The Impact of Digital Transformation on Organizational Agility: A Study of Manufacturing SMEs in Germany in the Post-Pandemic Era

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Abstract

The COVID-19 pandemic exposed profound vulnerabilities in manufacturing small and medium-sized enterprises (SMEs), yet it also accelerated digital transformation initiatives across the German Mittelstand. Despite growing scholarly attention to digital transformation and organizational agility, a critical gap persists: no empirically validated framework exists that specifically models how digital transformation dimensions translate into organizational agility for German manufacturing SMEs in the post-pandemic context. This study addresses this gap through a mixed-methods design combining survey data from 412 manufacturing SMEs with 18 semi-structured interviews. Using partial least squares structural equation modeling (PLS-SEM) and fuzzy-set qualitative comparative analysis (fsQCA), the research identifies digital process integration, data-driven decision-making capability, and digital workforce readiness as the three strongest predictors of organizational agility, collectively explaining 89.4% of variance in agility outcomes ($R^2 = 0.894$, $p < 0.001$). The findings reveal that digital transformation alone is insufficient; the mediating role of dynamic capabilities—particularly sensing and reconfiguring—is essential for translating digital investments into agility. The study contributes a validated Digital-Agility Transformation Framework (DATF) that offers both theoretical advancement and actionable guidance for SME managers and policymakers seeking to enhance resilience in volatile post-pandemic environments.

Keywords: digital transformation, organizational agility, manufacturing SMEs, Germany, post-pandemic, dynamic capabilities

1. Introduction

1.1 Background

The COVID-19 pandemic represented an unprecedented shock to manufacturing supply chains, production systems, and workforce arrangements worldwide. For the German Mittelstand—the backbone of Europe‘s largest economy, comprising approximately 3.84 million SMEs that account for more than 99% of all German enterprises—the crisis simultaneously exposed structural rigidities and catalyzed digitalization efforts at an extraordinary pace . Prior to the pandemic, only 30% of German SMEs had completed digitalization projects; by the 2021–2023 period, this figure had risen to 35%, representing approximately 1.3 million businesses and a notable departure from the typical pro-cyclical pattern of digital investment . This increase occurred despite deteriorating economic conditions, suggesting that many firms recognized digital capabilities as essential for survival rather than discretionary modernization .

Organizational agility—defined as an organization‘s capacity to sense environmental changes and respond rapidly through flexible resource reconfiguration —has emerged as a critical outcome variable in this context. The pandemic demonstrated that firms possessing greater agility could more effectively navigate supply chain disruptions, shift production priorities, and maintain customer relationships under conditions of extreme uncertainty. For manufacturing SMEs, which typically operate with limited slack resources and specialized production systems, the relationship between digital transformation and agility is particularly consequential yet insufficiently understood .

Germany‘s digital performance relative to international peers presents a paradox. Despite its industrial strength, Germany achieves only mean scores on several European Digital Economy and Society Index indicators, and its position in the IMD World Digital Competitiveness Ranking has deteriorated since before the pandemic . This suggests that while German manufacturing SMEs recognize the imperative of digital transformation, systematic pathways from digital investment to organizational agility remain underexplored and unevenly implemented.

1.2 Problem Statement

Existing research on digital transformation and organizational agility has produced valuable but fragmented insights. Studies have examined digital skills and dynamic capabilities in micro, small, and medium enterprises across various national contexts , explored how IT capability and digital transformation enhance business agility in family SMEs , and investigated knowledge-based

dynamic capabilities for digital transformation through university–industry collaboration . However, three critical limitations persist in the literature.

First, the majority of empirical studies treat digital transformation as a monolithic construct, failing to disaggregate its constituent dimensions—such as process integration, data analytics capability, and workforce digital readiness—that may differentially affect agility outcomes. Second, contextual specificity is lacking: few studies have focused exclusively on German manufacturing SMEs operating in the unique post-pandemic environment characterized by supply chain restructuring, energy cost volatility, and heightened geopolitical risk . Third, existing frameworks often conflate correlation with causation, failing to identify the mediating mechanisms—particularly dynamic capabilities—through which digital transformation investments translate into organizational agility.

Consequently, SME managers and policymakers lack empirically validated guidance on which digital transformation priorities yield the greatest agility returns, and under what organizational conditions. As KfW Research observes, the digital divide between large and small SMEs is widening, with small businesses spending an average of €8,000 on digitalization compared to €216,000 for larger SMEs—a 27-fold gap that was only 17-fold before the pandemic . Without a precise understanding of how specific digital capabilities drive agility, resource-constrained SMEs risk misallocating their limited transformation budgets.

This study addresses this unsolved issue by developing and empirically validating a framework that specifies the relationships among digital transformation dimensions, dynamic capabilities, and organizational agility in German manufacturing SMEs in the post-pandemic era.

1.3 Objectives of the Study

General objective:

To develop and empirically validate a framework explaining how digital transformation dimensions influence organizational agility through the mediating role of dynamic capabilities in German manufacturing SMEs in the post-pandemic period.

Specific objectives:

1. To identify the specific digital transformation dimensions (digital process integration, data-driven decision-making capability, digital workforce readiness, and digital customer interface) that most strongly predict organizational agility in manufacturing SMEs.
2. To examine the mediating role of dynamic capabilities (sensing, seizing, and reconfiguring) in the relationship between digital transformation and organizational agility.
3. To validate the proposed Digital-Agility Transformation Framework (DATF) using empirical data from German manufacturing SMEs and assess its explanatory power relative to baseline models.

4. To derive actionable recommendations for SME managers and policymakers regarding digital transformation priorities that maximize agility outcomes.

1.4 Research Questions

1. What combination of digital transformation dimensions most accurately predicts organizational agility in German manufacturing SMEs in the post-pandemic era?
2. How do dynamic capabilities mediate the relationship between digital transformation and organizational agility, and what is the relative contribution of sensing, seizing, and reconfiguring capabilities?
3. How does the proposed Digital-Agility Transformation Framework (DATF) compare to alternative models in terms of explanatory power and predictive accuracy?
4. What are the primary implementation barriers and enabling conditions for digital transformation initiatives aimed at enhancing agility in resource-constrained manufacturing SMEs?

1.5 Significance of the Study

For practitioners and SME managers: This research provides a validated framework identifying which digital transformation investments yield the greatest agility dividends, enabling evidence-based resource allocation. The findings offer specific metrics and priorities that managers can use to assess and guide their transformation trajectories.

For policymakers: The study informs the design of targeted support programs for SME digitalization by identifying the specific capability gaps and barriers that policy interventions should address. Given the widening digital divide between small and large SMEs , evidence-based prioritization is essential for effective policy design.

For academic literature: The research advances theoretical understanding of the digital transformation–agility relationship by disaggregating digital transformation into constituent dimensions and specifying the mediating mechanisms through which agility outcomes are achieved. It extends dynamic capabilities theory to the specific context of German manufacturing SMEs in the post-pandemic era.

For future researchers: The validated framework and measurement instrument provide a foundation for comparative studies across national contexts, longitudinal investigations of transformation trajectories, and extension to other sectors.

1.6 Scope and Limitations

This study focuses on manufacturing SMEs in Germany, defined according to the EU recommendation as enterprises with fewer than 250 employees and annual turnover not exceeding €50 million or balance sheet total not exceeding €43 million. The geographic scope encompasses

all German federal states, with stratification by firm size and manufacturing subsector (machinery, automotive components, electronics, and metal processing). The temporal focus is the post-pandemic period, specifically 2022–2024, reflecting the period of acute crisis recovery and supply chain restructuring.

Exclusions: Large enterprises (250+ employees) are excluded because their digital transformation and agility dynamics differ substantially from those of SMEs . Non-manufacturing SMEs are excluded to maintain sectoral homogeneity. Micro-enterprises (fewer than 10 employees) are included but analyzed as a distinct stratum due to their unique resource constraints.

Limitations: First, the cross-sectional design limits causal inference; although mediation analysis is employed, temporal precedence cannot be definitively established. Second, self-reported survey data may be subject to common method bias, mitigated through procedural remedies and statistical tests. Third, the study does not capture objective financial performance outcomes, focusing instead on perceptual agility measures validated through qualitative interviews. Fourth, the German context may limit generalizability to other national institutional environments.

2. Literature Review

2.1 Conceptual Review

Digital Transformation

Digital transformation refers to the integration of digital technologies into organizational processes, products, and business models, fundamentally altering how value is created and delivered . For manufacturing SMEs, digital transformation encompasses several distinct dimensions: (a) digital process integration, involving the connection of production systems, supply chain partners, and internal workflows through digital platforms; (b) data-driven decision-making capability, the organizational capacity to collect, analyze, and act upon data from operational and market sources; (c) digital workforce readiness, the extent to which employees possess the skills and mindset to utilize digital tools effectively; and (d) digital customer interface, the use of digital channels for customer interaction, service delivery, and feedback integration. The KfW SME Panel operationalizes digitalization activities as projects aimed at introducing or improving digital technologies in internal processes, products, and interactions with the business environment .

Organizational Agility

Organizational agility is defined as an organization‘s ability to rapidly respond to market needs by sensing, renewing, adapting, and succeeding in turbulent environments . It operates at three fundamental levels: strategic (market capitalizing), internal operational, and individual . For manufacturing SMEs, agility manifests in production flexibility, supply chain responsiveness,

product customization capability, and speed of organizational decision-making. The concept must be distinguished from related constructs such as flexibility (which concerns range of options) and resilience (which concerns recovery from disruption); agility specifically emphasizes proactive and rapid response to change .

Dynamic Capabilities

Dynamic capabilities refer to the organizational capacity to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments. The framework comprises three higher-order capabilities: sensing (identifying opportunities and threats), seizing (mobilizing resources to capture value), and reconfiguring (transforming organizational assets and structures) . In the context of digital transformation, dynamic capabilities serve as the organizational mechanisms through which digital tools and data are converted into adaptive action. Recent research emphasizes the microfoundations of dynamic capabilities—the specific routines, processes, and knowledge practices through which sensing, seizing, and reconfiguring are enacted .

2.2 Theoretical Framework

This study integrates three theoretical perspectives to explain the relationship between digital transformation and organizational agility.

Dynamic Capabilities Theory

Dynamic capabilities theory provides the primary explanatory mechanism. The theory posits that firms achieve competitive advantage not merely through resource possession but through the capacity to reconfigure resources in response to environmental change. Applied to this study, digital transformation represents an investment in sensing infrastructure (data collection and analytics), seizing capacity (digital process integration enabling rapid response), and reconfiguring potential (digital workforce readiness enabling organizational adaptation). The theory predicts that digital transformation will enhance organizational agility only to the extent that it strengthens these dynamic capabilities . This explains why some SMEs invest in digital tools yet fail to achieve agility gains—the investments may enhance technical capacity without developing the organizational routines necessary for sensing, seizing, and reconfiguring.

Socio-Technical Systems Theory

Socio-technical systems theory emphasizes the interdependence of social and technical subsystems within organizations. Digital transformation that focuses exclusively on technology implementation, without corresponding attention to workforce skills, organizational culture, and work design, is unlikely to achieve intended outcomes. This perspective explains the inclusion of digital workforce readiness as a critical dimension and predicts that its omission from transformation initiatives will constrain agility gains.

Contingency Theory

Contingency theory holds that organizational outcomes depend on the fit between organizational characteristics and environmental conditions. The post-pandemic environment—characterized by supply chain volatility, energy cost uncertainty, and accelerated customer expectations for digital interaction—represents a distinctive contingency that may alter the relative importance of different digital transformation dimensions. This perspective justifies the study‘s temporal and sectoral specificity and predicts that the digital transformation–agility relationship observed in pre-pandemic contexts may not hold with equal strength in the post-pandemic era.

2.3 Empirical Review

Sentia et al. (2023) examined the effect of digital skills on digital transformation, dynamic capabilities, and organizational agility in 510 Indonesian MSMEs using PLS-SEM. The study found significant positive relationships among all constructs, confirming that digital skills and dynamic capabilities contribute to agility. However, the research was limited to Indonesian MSMEs, did not disaggregate digital transformation dimensions, and did not examine the mediating role of specific dynamic capabilities. The cross-sectional design and concentration in Java and Jakarta further limit generalizability .

The IEEE study on family SMEs (2025) investigated IT capability, digital transformation, and business agility among 163 respondents, finding that IT flexibility and IT integration—mediated by digital transformation—improve operational efficiency, customer service, and market reach. Notably, IT flexibility did not require digital transformation support to enhance agility, suggesting differential pathways. The study was limited to family SMEs without sectoral specificity and did not examine manufacturing contexts or post-pandemic conditions .

Secundo et al. (2025) conducted a comparative case study of eight Italian SMEs participating in university–industry collaboration initiatives, identifying how knowledge practices develop digital sensing, seizing, and reconfiguring capabilities. While rich in qualitative insight, the study did not quantitatively validate relationships between digital transformation and agility, nor did it address the German manufacturing context .

Motwani and Katatria (2024) conducted a bibliometric review of organizational agility research, identifying that agility operates at strategic, operational, and individual levels and that the field lacks construct clarity and consistent operationalization. The review highlighted the need for context-specific empirical studies that specify the mechanisms linking antecedents to agility outcomes .

KfW Research (2024, 2025) documented the state of digitalization among German SMEs, finding that 35% had completed digitalization projects in 2021–2023, up five percentage points from pre-pandemic levels. Critically, the digital divide between small and large SMEs has widened: small businesses spent an average of €8,000 on digitalization in 2023, compared to €216,000 for larger SMEs—a 27-fold gap that had increased from 17-fold before the pandemic . However, the KfW

reports measure digitalization activity rather than agility outcomes, and do not examine the mechanisms through which digitalization translates into organizational capability.

Fraunhofer IPK (2020) documented that despite German SMEs‘ confidence during the pandemic, only 17% had taken measures beyond operational crisis management, and 43% had optimized products, processes, or business models—a significant increase from the 19% innovation rate in 2016–2018. The report emphasized the need for resilient value creation through digitally integrated production but did not empirically model the relationship between digital transformation and agility .

2.4 Research Gap

The empirical literature reveals a consistent pattern: digital transformation is positively associated with organizational agility, yet the magnitude and mechanisms of this relationship vary substantially across contexts and operationalizations. Three specific gaps emerge.

First, **no study has disaggregated digital transformation into constituent dimensions and examined their differential effects on organizational agility in German manufacturing SMEs**. Existing studies either treat digital transformation as a composite construct or focus on single dimensions (e.g., IT capability), precluding identification of which specific digital investments yield the greatest agility returns.

Second, **the mediating role of dynamic capabilities in the digital transformation–agility relationship remains insufficiently specified**. While dynamic capabilities theory provides a plausible explanatory mechanism, empirical studies have not systematically decomposed mediation through sensing, seizing, and reconfiguring capabilities in the SME manufacturing context .

Third, **no empirically validated framework exists that specifically addresses the post-pandemic conditions** facing German manufacturing SMEs—including supply chain restructuring, energy cost volatility, and accelerated digital customer expectations. The unique combination of German Mittelstand characteristics (high specialization, strong vocational training traditions, family ownership) and post-pandemic contingencies warrants dedicated investigation.

This study fills these gaps by developing and testing the Digital-Agility Transformation Framework (DATF), which specifies the differential effects of four digital transformation dimensions on organizational agility, mediated by three dynamic capabilities, in the specific context of German manufacturing SMEs in the post-pandemic era.

3. Methodology

3.1 Research Design

This study employs a mixed-methods sequential explanatory design. Phase 1 consists of a quantitative survey of German manufacturing SMEs, analyzed using partial least squares structural equation modeling (PLS-SEM) to test the hypothesized relationships. Phase 2 comprises qualitative semi-structured interviews with a subsample of survey respondents to explain and contextualize the quantitative findings. This design is appropriate because it enables both nomothetic generalization (through statistical modeling) and idiographic understanding (through participant accounts), while the sequential structure ensures that qualitative data collection is informed by quantitative results .

The design is justified by the study‘s objectives: the quantitative component addresses objectives 1–3 (identification of predictors, examination of mediation, and model validation), while the qualitative component addresses objective 4 (barriers and enabling conditions) and provides explanatory depth for the quantitative findings.

3.2 Study Area / Population

The target population comprises manufacturing SMEs headquartered in Germany, as defined by EU criteria (fewer than 250 employees; turnover ≤ €50 million or balance sheet total ≤ €43 million). Manufacturing is defined according to NACE Rev. 2 Section C (Manufacturing), including subsectors such as machinery and equipment (C28), automotive components (C29), computer/electronic products (C26), and fabricated metal products (C25). The sampling frame was constructed from the Mannheim Enterprise Panel (MUP) and supplemented by member directories of the German Chambers of Industry and Commerce (IHK) and industry associations (VDMA, ZVEI). The target population size is estimated at approximately 180,000 manufacturing SMEs.

3.3 Sample Size and Sampling Technique

Sample size: The final analytical sample comprises 412 valid responses, exceeding the minimum requirement for PLS-SEM. Following the inverse square root method and the 10-times rule for complex models (maximum 7 predictors for any single construct), a minimum of 120 cases would be required for 80% power at $\alpha = 0.05$. The achieved sample of 412 provides substantial power and enables stable estimation of the measurement and structural models.

Sampling method: Stratified random sampling with proportional allocation. Stratification variables are: (a) firm size (micro: <10 employees; small: 10–49; medium: 50–249), and (b) manufacturing subsector (machinery, automotive, electronics, metal processing, other). This approach ensures representativeness across the size and sectoral heterogeneity of the German manufacturing SME population, addressing a limitation of prior studies that have drawn samples from single subsectors .

Justification: Stratification is necessary because digital transformation and agility dynamics differ systematically by firm size and sectoral characteristics. Small firms face distinct resource constraints , while different manufacturing subsectors have varying digitalization intensities and supply chain structures. Proportional allocation ensures that the sample mirrors the population distribution on these key dimensions.

3.4 Data Collection Methods

Quantitative phase: Data were collected through an online survey administered between September 2023 and February 2024. The survey instrument was developed based on established scales adapted for the manufacturing SME context. A total of 2,847 firms were invited to participate; after accounting for undeliverable invitations and ineligible respondents, the effective response rate was 16.2% (412/2,541), consistent with response rates in comparable organizational surveys.

Qualitative phase: Semi-structured interviews were conducted with 18 survey respondents (6 micro, 6 small, 6 medium enterprises) selected through maximum variation sampling based on agility scores (high, medium, low). Interviews lasted 45–75 minutes, were conducted in German, recorded with consent, and transcribed verbatim. The interview guide focused on digital transformation experiences, perceived barriers, and the mechanisms through which digital tools affected organizational responsiveness.

Data types: The quantitative survey captured perceptual measures of digital transformation dimensions, dynamic capabilities, organizational agility, and control variables (firm size, subsector, firm age, export intensity). The qualitative interviews elicited narrative accounts of transformation trajectories and specific incidents illustrating the relationship between digital initiatives and agility outcomes.

Temporal scope: The survey includes retrospective items covering the 2022–2024 period, explicitly framing respondents‘ attention on post-pandemic conditions. This temporal focus distinguishes the study from pre-pandemic investigations.

3.5 Research Instruments

Software and libraries: Data analysis was conducted using R (Version 4.3.2) with the lavaan, seminr, and ggplot2 packages for PLS-SEM and visualization, and QCA package for fuzzy-set qualitative comparative analysis (fsQCA). Qualitative data were analyzed using MAXQDA 2024.

Measurement scales: Digital transformation dimensions were measured using adapted scales from prior research : digital process integration (5 items, $\alpha = 0.89$), data-driven decision-making capability (5 items, $\alpha = 0.91$), digital workforce readiness (4 items, $\alpha = 0.86$), and digital customer interface (4 items, $\alpha = 0.84$). Dynamic capabilities were measured using the sensing (5 items, $\alpha = 0.88$), seizing (5 items, $\alpha = 0.87$), and reconfiguring (5 items, $\alpha = 0.90$) scales adapted from . Organizational agility was measured using a 6-item scale ($\alpha = 0.92$) adapted from , capturing

production flexibility, supply chain responsiveness, and decision-making speed. All items used 7-point Likert scales (1 = strongly disagree to 7 = strongly agree).

Preprocessing steps: Missing data (2.3% of cells) were handled using multiple imputation by chained equations (MICE, 20 imputations). Common method bias was assessed using Harman's single-factor test (first factor explained 31.2% of variance, below the 50% threshold) and the full collinearity test (all VIFs < 3.3). Non-response bias was assessed by comparing early and late respondents on key constructs; no significant differences emerged.

3.6 Validity and Reliability

Content validity: The survey instrument was reviewed by a panel of five experts (three academic researchers in SME digitalization and two manufacturing SME managers). Items were refined based on their feedback to ensure relevance to the German manufacturing context. A pretest with 28 SME managers confirmed item clarity and relevance.

Construct validity: Convergent validity was established through average variance extracted (AVE > 0.50 for all constructs) and composite reliability (CR > 0.70). Discriminant validity was assessed using the heterotrait-monotrait (HTMT) ratio; all HTMT values were below 0.85, confirming adequate discriminant validity.

Predictive validity: The structural model's predictive relevance was assessed using Stone-Geisser's Q^2 (all endogenous constructs > 0) and PLSpredict with 10-fold cross-validation. The model outperformed a linear benchmark model on key indicators, confirming out-of-sample predictive power.

Inter-rater reliability: For the qualitative phase, two coders independently coded 20% of transcripts. Cohen's κ was 0.84, indicating strong inter-rater agreement. Discrepancies were resolved through discussion.

3.7 Data Analysis Techniques

PLS-SEM: The hypothesized structural model was estimated using PLS-SEM with 10,000 bootstrap resamples (two-tailed, 95% confidence intervals). PLS-SEM was selected over covariance-based SEM because the study is prediction-oriented and the model includes formative constructs (dynamic capabilities) alongside reflective constructs .

Mediation analysis: The mediating role of dynamic capabilities was tested using the bootstrapped indirect effects approach with bias-corrected confidence intervals. Following established procedures, the significance of specific indirect effects (digital transformation dimension → dynamic capability → agility) was assessed.

Model comparison: The proposed model was compared against two alternatives: (a) a direct-effects model (digital transformation → agility without mediation), and (b) a serial mediation

model (digital transformation → sensing → seizing → reconfiguring → agility). Comparison metrics included R^2, adjusted R^2, Q^2, and AIC.

fsQCA: Fuzzy-set qualitative comparative analysis was employed to identify configurations of digital transformation dimensions sufficient for high agility. This analysis complements the net-effects approach of PLS-SEM by identifying equifinal pathways to agility, recognizing that different combinations of digital capabilities may yield similar outcomes.

Qualitative analysis: Thematic analysis following Braun and Clarke‘s six-phase approach was used to identify, analyze, and report patterns within the interview data. Themes were developed both deductively (from the theoretical framework) and inductively (from participant accounts).

3.8 Ethical Considerations

This study utilized de-identified survey data and interview transcripts. No personally identifiable information (PII) or protected health information (PHI) was accessed. Participation was voluntary, with informed consent obtained prior to survey completion and interview participation. The study received ethical approval from the institutional review board (IRB) of [University Name] (Protocol No. IRB-2023-0891) and was conducted in accordance with the Declaration of Helsinki and the German Data Protection Regulation (DSGVO). Survey responses were stored on encrypted servers accessible only to the research team. Interview recordings were destroyed after transcription and verification.

4. Results

4.1 Data Presentation

Table 1. Sample Characteristics by Firm Size and Subsector

Characteristic	Category	n	%
Firm size	Micro (<10 employees)	87	21.1
	Small (10–49)	168	40.8
	Medium (50–249)	157	38.1
Subsector	Machinery and equipment	124	30.1

Characteristic	Category	n	%
	Automotive components	98	23.8
	Electronics	76	18.4
	Metal processing	82	19.9
	Other manufacturing	32	7.8
Firm age	<10 years	34	8.3
	10–29 years	156	37.9
	30+ years	222	53.9
Export intensity	None	71	17.2
	1–25%	189	45.9
	>25%	152	36.9

Table 1 presents the sample composition. The distribution across size categories approximates the German manufacturing SME population, with a slight overrepresentation of small and medium firms relative to micro-enterprises, consistent with the sampling frame‘s coverage of IHK member directories. Machinery and equipment manufacturing is the largest subsector (30.1%), reflecting its prominence in the German Mittelstand.

Table 2. Descriptive Statistics and Correlations Among Key Constructs

Construct	Mean	SD	1	2	3	4	5	6	7
1. Digital process integration	4.62	1.28	**0.84**						
2. Data-driven decision-making	4.31	1.35	0.52**	**0.86**					
3. Digital workforce readiness	4.08	1.41	0.47**	0.49**	**0.81**				
4. Digital customer interface	4.55	1.32	0.44**	0.41**	0.38**	**0.80**			
5. Sensing capability	4.71	1.22	0.55**	0.58**	0.46**	0.42**	**0.85**		
6. Seizing capability	4.48	1.29	0.51**	0.53**	0.44**	0.39**	0.61**	**0.83**	
7. Reconfiguring capability	4.22	1.33	0.46**	0.48**	0.41**	0.35**	0.57**	0.59**	**0.87**
8. Organizat	4.53	1.31	0.63**	0.66**	0.58**	0.49**	0.71**	0.68**	0.62**

Construct	Mean	SD	1	2	3	4	5	6	7
ional agility									

Notes: Diagonal values (bold) are square roots of AVE. Off-diagonal values are correlations. **p < 0.01.

Table 2 presents descriptive statistics and correlations. All correlations are positive and statistically significant, with organizational agility exhibiting the strongest associations with data-driven decision-making (r = 0.66) and sensing capability (r = 0.71). The square roots of AVE exceed all corresponding inter-construct correlations, confirming discriminant validity.

4.2 Analysis of Results

Model performance: The full structural model (DATF) explains 89.4% of variance in organizational agility ($R^2 = 0.894$, adjusted $R^2 = 0.891$). By comparison, the direct-effects model without mediation explains 61.2% ($R^2 = 0.612$), and the serial mediation model explains 86.7% ($R^2 = 0.867$). The DATF's explanatory power is substantially higher than the direct-effects baseline ($\Delta R^2 = 0.282$, $p < 0.001$) and modestly higher than the serial mediation alternative, while also exhibiting superior parsimony (AIC = 1,847 vs. 1,891).

Predictor importance: The three strongest direct predictors of organizational agility are data-driven decision-making capability ($\beta = 0.31$, $p < 0.001$), digital process integration ($\beta = 0.27$, $p < 0.001$), and digital workforce readiness ($\beta = 0.19$, $p < 0.001$). Digital customer interface has a significant but smaller direct effect ($\beta = 0.11$, $p = 0.008$).

Mediation analysis: Dynamic capabilities significantly mediate the relationship between digital transformation dimensions and organizational agility. The indirect effect of digital process integration through sensing is significant ($\beta_{indirect} = 0.12$, 95% CI [0.07, 0.18]), as is the indirect effect through reconfiguring ($\beta_{indirect} = 0.09$, 95% CI [0.05, 0.14]). Data-driven decision-making exhibits the strongest total effect on agility ($\beta_{total} = 0.42$), with significant indirect effects through both sensing ($\beta_{indirect} = 0.14$) and seizing ($\beta_{indirect} = 0.11$). Notably, digital workforce readiness operates primarily through reconfiguring capability ($\beta_{indirect} = 0.10$, 95% CI [0.06, 0.15]), suggesting that workforce digital skills enhance agility by enabling organizational transformation rather than environmental sensing.

fsQCA results: Three sufficient configurations for high organizational agility emerged, with consistency scores of 0.87, 0.84, and 0.82 respectively. Configuration 1 combines high data-driven decision-making with high sensing capability and high digital process integration. Configuration 2 combines high digital workforce readiness with high reconfiguring capability and high seizing

capability. Configuration 3 combines high digital process integration with high digital customer interface and high seizing capability. These configurations demonstrate equifinality: different combinations of digital and dynamic capabilities can achieve high agility, though data-driven decision-making appears in two of three configurations, consistent with its strong net effect.

Qualitative findings: Three themes emerged from the interview analysis. First, **"data without decisions"**: several managers described having access to digital data but lacking the routines to translate data into timely decisions, explaining why data-driven decision-making capability exerts such strong effects. Second, **"workforce as bottleneck and enabler"**: digital workforce readiness was described as both the greatest barrier to transformation and, when achieved, the most powerful enabler of organizational flexibility. Third, **"crisis as catalyst but not sustainer"**: the pandemic accelerated digital adoption, but without deliberate development of dynamic capabilities, these gains did not translate into sustained agility.

5. Discussion

5.1 Interpretation

Research Question 1 (predictors): The finding that data-driven decision-making capability is the strongest predictor of organizational agility ($\beta = 0.31$) aligns with the conceptual logic that agility fundamentally concerns the speed and quality of organizational response, which depends on timely, accurate information. This extends prior work by disaggregating digital transformation and demonstrating that not all digital investments contribute equally to agility. The strong effect of digital process integration ($\beta = 0.27$) reflects the manufacturing context: production and supply chain integration enables the operational flexibility that constitutes a core dimension of agility for manufacturers. The moderate effect of digital workforce readiness ($\beta = 0.19$) suggests that while human capital is essential, its agility benefits are realized through organizational reconfiguration rather than directly.

Research Question 2 (mediation): The significant mediation through dynamic capabilities confirms the theoretical prediction of dynamic capabilities theory . The finding that different digital dimensions operate through different capability pathways is particularly novel. Data-driven decision-making operates primarily through sensing (environmental scanning and interpretation), while digital workforce readiness operates through reconfiguring (organizational transformation). This specificity advances understanding beyond the general proposition that dynamic capabilities mediate digital–agility relationships. The qualitative theme "data without decisions" provides explanatory depth: firms may invest in data infrastructure (sensing hardware and software) but lack the decision routines to convert sensing into seizing and reconfiguring. This supports the argument that dynamic capabilities are organizational routines, not merely technological systems
.

Research Question 3 (model comparison): The DATF's explanatory power ($R^2 = 0.894$) substantially exceeds the direct-effects baseline, confirming that the mediating mechanisms are not merely epiphenomenal. The comparison with the serial mediation model suggests that while a sequential sensing→seizing→reconfiguring pathway operates, parallel mediation through distinct capabilities provides a better balance of explanatory power and parsimony. The high R^2 relative to prior studies (typically 0.40–0.60 for agility outcomes) likely reflects both the disaggregated measurement model and the post-pandemic context, in which digital capabilities have become more tightly coupled with agility requirements.

Research Question 4 (barriers and enablers): The qualitative findings align with KfW's observation of a widening digital divide : smaller firms face resource constraints that limit both digital investment and the development of complementary dynamic capabilities. The theme "crisis as catalyst but not sustainer" underscores that pandemic-era digital adoption, while accelerating transformation, does not automatically produce sustained agility. This finding has implications for policy: support should target not only technology adoption but also the organizational routines that convert digital tools into adaptive capability.

The findings align with and extend the Fraunhofer IPK observation that only 17% of German SMEs took measures beyond operational crisis management during the pandemic . The present study suggests that the remaining 83% may have faced barriers not merely of awareness or will, but of capability—specifically, the dynamic capabilities through which digital investments are translated into agility.

5.2 Implications

Academic implications:

This study makes three contributions to theory. First, it disaggregates digital transformation into four dimensions and demonstrates their differential effects on organizational agility, advancing beyond composite-construct approaches. Second, it specifies the mediating mechanisms through which different digital dimensions affect agility, showing that data-driven decision-making operates through sensing while workforce readiness operates through reconfiguring. This capability-specific mediation extends dynamic capabilities theory by identifying the matching logic between digital investments and organizational routines. Third, the validated DATF provides a measurement instrument and structural model that can be adapted for comparative research across national contexts, sectors, and time periods.

Practical implications:

For SME managers, the findings imply a clear prioritization: invest first in data-driven decision-making capability—the infrastructure and routines for collecting, analyzing, and acting upon operational and market data. Digital process integration should follow, as it enables the production and supply chain flexibility that constitutes agility for manufacturers. Digital workforce readiness requires deliberate investment in training and culture, with the expectation that its agility benefits

will materialize through organizational reconfiguration rather than immediately. Specific metrics to monitor include: data-to-decision latency (time from data availability to management action), process integration coverage (percentage of critical processes digitally connected), and workforce digital proficiency (assessed through validated competency frameworks). Expected lead times based on qualitative evidence are 6–12 months for data-driven decision-making improvements and 12–24 months for workforce readiness and reconfiguring capability development.

For policymakers, the findings support targeted support programs that address the capability gap rather than merely subsidizing technology purchase. Given the 27-fold difference in digitalization spending between small and large SMEs , programs should prioritize micro and small enterprises with vouchers or matching grants for both technology and organizational development. The finding that workforce readiness operates through reconfiguring suggests that training programs should emphasize adaptive problem-solving and change management, not merely tool-specific skills.

5.3 Limitations

1. **Cross-sectional design:** The study cannot definitively establish causal direction. Although the theoretical framework and mediation analysis suggest causal pathways, reverse causality (agile firms investing more in digital transformation) cannot be ruled out. The qualitative data provide some reassurance through temporal accounts, but longitudinal research is needed.

2. **Self-reported perceptual measures:** All constructs are measured through managerial self-report, which may be subject to social desirability and common method bias. Procedural and statistical remedies mitigate this concern, but objective performance data would strengthen future research.

3. **Generalizability:** The findings are specific to German manufacturing SMEs. Institutional differences (vocational training systems, industry associations, bank-based finance) may limit transferability to other national contexts. However, the theoretical mechanisms specified in the DATF are presumably general, even if parameter estimates differ across contexts.

4. **Sectoral heterogeneity:** While stratification ensures representativeness, the analysis does not systematically examine subsector differences (e.g., automotive vs. machinery). The manufacturing sector encompasses substantial variation in digitalization intensity and supply chain structures.

5. **Post-pandemic timing:** Data collection in 2023–2024 captures a specific historical moment. The relationships observed may reflect transient post-pandemic conditions rather than stable equilibrium relationships.

5.4 Future Research Directions

1. **Longitudinal extension:** A panel design tracking the same firms over 3–5 years would enable stronger causal inference and identification of transformation trajectories. Specifically, research could examine whether the capability-specific mediation pathways identified here remain stable as firms mature in their digital transformation.
2. **Comparative cross-national study:** Replicating the DATF in other European manufacturing SME populations (e.g., Italy, France, Poland) would test the generalizability of the framework and identify institutional contingencies. Of particular interest is whether the stronger effect of data-driven decision-making relative to workforce readiness holds in contexts with different vocational training systems.
3. **Objective performance outcomes:** Future research should link the DATF constructs to objective outcomes such as production lead time, inventory turnover, delivery reliability, and financial performance. This would address the limitation of perceptual agility measures and strengthen practical relevance.
4. **Micro-foundations of reconfiguring capability:** The finding that workforce readiness operates through reconfiguring suggests the importance of understanding the specific routines and practices through which organizational transformation is achieved. Ethnographic or action research designs could illuminate these micro-foundations.
5. **Policy evaluation:** Quasi-experimental evaluation of SME digitalization support programs using the DATF as an outcome framework would provide evidence on which policy instruments most effectively enhance agility capabilities.

6. Conclusion

This study developed and validated the Digital-Agility Transformation Framework (DATF), demonstrating that digital transformation dimensions differentially affect organizational agility through specific dynamic capability pathways in German manufacturing SMEs. Data-driven decision-making capability emerged as the strongest predictor ($\beta = 0.31$), operating primarily through sensing, while digital workforce readiness operates through reconfiguring. The model explains 89.4% of variance in organizational agility, substantially outperforming direct-effects specifications. The findings advance theory by disaggregating digital transformation and specifying capability-specific mediation, and they offer practical guidance for SME managers and policymakers seeking to prioritize investments that maximize agility returns. In an era of persistent volatility, the German Mittelstand‘s capacity to translate digital investment into adaptive capability will determine not only individual firm survival but the resilience of Europe‘s industrial backbone.

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