development of capabilities (Mettler et al., 2010; Santos-Neto & Costa, 2019). They map maturity pathways by classifying stages and describing each stage's capabilities (Röglinger et al., 2012). Maturity models are applied in IS research domains like DT (e.g., Gollhardt et al., 2020), IT (e.g., Pereira & Serrano, 2020), or business process management (e.g., Röglinger et al., 2012) and related domains such as industry 4.0 (e.g., Santos & Martinho, 2020). They deal with dynamic capabilities and describe how organizations can realize transformations, e.g., DT (Berger et al., 2020) or ST (Vásquez et al., 2021).

Maturity models are considered valuable artifacts in DSR as they provide a status-quo assessment of an organization's capabilities and derive measures for improvement (e.g., Becker et al., 2009; Looy et al., 2017; Mettler & Ballester, 2021). They are commonly designed as matrices that feature maturity stages on the horizontal axis and dimensions on the vertical axis (Fraser et al., 2002; Lasrado et al., 2015). Maturity stages represent typical stages of maturity that exhibit a unique set of characteristics (Fraser et al., 2002). Irrespective of the fact that maturity models are widely used in practice (e.g., Proença & Borbinha, 2016), research points out different weaknesses, such as the over-simplification of the real world through the multi-stage approach (de Bruin et al., 2005) and apparent path dependencies prescribed by the outlined maturity path, which is presented as the single true path to reach the final stage (Teo & King, 1997). Further, maturity models often imply that the final stage is the end stage, neglecting the continuous change and permanent transformation of organizations and their environment (King & Kraemer, 1984). To counteract these weaknesses, it is a common approach in IS research to conduct a literature review on existing maturity models in the related research fields, which can either already solve the defined research problem or be used as a basis for the development of a new maturity model (Becker et al., 2009). Table 1 shows the results of our structured literature review, which we conducted in the realm of DT and ST and used as the basis for the development of our TTCMM.

Additionally, design decisions for maturity models are made in the beginning of their development process as different maturity model types, such as continuous, focus area, and staged maturity models, exist for different purposes (van Steenbergen et al., 2007). While continuous maturity models distinguish several focus areas and use generic maturity stages, focus area maturity models may integrate different focus areas with their own set of maturity stages (van Steenbergen et al., 2007). In this work, we chose to develop

a *staged maturity model* following a top-down approach with predetermined maturity stages since the initial focus lies on what twin transformation maturity means and how it can be developed. In staged maturity models, capabilities must be assigned to exactly one maturity stage, outlining the maturity pathways between capabilities (United States Government Accountability Office, 2010). Hence, maturity stages generic to all dimensions are defined. The top-down approach works well in fields like twin transformation that are relatively unexplored and when there is little guidance on what is considered mature and what the process to maturity looks like (de Bruin et al., 2005). Maturity models are either descriptive, prescriptive, comparative, or combined (de Bruin et al., 2005). As we investigate the relatively new phenomenon of twin transformation, we chose a prescriptive purpose for our maturity model to assist organizations in determining a desirable stage of maturity by suggesting measures for achieving it.

To structure relevant dynamic capabilities, we identified capability dimensions using the structured literature review. Exemplary capability dimensions in existing literature are *strategy* (e.g., Amaral & Peças, 2021; Gollhardt et al., 2020), *culture* (e.g., Amaral & Peças, 2021; Sjödin et al., 2018), *ecosystem* (e.g., Amaral & Peças, 2021; Gökalp & Martinez, 2021), *products* (e.g., Sjödin et al., 2018; Uhrenholt et al., 2022), *operations* (e.g., Aguiar et al., 2019; Gökalp & Martinez, 2021) and *technology* (e.g., Gökalp & Martinez, 2021; Sjödin et al., 2018). We aim to identify dynamic capabilities for twin transformation structured along suitable capability dimensions and stages for twin transformation. Table 8 in the Appendix shows the background information on each of our capability, i.e., the capability's capacity and source.

3 Method

To develop a maturity model, we follow the DSR paradigm (Gregor & Hevner, 2013; Peffers et al., 2007), aiming to develop innovative artifacts (e.g., constructs, models, or methods) to address practical problems and enhance their respective environments (vom Brocke et al., 2020). In alignment with Peffers et al. (2007), our study adopts a six-step iterative DSR approach. The dedicated procedural model by Becker et al. (2009) provides designated DSR activities structuring the maturity model development. Additionally, we conducted ex-ante and ex-post evaluations following Sonnenberg and vom Brocke's (2012) EVAL 1–4 patterns. In sum, our research method consists of four main phases to develop and evaluate a maturity model for twin transformation capabilities, illustrated in Fig. 1. Each phase covers activities and connected evaluation patterns based on the two main types of action in DSR: design and evaluation (March & Smith, 1995). In this work, the pathways, stages, dimensions, and capabilities of the TTCMM are written in italics.

Phase 1: Problem Identification by Structured Literature Review. Following Peffers et al. (2007), the first activity of the DSR process is problem identification. To ensure the novelty and the importance of designing a TTCMM (Sonnenberg & vom Brocke, 2012), we compared existing models that identify and solve problems in the same and related research areas, namely, DT, ST, and integrated concepts. To this end, we conducted a structured literature review (vom Brocke et al., 2015). Following Leidner's (2018) polylithic framework of research and theory development papers, we categorize our structured literature review as an "assessing review" as the research objective was a literature synthesis, and the focus was on identifying research needs and opportunities. We structured it with the help of the three steps proposed by vom Brocke et al. (2015) consisting of search strategy and literature search, selection, and synthesis.

Search Strategy and Literature Search. As our topic is interdisciplinary, we selected literature bases covering IS and other fields, such as organizational change management and sustainability research. We searched *AISeL*, as it includes the most relevant IS outlets. Further, we searched for DT and ST maturity models in all disciplines using *Web of Science (WoS)*, *ScienceDirect*, and *Scopus*. We filtered

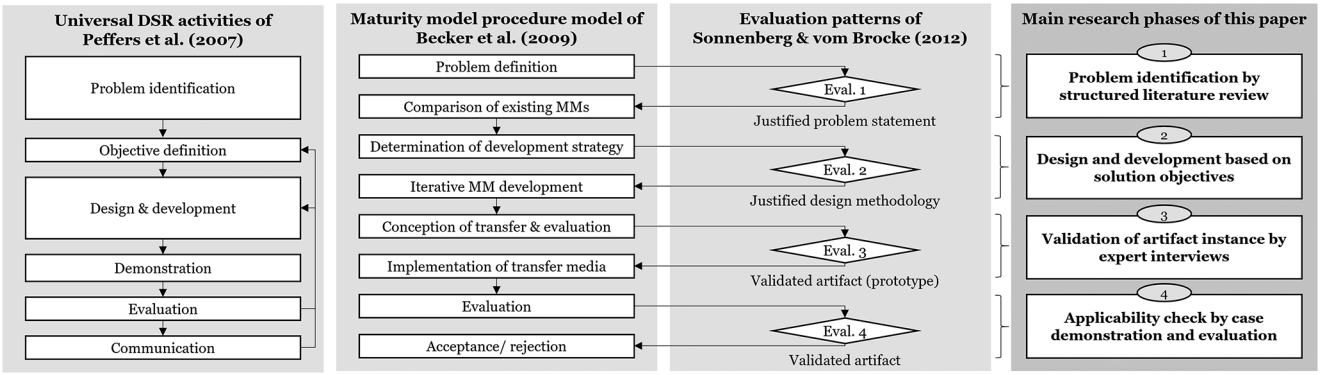

Fig. 1 Research Approach (inspired by Stahl et al., 2023)

for peer-reviewed publications in the English language published either in conference proceedings or in journals. Our search string focused on relevant contributions to designing maturity models in the appropriate fields: "maturity model" AND ("sustainability" OR "digital" OR "twin") AND ("transformation" OR "transition"). Due to syntactic and technical restrictions, the queries slightly varied for *ScienceDirect* and *AISeL* but were semantically equivalent. We applied the filters for title, abstract, and keywords. The search yielded 475 results (243 studies in *Scopus*, 116 in *WoS*, 83 in *ScienceDirect*, and 33 in *AISeL*).

Selection. After removing duplicates (93 in total), we screened titles, abstracts, and keywords of the 382 studies (vom Brocke et al., 2015), resulting in further consideration of 90 articles. Here and for the subsequent full-text reading, we followed our priorly determined inclusion criteria (Webster & Watson, 2002): (A) The focus lies either on the development or (B) the application of a maturity model, (C) the context of application is organizational and (D) is generalizable to our transformation context. An exemplary reason for exclusion was that maturity models were designed for too specific, merely generalizable contexts, e.g., a DT capability maturity model for cost consultation enterprises (e.g., Han et al., 2022). After full-text reading, adding relevant articles through forward and backward searches, and discussing debatable cases within the author team, 34 maturity model articles were included. Table 6 in the Appendix illustrates the 34 maturity models related to our research endeavor in the DT and ST realm.

Synthesis. To create the TTCMM, we developed a new maturity model drawing on structure from existing research and practical insights. To incorporate existing research, we analyzed the final 34 articles resulting from the structured literature review. Of the results, 26 articles presented maturity models and meta-analyses of maturity models in the DT realm; three designed maturity models for integrating DT and ST, and five solely focused on the ST realm. This leads to the observation that research about DT maturity is already well-established, while ST maturity literature does not yet offer far-reaching insights. Table 1 gives an overview of the researched focus areas of the existing maturity models. The investigation reveals that the problem of uncovering dynamic capabilities and maturity stages for twin transformation has not been investigated while valuable foundations were laid.

Phase 2: Design and Development Based on Solution Objectives. To address the problem of missing investigations of dynamic capabilities and maturity stages for twin transformation, we formulated solution objectives to develop a capability maturity model for twin transformation. Defining solution objectives is important as they specify the goals that a new or improved artifact should achieve (Peffers et al., 2007). We established solution objectives to guide the development of an artifact aimed at systematically fostering dynamic capabilities for twin transformation, enabling organizations to assess their twin transformation maturity. To purposefully guide the development and evaluation process of the TTCMM, we derived the solution objectives from the existing twin transformation literature and relevant literature in the fields of DT and ST, as discussed in Sect. 2. In the evaluation phase, we also compared how well the TTCMM supports a solution to the problem.

Organization-wide transformations, such as twin transformation, are complex and cross-functional but are crucial learning phases for attaining transformation maturity (Bonnet, 2022). For example, increasing twin transformation maturity requires digitalization and sustainability investments (Aslanova & Kulichkina, 2020; Dangelico et al., 2017) and recruiting talents with appropriate skills (Yazici, 2020). To achieve successful transformations, organizations need dynamic capabilities in all relevant dimensions to adapt their practices (Steininger et al., 2022; Teece, 2014). Therefore, the TTCMM should be based on the recognition that assessing twin transformation maturity requires a comprehensive analysis of diverse organizational dimensions. By considering these dimensions, organizations can achieve a deep understanding of the transformative journey and effectively navigate the complexities associated with twin transformation. Our first solution objective is defined as follows:

Solution Objective 1. TTCMM Must Include DT and ST Capabilities for Holistic Organizational Assessment. DT and ST represent two fundamental drivers of organizational change (Hanelt et al., 2021; Sancak, 2023). To manage any transformation, organizations need dynamic capabilities to adapt and reconfigure processes in fast-changing environments (Steininger et al., 2022; Teece, 2014). Although each single transformation offers benefits, integrating them enhances organizational effectiveness. Further, research and practice indicate that instead of merely integrating the two transformations, organizations should view DT and ST as equals and integrate them on eye level (e.g., Christmann et al., 2024; Graf-Drasch et al., 2023; Ollagnier et al., 2021). Consequently, the TTCMM requires a balanced consideration of DT- and ST-related capabilities for thorough transformation maturity assessment. This balance fosters the development of integrated transformation capabilities within the TTCMM, enabling organizations to address challenges and synchronize their transformation efforts strategically and holistically. Therefore, our second solution objective is:

Solution Objective 2. TTCMM Must Consider DT and ST as Equally Important. It is important to recognize that organizations are at different stages of their transformation

journeys and have varying levels of expertise in both DT and ST (Allen & Malekpour, 2023; Fischer et al., 2023). Consequently, organizations are equipped with varying levels of DT- and ST-related capabilities. The TTCMM aims to comprehensively assess organizations' twin transformations, considering diverse starting points and capability levels to provide a structured model for nuanced evaluation and strategic planning. As a result, organizations should be able to assess their twin transformation maturity to address specific challenges, leverage existing DT- and ST-related capabilities, and progress toward more mature states in twin transformation. Thus, we have defined the third objective for our solution:

Solution Objective 3. TTCMM Must Consider the Different Starting Points of Organizations. The results of the structured literature review of research phase 1 and the solution objectives form the basis for the design and development phase. We developed a staged maturity model based on the assumption that the integrated capabilities build upon each other and must be differentiated in terms of difficulty. Each dynamic capability is assigned to the most reasonable maturity stage. Thus, organizations that reach the last stage of maturity have already established the easier ones of the earlier stages. The TTCMM development process is shown in Fig. 2.

In line with Becker et al. (2009), we started with the maturity model's architectural design, i.e., the basic structure of maturity stages and capability dimensions, before identifying relevant dynamic capabilities. Subsequently, we mapped capabilities vertically (i.e., to the predefined capability dimensions) and horizontally (i.e., to the predefined maturity stages). Afterward, the maturity stages and capability dimensions were refined regarding their problem adequacy, internal consistency, and clarity through expert interviews. In the following, the TTCMM development process is explained in detail.

Architectural Design of Maturity Stages and Capability Dimensions. To design the TTCMM, we integrated DT and ST maturity stages based on existing DT maturity models (e.g., Gollhardt et al., 2020) and ST maturity models (e.g., Kayikci et al., 2022) and adapted them for the twin transformation context. Our final set of four maturity stages does not correspond with the typical maturity model design, as the initial stage, *#1 Awareness of combining digitalization and sustainability* consists of separate DT- and ST-related capabilities and is followed by three joint development stages, namely *#2 Twin transformation development*, *#3 Twin transformation implementation* and *#4 True twin transformer*. This design choice has pointed out the importance of awareness creation for undertaking joint twin transformation efforts as a starting point. Based on the results of the structured literature review and in line with solution objective 3, it became clear that existing maturity models comprehensively cover relevant capabilities for reaching DT maturity but not ST maturity. Therefore, we further engaged in searching for articles on ST capabilities. We explicitly searched for the keywords *"sustainability transformation capabilit*"* in two literature bases, i.e., *WoS* and *Scopus*. We executed a forward and backward search until we found a considerable amount of distinct and usable ST-related capabilities.

Vertical and Horizontal Mapping of an Initial Set of Capabilities. In the next step, we synthesized the dynamic capabilities per maturity stage and dimension through discussion rounds within the author team. Thereby, we followed a two-phased approach. First, we extracted dynamic capabilities from existing literature, resulting from research phases 1 and 2, that cover DT or ST contexts and are also suitable for the twin transformation context. For instance, the dynamic capability for twin transformation *establish data governance mechanisms to enhance the data and information sovereignty* in stage #1 was adapted from the existing dynamic capability for DT "data and information sovereignty" (Kırmızı & Kocaoglu, 2022). For our TTCMM, the sovereign handling of data and information shall be achieved right at the beginning, when the organization takes the first steps to see DT and ST at eye level. Second, we extracted matching capabilities in DT and ST literature and merged them into one. For instance, *redesign or develop products and services as per twin transformation objectives*, emerged from existing dynamic capabilities for DT and ST. The dynamic DT capability, the "capacity of agile reconfiguration of products" (Santos & Martinho, 2020), was merged with the dynamic ST capability, "redesigning products/services as per environmental criteria" (Singh & El-Kassar, 2019). An overview of the final capabilities is provided in the Appendix (Table 8).

Refinement of the Maturity Model (i.e., Stages, Dimensions, Capabilities). The iterative maturity model development process was completed by conducting five

Fig. 2 Twin Transformation Capability Maturity Model Development Process

expert interviews for refinement. For these five interviews and the eight interviews of phase 3, we followed the same expert sampling approach (Bhattacherjee, 2012) by inviting experts via active sourcing using LinkedIn and our networks. We defined an expert as someone with DT and/or ST knowledge that s/he applies in the current job position, whereby the position is independent of the industry. An overview of the expert interviews can be found in the Appendix (Table 7). The interviews were performed as follows: First, the interviewer (i.e., one of the authors) explained the research motivation and introduced the research question. Second, the TTCMM was displayed, giving an overview of the stages, dimensions, and capabilities. All interviews were digitally recorded and transcribed.

Within the first five interviews in phase 2, we aimed to discuss the first, solely literature-based version of the TTCMM and welcomed any ideas for practitioner-oriented model adjustments. As we directly integrated adjustments after each interview, each next expert saw an iteratively improved version. The experts confirmed that the TTCMM covers most contexts in their organizations. For example, we extracted the dimension *strategy* from the literature (e.g., Amaral & Peças, 2021; Gollhardt et al., 2020) and minimally adjusted the wording temporarily into *strategy and leadership involvement* after the interview with expert ID2 and finally in *strategy and leadership* after the interview with expert ID4. These adjustments were implemented as the experts emphasized leadership involvement's substantive relevance, which increased comprehensiveness. Furthermore, minimal adjustments like the numbering of the maturity stages were realized in this last step of the maturity model development process. Concerning consistency, the experts acknowledged that the TTCMM provides a reliable path for assessing an organization's maturity stage. As for problem adequacy, the experts confirmed the research gap and supported the relevance of our research to help organizations mastering twin transformation as they affirmed that organizations are engaged in and challenged by both DT and ST individually.

Phase 3: Validation of Artifact Instance by Expert Interviews. The third phase validated the model by interviewing eight additional experts from practice regarding the model's operationality and completeness (Becker et al., 2009; Salah et al., 2014; Sonnenberg & vom Brocke, 2012), helping to refine the TTCMM's maturity stages and capability dimensions. During the process, new dynamic capabilities were added, such as *influence legislators on twin transformation standards*. Others were rephrased, for example, *offer sustainable services based on acquired data of products* was further developed to *redesign or develop products and services as per twin transformation objectives*. Additionally, dynamic capabilities were rearranged. As the last interviewees classified the TTCMM as operationally useful and complete in the sense that it creates value for potential users, we ended the evaluation phase after the eighth expert. Overall, the experts stated that the endeavors of single-stream transformations, namely DT and ST, could not generate the same value as taking the integrated perspective of twin transformation. The experts particularly appreciated the model's action-oriented dynamic capabilities and confirmed its coverage of relevant dynamic capabilities and its realistic distribution across maturity stages.

The interviews also revealed three pathways to becoming a *true twin transformer.* Consequently, we established three pathways to twin transformation maturity — *twin transformation newcomer*, *DT expert*, and *ST expert* — reflecting different organizational knowledge bases. These pathways help pinpoint relevant actions for achieving maturity, with the model's stage #1 depicting the two transformations', DT and ST, separate starting points from which awareness of the opportunities of twin transformation can be created.

Phase 4: Applicability Check by Case Demonstration and Evaluation. Lastly, we tested the TTCMM's clarity and applicability (Sonnenberg & vom Brocke, 2012) through a case demonstration with a senior sustainability manager from a DAX 40 company's IT services subsidiary. We thoroughly assessed dynamic capabilities by maturity stage and capability dimension during a case demonstration with four objectives: (I) find out the status quo, (II) the desired target stage of the company's twin transformation capabilities, (III) understand initiatives taken by the case demonstration company (CDC) that demonstrate its maturity in the different capability dimensions, and (IV) identify challenges faced in advancing its twin transformation. The case demonstration was a two-hour online workshop in September 2023, where the TTCMM was displayed and discussed using collaboration tools. The current and desired maturity stages of the company were noted, and the participant, the senior sustainability manager of CDC, detailed their initiatives and challenges for each maturity stage and capability. When the participant could not name initiatives for at least one of the capabilities of the upcoming stage, the current stage was determined as the status quo.

The evaluation of artifacts such as the TTCMM is a crucial activity in the DSR paradigm (e.g., Hevner et al., 2004; Peffers et al., 2007; Venable et al., 2016). To evaluate the TTCMM's effectiveness, we compared its functionality against the solution objectives from phase 2, confirming it fully satisfies the criteria. The TTCMM defines six capability dimensions, offering a comprehensive view of organizations, satisfying solution objective (1) Both expert feedback and demonstration affirmed the equal importance of DT- and ST-related capabilities, meeting solution objective (2) Additionally, all experts could categorize their organizations

within the TTCMM regardless of their specific transformation focus or progress, fulfilling solution objective (3) Further, we conducted an ex-ante and ex-post evaluation, following the evaluation frameworks described in EVAL 1–4 by Sonnenberg and vom Brocke (2012). The evaluations conclude that the TTCMM is effective, and there is no need to revisit phase 2. Following Peffers et al. (2007), the last step of the DSR process is communication to disseminate the resulting knowledge. The objective of this paper is to emphasize the problem's importance, the TTCMM itself, its utility and novelty, the pathways, the rigor of its design, and its significance to researchers and other relevant audiences, such as practitioners. Further, we already exploit the findings in applied research projects and teaching.

4 Capability Maturity Model and Pathways towards Twin Transformation Maturity

The organization's twin transformation becomes apparent through four maturity stages, as illustrated in Table 2.

When developing the TTCMM, we recognized that twin transformation capability development differs from the development of other dynamic capabilities, which usually follow maturity stages in a linear form. Given the dual focus of twin transformation, we found that organizations start their twin transformation journey from different capability starting points, not only in terms of general maturity but also in terms of their previous experience and expertise in DT or ST. Organizations may already be very mature regarding dynamic DT capabilities but lack the sustainability equivalents and vice versa. One of our experts (ID1) confirmed this, emphasizing that prior knowledge of organizations regarding DT and ST plays a significant role in the twin transformation climb. To account for such different starting points, our TTCMM outlines three pathways to becoming a *true twin transformer* (stage #4): pursuing twin transformation as a *DT expert*, *ST expert*, or *twin transformation newcomer*. We illustrate these pathways in Fig. 3, which sketches a climb to the twin transformation mountain. Organizations that are already *DT experts* (i.e., having a high maturity of DT capabilities) may save themselves a bit of a climb to the top of the twin transformation mountain as they start their twin transformation journey from stage #2. This also applies to *ST experts* with a high maturity of ST capabilities. To reach twin transformation maturity stage #2, DT and ST capabilities are required but suffice in isolation. From twin transformation maturity stage #2, DT and ST capabilities need to be integrated, thought together and brought together on equal footing. For all twin transformation pathways, the capability dimensions are the building blocks of the twin transformation mountain to be considered by organizations. Each pathway is outlined in detail in the following, and exemplary integrated capabilities that may be leveraged with existing knowledge and infrastructure are explained.

Table 2 Twin Transformation Maturity Stages

#	Maturity stage	Description
1	Awareness of combining digitalization and sustainability	An organization deals with none, or standalone digitalization or sustainability efforts but is **aware of the synergetic potential of combining digitalization and sustainability efforts**. It takes initial steps by testing selected integrated DT-ST projects driven by one leading transformation type (either DT or ST).
2	Twin transformation development	An organization develops a **twin transformation strategy** manifested in a twin transformation roadmap. Long-term-oriented **projects joining forces for DT and ST** implementation are developed. It rolls out and evaluates the twin transformation strategy in a pilot phase.
3	Twin transformation implementation	An organization uses the experiences of the development stage (i.e., project pilot phases) and **operationalizes** the twin transformation strategy for **global implementation** throughout the organization.
4	True twin transformer	An organization considers twin transformation criteria as the **bottom line for all decisions**. It is committed to **continuously self-optimizing and steadily aligning organizational activities** (e.g., business plans) and twin transformation objectives.

The full set of capabilities required for climbing the four stages can be found in Table 3. *DT experts* possess DT-related capabilities. Hence, they develop ST-related and integrated capabilities during their twin transformation journey. The same applies to ST experts the other way around. First, *DT experts* have an advantage in capabilities based on an existing technology stack and DT knowledge. Existing exemplary capabilities that can be leveraged on this pathway include *foster the development of digital services. DT experts* have digital technologies in place and know how to deploy them. One expert (ID8) confirmed that "companies are at different stages concerning digitalization and sustainability. A company can be very far along in digitalization but not yet have anything to do with sustainability." Nevertheless, organizations taking the *DT expert* pathway often lack sustainability knowledge, which they need to build up in their maturity journey starting on stage #2. One expert (ID12) stated that her organization "is well positioned about digital services but is not yet concerned with sustainability in the development of these." Second, some organizations start the twin transformation climb as *ST experts*. These organizations can contribute their existing ST capabilities, for instance, existing sustainable products and services to the twin transformation climb. These organizations have

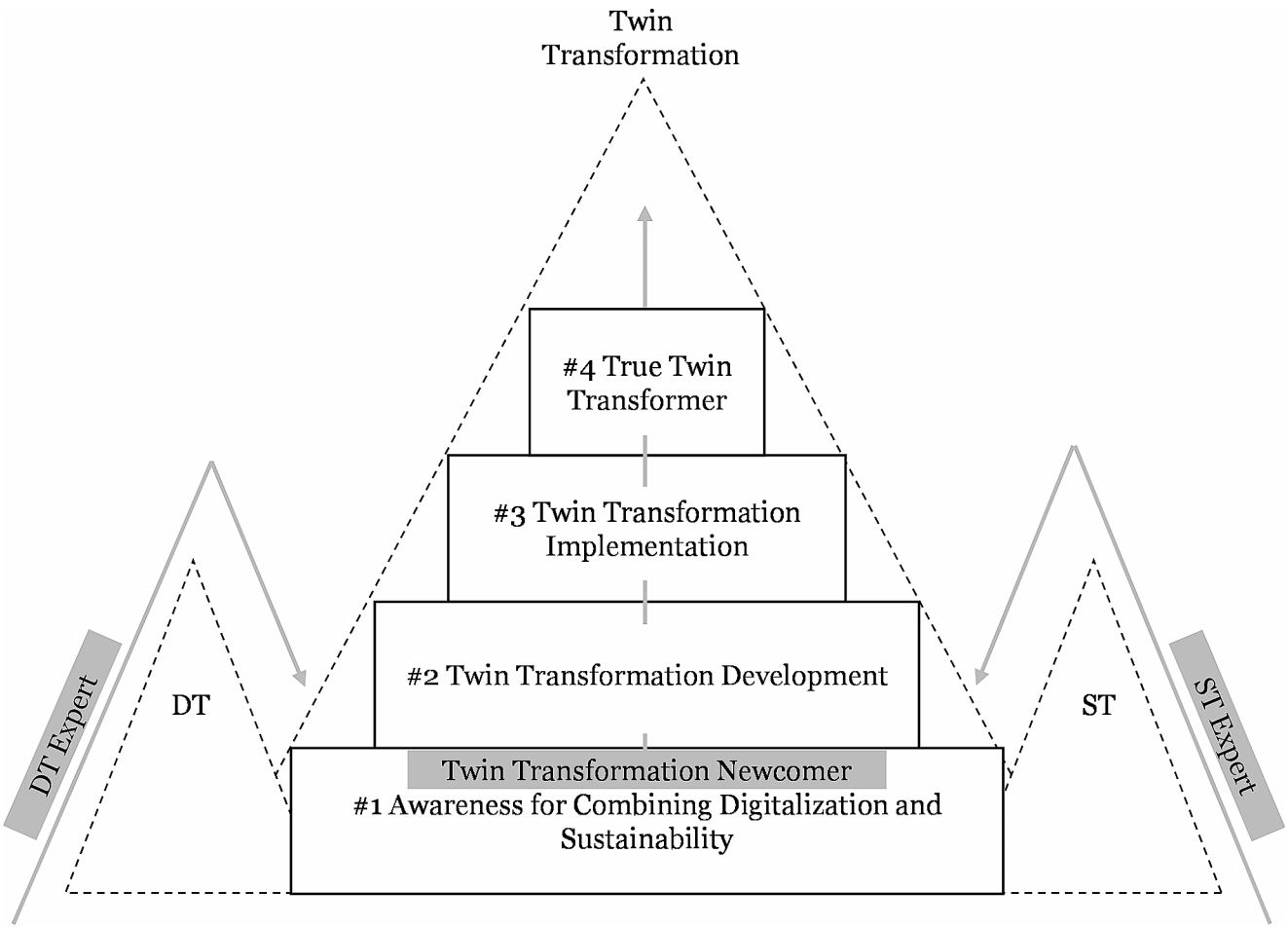

Fig. 3 Three Pathways towards Twin Transformation Maturity

an advantage regarding ST capabilities like *foster the performance of a life-cycle analysis*. To date, such ST-focused organizations frequently lack digitalization knowledge. One expert (ID 5) stressed that "companies are already very good at ST, e.g., using environmentally friendly materials, but are not yet digital at all." Thus, *DT* and *ST experts* narrow their knowledge gaps on the respective subject area in which they are not experts on the way to twin transformation maturity within stage #2. Subsequently, *DT experts* understand sustainability and *ST experts* understand digitalization; organizations from both backgrounds start with the *twin transformation development* in stage #2. Third, organizations with limited DT- and ST-related capabilities start their twin transformation climb from scratch as *twin transformation newcomers. Twin transformation newcomers* align and integrate DT and ST transformation efforts from the start, which saves resources (Ollagnier et al., 2021). Within maturity stage #2, the three twin transformation pathways merge following the same route (i.e., stages) to the twin transformation top (i.e., to become a *true twin transformer)*.

Proceeding the twin transformation climb, organizations must understand twin transformation as a holistic transformation that affects the entire organization (Graf-Drasch et al., 2023). This is also evident in our TTCMM, as the different capabilities increasingly depend on each other the higher the stage of maturity reached. Organizations have reached a certain stage when they fulfill all capabilities of one dimension within their solution space, i.e., those capabilities that they can achieve with their business model. It is possible to reach different maturity stages in different capability dimensions. In stage #1, DT- and ST-related capabilities exist separately. In later stages, DT- and ST-related capabilities intertwine. For example, *foster dialogue with partners* within the capability dimension *ecosystem and partnerships* relates to the capability *focus on cradle-to-cradle approaches* within the capability dimension *products and services*. Another example is a dependency between the *technology* capability *foster advanced analytics in management dashboards to monitor twin transformation objectives*, and the *products and services* capability *establish data analytics to enhance the sustainability of products/services.*

Table 3 Twin Transformation Capability Dimensions

Capability dimension	Description
Strategy and leadership	A **digital and sustainability strategy** includes principles that are prerequisites for the full development of twin transformation and clearly expresses the benefits of twin transformation. These include apparent **leadership involvement, cross-departmental and cross-organizational collaboration, and information sharing** (Stelzl & Röglinger, 2020).
Culture and employees	The collective **values and beliefs** regarding the organization encompass attitudes and behaviors. Culture also covers **employees' capabilities**, continually enhancing and applying their operational and management skills and knowledge about twin transformation (Gollhardt et al., 2020; Stelzl & Röglinger, 2020).
Ecosystem and partnerships	A **multilayer network of partners** that grew historically or was created and **nurtured by management choices** to leverage twin transformation market opportunities (Tsujimoto et al., 2018).
Products and services	A **new generation of digital and sustainable products or services** is characterized by servitization, i.e., digital services and sustainability endeavors (Yin et al., 2020).
Operations	The **value creation processes**, system thinking, and other system design techniques enable digital sustainable value creation and decision-making methods in the whole organization (Colli et al., 2018; Gollhardt et al., 2020).
Technology	**Methods and information systems** are tools and techniques that support and enable the design, implementation, execution, monitoring, control, and **improvement of digitalization and sustainability activities and objectives** within organization-spanning initiatives (Bharadwaj et al., 2013; Colli et al., 2018).

Twin transformation objectives are an integral part of integrated capabilities and form the basis for the twin transformation process, encompassing ST and DT at eye level.

As a foundation of the outlined twin transformation stages and pathways, we present the TTCMM comprising six capability dimensions, structuring 45 capabilities. Table 8 in the Appendix reveals background information on each capability, i.e., the capability's capacity and source. The capability dimensions are illustrated in Table 4. The twin transformation capabilities are structured along the defined maturity stages and capability dimensions.

Our dynamic capabilities encompass the three sustainability dimensions (i.e., environmental, social, and economic sustainability). To illustrate the sustainability dimensions, we make use of three exemplary dynamic capabilities. First, in stage #2 *Twin transformation development*, the dimension *culture and employees* includes the dynamic capability *introduce values underlining the vision of a digital and sustainable organization.* Those values are not limited to economic sustainability but also include environmental and social sustainability. An exemplary value is "integrity", which can be described as being a role model for others by consistently adhering to set principles or ethical standards, which leads to building trust, credibility, and a positive reputation. Second, in stage #3 *Twin transformation implementation*, we elaborated the dynamic capability *redesign or develop products and services as per twin transformation objectives* in the *products and services* dimension. This is in line with Zimmer and Järveläinen (2022, p.106), who state that "sustainable digital innovations transform organizations into digital but also sustainable organizations" and give the example of bext360, a service platform for coffee roasteries, which uses technological solutions such as machine vision to improve the supply chain transparency of coffee. This sustainable digital service innovation has a positive social impact, as through a fair representation of their products' quality, the farmers gain a better bargaining position, and thus a fairer market is created. The innovation also has a positive environmental impact, as it can be evaluated whether forests were fire-cleared to grow coffee, which can be penalized by potential buyers with values underlining sustainability. Thus, the new service enables more informed coffee buying choices and thus potentially redesigns the coffee market. The service of bext360 could be taken a step further to stage *#4 True twin transformer*, with the dynamic capability *focus on cradle-to-cradle approaches* by making their service more sustainable, e.g., by using open-source data instead of generating new data, by employing low code solutions or by minimizing created data waste. Among others, these activities make the approach a cradle-to-cradle one, as not only the outcomes, but also the means are evaluated applying twin transformation objectives. Third, another example

Table 4 Twin Transformation Capability Maturity Model

Capability dimension	Maturity stage				
	#1 Awareness of combining digitalization and sustainability		#2 Twin transformation development	#3 Twin transformation implementation	#4 True twin transformer
	DT-related capabilities	ST-related capabilities	Integrated DT and ST-related capabilities		
Strategy and leadership	– Understand the economic potential of DT – Foster the use of digital technologies	– Understand sustainability as a must-do – Foster the performance of a life-cycle analysis	– Develop a twin transformation strategy and derive measurable digitalization and sustainability objectives that are not mutually exclusive – Strengthen digitalization and sustainability investments – Establish digitalization and sustainability key performance indicators – Foster twin transformation development through (top) management commitment	– Foster twin transformation implementation through the (top) management – Integrate investments in twin transformation innovations – Allow integrated digital and sustainability-related changes to the value proposition and organizational identity	– Evaluate activities regarding twin transformation objectives[1] – Develop twin transformation business models
Culture and employees	– Develop human capital regarding digital skills	– Develop human capital regarding sustainability skills	– Enable creativity and self-realization to foster digital and sustainability innovation – Introduce values underlining the vision of a digital and sustainable organization	– Establish twin transformation training for employees – Enable new digital and self-determined work	– Integrate twin transformation key performance indicators in reward systems of employees and (top) management
Ecosystem and partnerships	– Enhance transparency in supply chains using digital technologies	– Foster dialogue with partners	– Reconfigure relationships with partners based on the results of data analytics enhancing the sustainability of products/services	– Integrate partners' twin transformation knowledge and competencies acquired thanks to established dialogue	– Influence legislators on twin transformation standards
Products and services	– Foster the development of digital services	– Foster the collection of environmental and social sustainability data on products/services	– Reconfigure product development teams to include sustainability and digital specialists	– Redesign or develop products and services as per twin transformation objectives[1] – Establish data analytics to enhance the sustainability of products/services	– Focus on cradle-to-cradle approaches
Operations	– Foster integrated information, communication, and operation systems	– Foster the introduction of criteria to digitally evaluate the sustainability performance of operations	– Establish data-based (sustainability) monitoring – Establish cross-departmental collaboration	– Reconfigure layouts, manufactural and logistical processes for sustainability effectiveness	– Establish data analytics to continuously improve the twin transformation performance of operations
Technology	– Establish data governance mechanisms to enhance the data and information sovereignty	– Build awareness for sustainability within the technology stack (Green/Effective IT) – Implement environmental, social, and governance (ESG) controlling	– Establish the usage of sustainable internal processes and technical infrastructure (Green/Effective IT)	– Facilitate cross-organizational cooperation by providing an organization-wide data management tool – Foster advanced analytics in management dashboards to monitor twin transformation objectives[1]	– Exploit the sustainability potential of emerging digital technologies – Establish a cross-ecosystem data management tool facilitating twin transformation

[1]Twin transformation objectives are objectives balancing digitalization and sustainability goals

also finds itself in stage #4 but in the dimension *technology*. The bext360 example by Zimmer and Järveläinen (2022) also serves for the dynamic capability *exploit the sustainability potential of emerging digital technologies*, as in the described case, digital technologies were used to measure the product's environmental footprint and thereby, enable informed decisions that make environmental protection possible. To sum up, the three examples show, how the dynamic capabilities in the TTCMM are interdependent. Without laying the foundations for the importance of twin transformation by *introducing values underlining the vision of a digital and sustainable organization* in stage #2, *redesigning products and services as per twin transformation objectives* would not serve the company's overall objectives.

5 Demonstration

To validate our artifact in practice, we applied the TTCMM with the CDC, a subsidiary of a group listed in the German DAX 40. The CDC has approximately 10.000 employees who work together from different locations worldwide, and it operates as an IT service provider for all other daughter companies belonging to the DAX 40 group. We took this step to demonstrate the model's practical use when transferred to real-world circumstances (Becker et al., 2009). Specifically, the CDC's senior sustainability manager used the model to analyze the status quo by reflecting on ongoing initiatives and defining a target maturity level for the CDC's twin transformation capabilities. Further, the application uncovered twin transformation challenges for the CDC and led to defining its specific pathway toward twin transformation maturity.

Table 5 gives an overview of the maturity stages reached per dimension and describes the initiatives taken per capability. As the desired target stage, the senior sustainability manager stated that the CDC wants to become a *true twin transformer* (stage #4) in every dimension apart from *operations* as those capabilities were not perfectly applicable to the CDC being an IT service provider. The senior sustainability manager reported three major challenges on their way to becoming a *true twin transformer*. First, the senior sustainability manager explained that silo-thinking between the different daughter companies of the group exists and needs to be broken down to achieve better holistic twin transformation results. The hierarchical structures that grew over decades in the globally active group hinder, for example, the sharing of best twin transformation practices and twin transformation innovations because silo-thinking enforces competition between the daughter companies. Second, the senior sustainability manager faces difficulties in enthusing all employees by presenting the advantages of twin transforming. According to the senior sustainability manager, older employees tend to believe that change is unnecessary based on their long-time positive experience within the CDC. Thus, making the necessity of becoming a true twin transformer an unanimously shared opinion is complicated. Third, the senior sustainability manager shares that the CDC faces problems with twin transformation when interacting within their ecosystem. As the CDC has already reached the higher stages #3 and #4 in five out of six dimensions of the TTCMM, the CDC is already very involved in the twin transformation process. Whenever they interact with partners in their ecosystem, the CDC is the company that has advanced the most in twin transformation. Consequently, they face situations where they set requirements that the partners cannot meet because they are still beginning twin transformation. These challenges are why the CDC has not yet reached its goal of becoming a *true twin transformer*.

Overall, this phase showed that the model fulfills the set evaluation requirements, i.e., understandability and applicability (Sonnenberg & vom Brocke, 2012), as the senior sustainability manager understood each of the dimensions, maturity stages, and capabilities and could provide relevant initiatives from practice in the CDC. Further, the case demonstration also revealed that the pathways toward twin transformation maturity are useful. The senior sustainability manager sees the CDC as "clearly coming from the DT perspective" as it is an IT service provider whose workforce is majorly made up of people with IT expertise. Digitalization is the core of the subsidiary's business model as its purpose is to digitally transform the group it belongs to. Thus, capabilities like *develop[ing] human capital regarding digital skills* and *foster[ing] the development of digital services* in stage #1 are the employees' daily business, consequently the CDC begins their twin transformation climb at stage #2. The company is a *DT expert* which became aware of the synergies that can be leveraged when twin transforming. Its senior sustainability manager stated that his/her job consists of "uniting the strong support of the DT with ST objectives".

6 Discussion

6.1 Contribution

"The summit is what drives us, but the climb itself is what matters." – attributed to Conrad Anker.

This study has been motivated by the promising interplay of DT and ST, which has recently been emphasized in the IS domain (Christmann et al., 2024; Graf-Drasch et al., 2023). Specifically, we aimed to guide organizations in becoming *true twin transformers* by taking an integrated

Table 5 Results of the Case Demonstration Applying the Twin Transformation Capability Maturity Model

Capability dimension	Maturity stage reached by CDC				Corresponding twin transformation capabilities of the maturity stage reached	Corresponding initiatives of the CDC
	1	2	3	4		
Strategy and leadership			X		– Foster twin transformation implementation through the (top) management	– The department "Strategy and Sustainability" reports directly to the top management of the CDC. Thus, the topic has top management's attention. Furthermore, sustainability key performance indicators are part of the target agreements of management from top to team level.
					– Integrate investments in twin transformation innovations	– Investments in twin transformation innovations take place. The CDC invests in developing and training a large language model with the sustainability reports of the largest groups in the world (e.g., all DAX 40 companies in Germany) to be able to compare themselves and learn from the actions taken by others.
Culture and employees			X		– Establish twin transformation training for employees	– As the company is a provider of technological services for its parent company, most of the employees work in IT departments. Thus, the offered sustainability trainings have a focus on combining existing digital transformation approaches with sustainability aspects.
					– Enable new digital and self-determined work	– The company has its working group of employees that are reinforced by the management to voluntarily spend some of their weekly working hours to work on sustainable solutions for hybrid and remote working models. The CDC's senior sustainability manager himself works remotely most of the time from a different location and comes to the office at the headquarters whenever the senior sustainability manager wants to/thinks it is important.
Ecosystem and partnerships				X	– Influence legislators on twin transformation standards	– When the German Energy Efficiency Law was adopted, the company did not have to change anything to comply with the law, as they already did. Thus, the senior sustainability manager was invited to openly speak about their agreements with their data center operators to serve as a best practice example for others. [Comment by the authors: The senior sustainability manager was not able to make any comments on how their public affairs department works with legislators, which is why we are satisfied with the given example.]
Products and services				X	– Focus on cradle-to-cradle approaches	– When the company purchases hardware, the circularity ambitions of the provider are an important aspect. The company prefers recyclable products and hardware, where broken components can be exchanged. When this is not possible, they proactively give feedback so that the provider can look for circular alternatives.
					– Redesign or develop products and services as per twin transformation objectives	– The developed and trained large language model to gain valuable insights about sustainability reports is a new product that can be marketed within the holding.
Operations		X			– Establish data-based (sustainability) monitoring	– Only applicable within a restricted application field due to the lack of production facilities in the context of a service-oriented company. Therefore, the CDC's senior sustainability manager did not see it as applicable to their company.
					– Establish cross-departmental collaboration	– The department "Strategy and Sustainability" works with many different departments to gain an overview of the challenges of twin transforming by taking different perspectives. This shall make a better holistic approach possible.
Technology				X	– Exploit the sustainability potential of emerging digital technologies	– The CDC promotes the in-house use of its own chatbot generative pre-trained transformer (GPT)-interface. An exemplary use of generative artificial intelligence is the large language model already mentioned. Furthermore, they established a working group that focuses on sustainable usage opportunities of artificial intelligence.
					– Establish a cross-ecosystem data management tool facilitating twin transformation	– The CDC implements a data lake to centrally collect the ESG data of partners. With this all-encompassing cross-ecosystem data management tool in place, ESG and sustainability data analytics becomes possible and delivers valuable insights for external stakeholders such as customers or investors and internal stakeholders such as executives, managers, and strategic planners.

view of DT and ST-related capabilities and assessing their pathway to twin transformation maturity. In general, it is crucial to use existing organizational capabilities as capability development is laborious and time-consuming (Teece et al., 1997). Dynamic capabilities being important for transforming, precise guidance is required for organizations to effectively develop dynamic capabilities for twin transformation (Christmann et al., 2024). Without precise guidance, organizations may struggle to find a starting point for which capabilities to acquire. Notably, organizations begin their twin transformation from different starting points, yielding individual dynamic capabilities considering the prior knowledge of organizations.

Our first contribution is revealing the three pathways towards twin transformation maturity, which account for the varying starting points of organizations regarding their DT and ST experience and expertise. IS scholars have called for integrating sustainability aspects in DT research (e.g., Harfouche et al., 2023; Kotlarsky et al., 2023; Veit & Thatcher, 2023). Therefore we built on valuable insights from a structured literature review and 13 expert interviews, which resulted in three specific pathways to twin transformation maturity: (1) *DT experts* who make DT sustainable (e.g., Melville, 2010; Seidel et al., 2014; vom Brocke et al., 2013), (2) *ST experts* who make ST digital (e.g., Sancak, 2023; Uhrenholt et al., 2022), and (3) *twin transformation newcomers* who integrate both transformations from scratch. By understanding the pathways, organizations can leverage their dynamic capabilities in a targeted manner, taking advantage of shortcuts in the twin transformation climb.

Our second contribution is the TTCMM, providing an integrated and aligned perspective on dynamic twin transformation capabilities. By rigorously adhering to Becker et al.'s (2009) methodology, we developed six integrated capability dimensions and four maturity stages that address both digital and sustainability demands. We developed an integrated maturity model presenting 45 literature-backed sensing, seizing, or transforming capabilities (according to Steininger et al., 2022; Teece, 2007, 2014) relevant for twin transformation (see Table 8). In response to Christmann et al.'s (2024) call for further research on developing a maturity model to provide guidance for twin transformation, we analyzed existing maturity models on either DT (e.g., Gökalp & Martinez, 2021; Stahl et al., 2023), ST (e.g., Uhrenholt et al., 2022; Vásquez et al., 2021) or the intersection of both transformations (e.g., Eisner et al., 2022; Kayikci et al., 2022). Thereby, we respond to Sancak's (2023, p. 8) call for "focusing on a joint model of sustainability and digital transformation" by identifying and structuring integrated digital and sustainability dynamic capabilities. For instance, sustainability measures may narrow the usage of digital technologies (Graf-Drasch et al., 2023), which is evident in our capability dimension *technology*. This can be achieved by including DT capabilities that contribute to mastering ST successfully by, among others, creating transparency. Consequently, it is imperative to critically evaluate the sustainability performance of digital technologies. Taking the work of Vial (2019) and his eight building blocks of DT as an example, our results illustrate that a transformational response to sustainability pressures on a strategic level is required. Hence, external sustainability pressures may form a transformational starting point, i.e., ST drivers, next to digital technologies, triggering an integrated strategic organizational response calling for a twin transformation strategy. We address the digital and sustainability changes in the business model in our capability dimension *strategy and leadership*, leading to new twin transformation business models. Moreover, sustainability measures influence the usage of digital technologies, enabling changes in value-creation paths for digital and sustainable products and services. Our dimension *products and services* provides the requisite integrated capabilities. This results in our TTCMM combining ST and DT for mutual advantage, thereby paving the way for developing dynamic capabilities to build digital and sustainable organizations, namely *true twin transformers*.

6.2 Implications for Research

Our work's implications for future research are twofold: By developing, structuring, and leveraging capabilities within our TTCMM and the three pathways, (1) we motivate current DT capability research to embed sustainability aspects, while we also encourage ST research to exploit the sustainability potential of DT and (2) we extend the foundation for further interdisciplinary twin transformation research by concretizing the climb toward being a *true twin transformer*.

First, our results imply that DT and ST research should join forces to explore how organizations can master one pathway to twin transformation by leveraging the mutual advantages of DT and ST. In line with Christmann et al. (2024), the capabilities within the TTCMM reveal that DT can enable ST-related capabilities, which is evident in the capability *reconfigure relationships with partners based on the results of data analytics enhancing the sustainability of products/services*, while ST redesigns the development of DT-related capabilities, which is evident in the capability *establish the usage of sustainable internal processes and technical infrastructure (Green/Effective IT)*. This interaction between DT and ST leads organizations to develop integrated twin transformation capabilities. Compared to prior sustainability (e.g., Dyllick & Muff, 2016) and DT research (e.g., Wessel et al., 2021), we take a novel approach by

revealing three different pathways for organizations to approach DT and ST in an integrated manner as twin transformation. By realizing the postulated dynamic capabilities on their twin transformation climb, organizations can also purposefully use the effect of ST to enhance their DT. The seminal work of Wessel et al. (2021) exemplifies the distinction between DT and IT-enabled organizational transformation by explaining differences in transformational activities. Applying the effect of integrating sustainability into DT to their work, we argue that the transformational activities of a twin transformation also differ from a DT, which is justified by the unique capability development approach integrating DT and ST-related capabilities. Our results call for expanding our understanding of the transformational activities of a DT towards a twin transformation. The altered organizations' transformational activities comprise a triad of digital technologies, sustainability measures, and the value proposition. The interplay of this triad is the bottom line for the capability development process structured in our TTCMM. Further, we encourage ST research concerning capability development as we structured and expanded existing ST-related capabilities (e.g., Shang et al., 2020; Wong & Ngai, 2021; Yazici, 2020), revealing integrated twin transformation capabilities. Doing so, we extend Dyllick and Muff (2016) by structuring dynamic capabilities that show organizations how to implement ST (in the course of twin transformation) and thereby head toward true business sustainability. By realizing the postulated capabilities, organizations can purposefully use the effect of DT to yield sustainability gains. In summary, we stimulate DT and ST research to join forces further to generate positive impacts toward resilience for organizations climbing one of the twin transformation pathways.

Second, our work has implications for investigating the intersection of DT and ST. The naming of concrete dynamic twin transformation capabilities specifies the concept of digital-sustainable co-transformation, as introduced by Zimmer and Järveläinen (2022). Our capabilities consider all three dimensions of ST and thus enable organizations to see the combination of DT and ST as a strategic imperative. We, therefore, build on Zimmer and Järveläinen's (2022) introduction of the three sustainability dimensions to DT research and follow their call to study DT beyond economic values. Further, by developing the TTCMM, we contribute to 'offering a solution' rather than more explicitly describing the problem. We highlight that research can further explore ways of making ST digital, providing valuable insights. Organizations may see ST as a "must" and may not be aware that making ST digital has a high propensity to save efforts and resources. We think of twin transformation as a holistic concept with DT and ST at eye level and tie in with Christmann et al. (2024). Hence, we argue that DT and ST (initiatives) should be considered together. This does not imply that organizations are not able to run both transformations separately. Of course, DTs can be – and in fact are – mastered without STs addressing specific (non-sustainability-related) purposes, e.g., meeting customer demands triggered by non-sustainability-related drivers (Hanelt et al., 2021; Wessel et al., 2021). However, organizations' traditional DTs that do not consider the sustainability perspective are subject to high failure rates (Bonnet, 2022). At the same time, organizations are confronted with rising sustainability pressures, which influence the organizations' environment and transformation drivers, e.g., customer demands and regulations. Hence, we conclude that pursuing a holistic twin transformation is much more suitable to keep up with the challenges of ever more complex organizational environments than focusing on DT or ST initiatives in isolation. In this research endeavor, we realized that DT and ST drivers become more and more intertwined. For instance, the DT driver *consumer behavior and expectations* (Vial, 2019) increasingly includes sustainability requirements in addition to digital requirements, i.e., a digital service may also be demanded to support pro-ecological and hence sustainable behavioral patterns. Pursuing twin transformation, organizations are able to introduce an ST perspective on DT, redesigning DT with a broader purpose beyond economic considerations like cost reduction or profitability (Christmann et al., 2024). This may, in turn, increase the chances of DT success, e.g., serving as a motivator for employees to be supportive of transformational activities or providing a joint purpose to guide transformation activities. The twin transformation approach may seem more laborious at first but saves efforts along the way. If DTs and STs are done separately, pressures from the respective other transformation will lead to the need to re-evaluate what has been achieved in the DT/ST. Thus, DT will have to be made sustainable retrospectively and vice versa, which is more difficult with hindsight. In sum, we therefore argue that all types of organizations should engage in twin transformation leveraging the synergies among DT and ST and developing integrated dynamic capabilities for the twin transformation.

6.3 Implications for Practice

In addition to its implications for research, our work also impacts practice. As organizations are already coping with DT and ST for sound reasons, the use of understanding which dynamic capabilities are necessary to unite efforts and leverage synergies toward twin transformation is nearby. With the findings of this paper, we provide practitioners with a maturity model that (1) makes the process of becoming a twin transformer transparent and (2) points out possible pathways. Furthermore, the case demonstrates that

the (3) individual twin transformation is highly interrelated with ecosystems and partnerships.

First, the TTCMM fulfills diagnostic purposes, which may help management to better understand and structure their twin transformation by assessing their current status quo with the help of our six capability dimensions and four maturity stages. As managers can see how mature the organization's dynamic capabilities are, the TTCMM enables them to reflect on what stage of twin transformation maturity should be aimed for and what dynamic capabilities are typically required for twin transformation. In doing so, the dynamic capabilities in the TTCMM guide organizations to initialize twin transformations.

Second, the definition of possible pathways toward twin transformation shows that *DT* or *ST experts* do not start from scratch but can incorporate their prior single-transformation efforts. Doing so, the twin transformation does not seek to undo the progress made in separate DT and ST efforts. Instead, it is essential to acknowledge that every organization brings different prerequisites at the starting point. These achievements are valued and incorporated into each organization's pathway towards twin transformation. The three pathways help organizations to navigate through more complex transformative contexts, such as tackling two transformations (i.e., DT and ST) in one (i.e., twin transformation). Hence, the pathways to twin transformation motivate managers to see twin transformation as an opportunity to join forces and take their efforts for resilience and a future competitive advantage up a notch.

Third, the case demonstration reveals that an organization's success regarding the twin transformation depends on effective collaboration with the relevant ecosystem and strategic partnerships. To successfully master the twin transformation, an organization needs an appropriate ecosystem and committed partners. In this context, leveraging synergies, collective knowledge, resources, and expertise of the ecosystem and partnership is crucial to achieve the desired twin transformation outcomes.

6.4 Limitations and Future Research

Our work has limitations. First, when evaluating maturity models, one criterion is to check for completeness (Becker et al., 2009). During our research process, we realized that reaching completeness is impossible in our context, i.e., the first endeavor to unify DT and ST capabilities in a TTCMM for different types of organizations. Therefore, we decided to use a top-down approach to develop a staged maturity model establishing first capability-development-focused insights into the big twin transformation picture. By revealing a first set of structured integrated dynamic capabilities, we set the foundation for future interdisciplinary research. For instance, developing a continuous twin transformation maturity model, which may be adapted to constantly changing environments leading to a revised and extended set of necessary dynamic twin transformation capabilities. Second, we exemplified how our dynamic capabilities consider the economic, environmental, and social aspects of sustainability. However, the TTCMM remains deliberately abstract on which aspects of sustainability are addressed by each dynamic capability (to ensure generalizability). For instance, we did not discuss the sustainability issues that arise from the dissemination of digital technologies in detail. We encourage future research endeavors that specifically elaborate how dynamic capabilities can be developed in a way that respects the triple bottom line of sustainability and accounts for the environmental footprint of digital technologies. Third, our research is limited by the search string focusing on relevant contributions to designing maturity models in DT, ST, and twin transformation. As we chose not to integrate terms in the field of capability development, we got a broader view of approaches taken to maturity model development by existing works. Future research is invited to use the results of our research endeavor adding additional iterations to consider specific capability literature. By doing so, they may investigate specific focus area perspectives, i.e., further specifying one of the dimensions, which can add value to the foundations we created. Fourth, while conducting the 13 expert interviews as an evaluation, the observation emerged that not every organization might have the financial resources to apply the TTCMM in a way that considers all the named capabilities equally important. We used an expert sampling approach (i.e., using the authors' networks) that enabled us to gain valuable insights but was specific to one world region. Fifth, during the case demonstration with the CDC being an IT service provider, it became clear that not all dimensions are equally relevant for every organization. The dynamic capabilities of the dimension *operations* were not perfectly applicable to an organization solely offering services. We argue that every organization must best match its possibilities with the stage it desires to reach and may use the TTCMM according to its conditions. We invite future researchers to apply our maturity model to organizations in different contexts, e.g., by contrasting service providers and manufacturing companies, to check its completeness for specific applications and adapt it if necessary. Following the examples of Eisner et al. (2022) and Kıyıklık et al. (2022) in related fields, a self-assessment tool could be developed to complement the maturity model as it delivers more detailed information and explanation as decision support for organizations.

7 Conclusion

Given the increasing importance of digital and sustainability challenges for organizations and our society, we investigate the synergetic potential of the interplay of DT and ST in an organizational context, aiming for a staged maturity model. Our study guides implementing DT and ST at eye level by realizing integrated dynamic capabilities and becoming a *true twin transformer*. Organizations transform from different starting points, leveraging their existing DT- or ST-related capabilities. By knowing the advantages of different pathways to twin transformation maturity, organizations can deploy their target-oriented dynamic capabilities, benefitting from shortcuts in the twin transformation climb. Our TTCMM structures 45 dynamic capabilities and helps organizations assess their current twin transformation maturity to make progress. In four steps, we iteratively developed and evaluated the TTCMM with an empirical perspective, whereby we interviewed 13 experts from practice throughout the development process and conducted a case demonstration with an IT service provider. Our results may stimulate research and practice kickstarting twin transformation.

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