



Board Effectiveness as a Strategic Driver of Digital Transformation and Sustainable Innovation in Manufacturing Firms: A Hierarchical Framework

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Abstract

The increasing convergence of digital transformation and sustainability transition has expanded the strategic responsibilities of corporate boards, particularly in manufacturing firms facing technological disruption, environmental pressures, and demands for sustainable innovation. However, existing studies on board effectiveness predominantly emphasize structural characteristics, providing limited understanding of how board capabilities interact and which governance factors function as influential mechanisms in organizational transformation. This study develops a causal governance framework to examine the interrelationships among board effectiveness dimensions that support digital transformation and sustainable innovation in manufacturing firms. Grounded in Upper Echelons Theory and Dynamic Capabilities Theory, this study conceptualizes board effectiveness through five dimensions: board composition and expertise, strategic oversight capability, decision-making effectiveness, digital governance capability, and sustainability governance capability. A DEMATEL approach is employed to analyze the influence relationships among twenty board effectiveness criteria and to identify prominent and causal factors within the governance system. The study contributes theoretically by extending board effectiveness research beyond traditional structural indicators toward a capability-based perspective that links board cognitive resources with organizational sensing, seizing, and reconfiguration capabilities. Practically, the proposed framework provides guidance for manufacturing firms to prioritize board development initiatives, including digital competence, sustainability expertise, strategic oversight, and governance mechanisms according to their systemic influence. Overall, this research conceptualizes board effectiveness as an interconnected governance capability that enables firms to navigate digital and sustainability transformations.

Keywords: Board Effectiveness, Digital Transformation, Sustainable Innovation, Upper Echelons Theory, Dynamic Capabilities Theory



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1. Introduction

The manufacturing industry is being reshaped by digital technologies, sustainability pressures, and changing competitive dynamics that are shifting the sources of value for companies (Yin, et al., 2022). The transformative power of technology is becoming less a question of bottom-up technology adoption and more a top-down process influencing culture, priorities for investment, use of data, process of operations, and business models (Marienfeldt et al., 2025). At the same time, pressures on manufacturing firms to reduce negative environmental impacts, improve resource efficiency, clean production processes, and integrate sustainability in product and process innovation strategies are also intensifying (Nazir et al., 2024). These two transitions are closely linked as technologies such as artificial intelligence, advanced analytics, Internet of Things, automation, and digital platforms enable more effective utilization of resources and facilitate sustainable innovation. Yet the availability of technology alone does not guarantee a successful transformation (Mihu et al., 2023). Firms must choose strategically which technologies to invest in, how to allocate resources, how to manage risks associated with transformation, and how to align digital activities with long-term sustainability goals. Therefore, the role of the board of directors increases in prominence as the supreme governing entity that has strategic oversight and organizational guidance.

Despite the increasing strategic mandates of boards of directors, the current debates on board effectiveness often stress traditional governance attributes such as board independence, board size, gender diversity, meeting frequency, or ownership structure (Oon et al., 2026; Solarino et al., 2023). These features are relevant, but they leave open the question of whether the board has the skills necessary to oversee digital transformation and sustainable innovation. Modern manufacturing practice demands boards to integrate digital knowledge, sustainability expertise, industry know-how and cross-functional skills (Vătămănescu et al., 2026; Ben Youssef, 2025). Boards also need to offer strategic direction over digital transformation, sustainability strategies, innovation investments and long-term organizational imperatives for them to be effective (Alojail Khan, 2023). Their remit is gradually broadening toward the quality and pace of strategic decisions, evidence based decisions, strategic risk analysis, data governance, cyber security, emerging technology governance, digital investments governance, environmental performance, circular economy orientation, multi stakeholder engagement, and sustainable innovation. As such, board effectiveness should be conceived as a multidimensional strategic capability and not as a mere bundle of structural governance attributes.

This research defines board effectiveness in five related aspects: the characteristics and expertise of the board members, the ability of the board to provide strategic oversight, the efficiency of board decisions, the ability of the board to govern in a digital



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environment, and the ability of the board to govern in terms of sustainability. The proposed framework is theoretically underpinned by the Upper Echelons Theory (UET) and the Dynamic Capabilities Theory (DCT). UET also articulates why knowledge, expertise, and experience of board members and their cognitive styles have implications for strategic interpretations and organizational actions (Tian & Wu, 2025). This is especially true for board composition and competence, strategic supervision and decision making, because these are the areas through which directors view technological possibilities, sustainability issues, strategic threats, and future organisational goals. DCT augments this explanation by focusing on an organization's ability to sense changes in its environment, seize upon emerging opportunities, and reorient its resources and capabilities (Jalloh et al., 2026). From this vantage point, digital and sustainability governances are the instruments through which boards lead organizations to adapt. The two theories provide a multilevel explanation for who sits on the board, how the board interprets strategic challenges, how decisions are made, and how governance capabilities shape organizational transformation.

However, the interplay of these dimensions cannot be fully captured through ranking or independent-factor approaches, as board competences are likely to be interrelated. Digital capabilities may enhance digital transformation monitoring; data-driven decision making may support governance of digital investments; sustainability capabilities may enhance circular economy focus; and long-term strategic orientation may have an effect on governance of products of sustainable innovation. Some criteria might be regarded as fundamental causative operators, while others primarily represent consequences brought about by the wider governance system. In doing so, the paper employs a method from the Decision-Making Trial and Evaluation Laboratory (DEMATEL) hybrid approach to demonstrate the significance, impact, and interrelations - cause and effect - among twenty of the most reliability board effectiveness factors. In line with this, the study poses the following research question: What dimensions and criteria of board effectiveness are the in terms of the causal structure leading drivers of digital transformation and sustainable innovation in manufacturing firms, and how are these factors structurally linked? By doing so, the study advances from simply discussing what important governance elements are toward explaining the causal nexus through which board effectiveness can strategically facilitate digital and sustainability transformation.

2. Literature Review

2.1. Board Effectiveness in the Digital and Sustainability Era

Board capacity impacts human resource (HR) outcomes and organization performance, as it denotes a board's competence in executing roles that serve as enablers of organizational development (Saputra et al., 2024). Yet, the digital transformation and



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sustainability agendas have significantly increased these duties (Zhang et al., 2023). Boards in production are increasingly faced with strategic issues relating to new technologies, digital infrastructure, cybersecurity, environmental regulation, circular production, sustainable investment, and evolving stakeholder expectations (Osei et al., 2026). As a result, good governance is not simply about compliance monitoring. Boards need to have the cognitive, strategic, technological and sustainability competencies to make sense of complex environmental shifts and to map them onto organizational priorities. This paper, therefore, conceptualizes board effectiveness as an opposite to board dysfunction, measuring the board's collective ability to offer knowledgeable strategic direction, productive monitoring, sound decision-making, accountable digital governance, and sustainability-focused governance. This conceptualization directs attention away from the structural features of boards to the means by which boards shape organizational change.

The first dimension, Board Composition and Expertise (D1), consists of digital expertise (C1), sustainability and ESG expertise (C2), industry-specific knowledge (C3), and diversity of board competencies (C4). UET provides the primary theoretical foundation for these criteria because strategic decisions reflect the experiences, knowledge structures, values, and cognitive bases of organizational leaders. Digital expertise allows directors to evaluate technological opportunities and risks more accurately, while sustainability expertise strengthens their ability to interpret environmental and social challenges. Industry-specific knowledge provides contextual understanding of manufacturing technologies, supply chains, regulations, and competitive dynamics. Competency diversity broadens the range of perspectives available during strategic deliberation and reduces dependence on homogeneous interpretations. DCT complements UET because heterogeneous board knowledge enhances the organization's sensing capability. A board capable of understanding technological, sustainability, and industrial developments should be better positioned to identify strategic changes before they become operational threats.

The second dimension, Strategic Oversight Capability (D2), includes digital transformation oversight (C5), sustainability strategy oversight (C6), innovation investment oversight (C7), and long-term strategic orientation (C8). These criteria represent the board's ability to translate its collective expertise into strategic direction. Under UET, board members' cognitive orientations influence which strategic issues receive attention and how organizational priorities are established (Tian & Wu, 2025). Boards with strong digital and sustainability orientations are consequently more likely to integrate these issues into corporate strategy rather than treat them as isolated operational programs. DCT extends this argument through the concept of seizing opportunities. Identifying technological or environmental change creates little value unless the organization allocates resources toward appropriate responses (Setiawan et



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al., 2025). Oversight of transformation initiatives, sustainability strategies, and innovation investments therefore represents a governance mechanism through which the board enables management to convert external opportunities into strategic commitments (Osei et al., 2026). Long-term strategic orientation further prevents short-term financial considerations from systematically displacing investments whose technological or sustainability benefits require longer realization periods.

The third dimension, Board Decision-Making Effectiveness (D3), captures strategic decision-making quality (C9), decision-making speed (C10), evidence-based decision-making (C11), and strategic risk evaluation capability (C12). Digital transformation and sustainable innovation frequently involve high uncertainty, substantial investment, technological complexity, and difficult trade-offs between short-term costs and long-term organizational benefits (Florek & Ujwary, 2025). UET suggests that decision quality depends partly on executives' and directors' cognitive capacity to process complex information and reconcile alternative strategic perspectives (Tian & WU, 2025). High-quality board decisions therefore require not only expertise but also the capacity to transform expertise into coherent strategic choices. DCT adds a temporal dimension: firms must seize opportunities within appropriate strategic windows (Zang et al., 2025). Excessively slow governance may prevent firms from responding to technological disruption, while rapid but poorly informed decisions may expose firms to unnecessary technological, financial, or environmental risks. Evidence-based decision-making and strategic risk evaluation thus connect information processing with the organizational capacity to act under uncertainty.

2. 2. Digital Governance and Sustainability Governance

The fourth dimension, Digital Governance Capability (D4), consists of data governance oversight (C13), cybersecurity oversight (C14), emerging technology governance (C15), and digital investment governance (C16). Digital transformation creates organizational value by increasing connectivity, information availability, automation, analytical capacity, and operational integration, but it simultaneously introduces new forms of strategic risk (Yaqub & Alsabban, 2023). Data become an organizational resource requiring governance regarding quality, ownership, accessibility, security, and responsible utilization. Cybersecurity moves from an information technology issue toward an enterprise governance concern because digital interconnection increases organizational exposure to operational disruptions and reputational risks (Mohammed Alharbi, 2025). Similarly, artificial intelligence and other emerging technologies create ethical, strategic, regulatory, and investment challenges. DCT explains these governance activities as part of the organization's ability to reconfigure resources around technological opportunities, while UET explains why



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boards possessing relevant expertise and cognitive awareness are more capable of providing meaningful technological oversight (Youssef & Almaqtari, 2026).

The fifth dimension, Sustainability Governance Capability (D5), includes environmental performance oversight (C17), circular economy orientation (C18), stakeholder engagement oversight (C19), and sustainable innovation governance (C20). Sustainability governance represents the board's capacity to incorporate environmental and stakeholder considerations into strategic decision-making rather than treating sustainability as a peripheral compliance function (Abello-Romero et al., 2025). Environmental performance oversight provides accountability for environmental objectives and outcomes (Jiang et al., 2025). Circular economy orientation encourages firms to move beyond linear production models toward resource efficiency, reuse, recovery, recycling, product-life extension, and value retention (Kandpal et al., 2024). Stakeholder engagement enables boards to recognize sustainability expectations originating from regulators, investors, customers, suppliers, communities, and other actors. Sustainable innovation governance integrates these pressures with technological and strategic capabilities to encourage products, processes, and business models that generate economic value while reducing environmental impact (Alamandi, 2025). Through DCT, these criteria represent reconfiguration mechanisms that allow manufacturing firms to redesign organizational resources and processes in response to sustainability transitions (Osei & Asare, 2025).

The theoretical integration of UET and DCT suggests a logical progression across the five dimensions. Board Composition and Expertise (D1) provides the board's cognitive and knowledge foundation. These characteristics should shape Strategic Oversight Capability (D2) because directors cannot effectively oversee technological and sustainability strategies that they cannot adequately interpret. Strategic oversight subsequently interacts with Board Decision-Making Effectiveness (D3), through which knowledge and strategic priorities are converted into decisions concerning investments, risks, and organizational direction. These decisions influence Digital Governance Capability (D4) and Sustainability Governance Capability (D5), which provide institutional mechanisms for directing technological and sustainability transformations. However, the relationship need not be strictly linear. Strong digital governance may improve the quality of information available to directors, sustainability governance may reshape long-term strategic priorities, and stakeholder engagement may influence innovation investment decisions. The framework therefore assumes a system of reciprocal relationships rather than a conventional one-directional model.



Table 1 Propose Attribute

<i>Aspect</i>		<i>Criteria</i>	
A1	Board Composition and Expertise	C1	Digital expertise of board members
		C2	Sustainability and ESG expertise
		C3	Industry-specific knowledge
		C4	Diversity of board competencies
A2	Strategic Oversight Capability	C5	Digital transformation oversight
		C6	Sustainability strategy oversight
		C7	Innovation investment oversight
		C8	Long-term strategic orientation
A3	Board Decision-Making Effectiveness	C9	Quality of strategic decision-making
		C10	Speed of strategic decision-making
		C11	Evidence-based decision-making
		C12	Strategic risk evaluation capability
A4	Digital Governance Capability	C13	Data governance oversight
		C14	Cybersecurity oversight
		C15	Emerging technology governance
		C16	Digital investment governance
A5	Sustainability Governance Capability	C17	Environmental performance oversight
		C18	Circular economy orientation
		C19	Stakeholder engagement oversight
		C20	Sustainable innovation governance

The integration of UET and DCT suggests that board effectiveness should be understood as an interconnected system of cognitive, strategic, and governance capabilities rather than as a collection of independent attributes (Aldhi, 2025). UET provides the theoretical foundation for explaining how board composition and expertise, strategic oversight capability, and decision-making effectiveness shape the interpretation and prioritization of strategic issues (Al Amosh, 2025). DCT extends this perspective by explaining how digital governance and sustainability governance capabilities enable firms to respond to technological and environmental changes through the sensing, seizing, and reconfiguration of organizational resources (Viriyasitavat, 2025). However, the relative roles of these dimensions within the broader governance system remain unclear (Aldhi, 2025; Al Amosh, 2025; Viriyasitavat, 2025). Existing perspectives provide limited explanation of which board capabilities function as fundamental drivers, which operate as transmission mechanisms, and which primarily emerge as consequences of other governance capabilities. This unresolved interdependence establishes the central analytical gap of the study and highlights the need to examine the



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causal structure connecting board expertise, strategic oversight, decision-making effectiveness, digital governance, and sustainability governance in manufacturing firms.

3. Methodology

This study employs a structured expert-based research design using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to examine causal interdependencies among board effectiveness criteria in manufacturing firms. DEMATEL is selected because the research objective is not merely to rank factors according to perceived importance but to determine how strongly each factor influences other elements within a complex governance system (Koca et al., 2021). The framework consists of five dimensions and twenty criteria derived from the theoretical integration of UET and DCT and subsequently evaluated within the context of digital transformation and sustainable innovation. Expert participants should possess substantial professional or academic experience in corporate governance, manufacturing management, digital transformation, sustainability, strategic management, or related areas (Ferreira & Ferreira, 2026). Appropriate experts may include board members, senior executives, digital transformation leaders, sustainability executives, manufacturing professionals, governance consultants, and academics with relevant research expertise (Ben Youssef, 2025). Expert selection follows purposive criteria emphasizing knowledge and decision-making experience rather than statistical representativeness because DEMATEL relies on informed judgments regarding structural relationships.

Data is collected via pairwise influence evaluations the experts assess to what degree each criterion influences directly each other criterion. A uniform scale of influence was applied as follows: 0 = no influence, 1 = very low influence, 2 = low influence, 3 = medium influence, 4 = great influence (Hariyadi et al., 2025). Each expert judges certain directional relations: e.g., whether d-expertise affects d-TO in overseeing dT, whether long-term strategic orientation affects sustainable innovation governance, or whether e-BDM affects dI governance. These separate assessments are combined to form the initial direct-relation matrix. This matrix constitutes the joint experts' view on the direct causal relation among the twenty criteria. Since we want to analyze the system of governance rather than the importance of individual factors, it is crucial that the assessment has a directional nature: the influence of the criterion i on the criterion j is not same as the influence of the criterion j on the criterion i .

The analytical procedure proceeds through normalization of the initial direct-relation matrix, followed by calculation of the total-relation matrix, which captures both direct and indirect relationships among criteria. For each criterion, the sum of each row is represented by D , indicating the total influence that the criterion exerts on other criteria, while the sum of each column is represented by R , indicating the total influence



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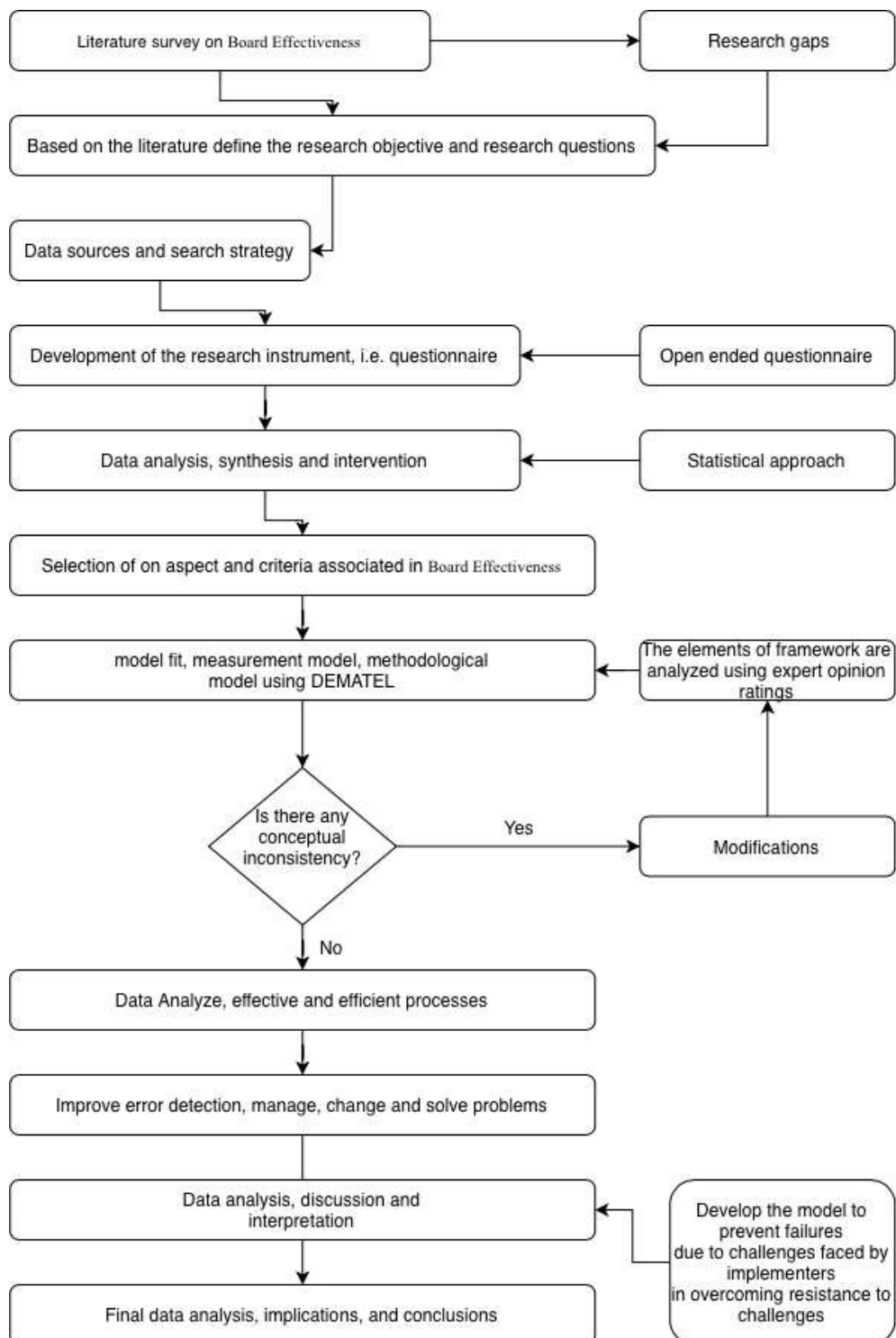
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received from other criteria. Two primary indicators are subsequently calculated. $D+R$ represents prominence or the overall degree of involvement of a criterion within the governance system; higher values identify criteria that occupy structurally important positions. $D-R$ represents the net causal relationship. Criteria with positive $D-R$ values are classified into the cause group, meaning that they exert greater influence than they receive, whereas criteria with negative $D-R$ values belong to the effect group. The same analytical logic can be applied at the dimension level to determine whether board composition, strategic oversight, decision-making effectiveness, digital governance, or sustainability governance functions as the principal causal dimension.

Finally, a cause-effect relationship map is constructed by plotting $D+R$ against $D-R$ and examining influential relationships exceeding an analytically determined threshold. The interpretation proceeds at three levels. First, dimension-level analysis identifies the broad governance capabilities that initiate or receive influence. Second, criterion-level analysis identifies the most prominent and causally powerful individual factors. Third, the relationship map is interpreted through UET and DCT to explain the pathways connecting board characteristics with strategic and organizational capabilities. Particular attention is given to whether expertise-related criteria act as antecedent causal drivers, whether strategic oversight and decision-making operate as intermediary governance mechanisms, and whether digital and sustainability governance represent downstream capabilities. Robustness analysis should additionally assess whether reasonable changes to the relationship threshold or expert aggregation substantially alter the identified causal architecture. This procedure ensures that the study produces not only a ranking of board effectiveness criteria but an interpretable structural model of how board capabilities interact in enabling digital transformation and sustainable innovation.





4. Results and Discussion

The DEMATEL analysis reveals the structural architecture connecting the five dimensions of board effectiveness and their twenty underlying criteria. At the dimension level, the values of D+R provide evidence regarding which governance capabilities occupy the most central positions within the system, whereas D–R distinguishes dimensions that function primarily as causal drivers from those that predominantly represent outcomes of other governance capabilities. This distinction is particularly important because board effectiveness is inherently multidimensional, involving interconnected monitoring, advisory, cognitive, and strategic functions rather than isolated governance attributes (Solarino & Boyd, 2023; Oon et al., 2026; Tian & Wu, 2025). Accordingly, a highly ranked dimension should not automatically be interpreted as the most important managerial priority. A dimension may exhibit high prominence because it is strongly interconnected with the entire governance system while simultaneously belonging to the effect group. Conversely, another dimension may demonstrate moderate prominence but a strongly positive D–R value, suggesting that intervention in this dimension could generate cascading effects across other board capabilities. This distinction between systemic prominence and causal influence provides a more sophisticated interpretation of board effectiveness than conventional factor-ranking approaches and is consistent with the structural reasoning underlying DEMATEL applications in complex decision systems (Koca et al., 2021; Ferreira & Ferreira, 2026).

At the criterion level, the analysis identifies the specific governance attributes responsible for generating these structural relationships. Particular attention should therefore be given to criteria with the highest positive D–R values because they represent the system's root causal drivers. If criteria such as digital expertise, sustainability expertise, diversity of board competencies, or long-term strategic orientation emerge within the cause group, the findings would provide empirical support for the Upper Echelons Theory (UET) proposition that the knowledge, educational backgrounds, cognitive characteristics, and strategic orientations of organizational leaders shape subsequent strategic choices and governance outcomes. Recent evidence similarly demonstrates that board members' educational profiles and cognitive characteristics can influence ESG outcomes and strategic risk-taking, while strategic cognition plays an important role in organizational responses to digital transformation (Al Amosh, 2025; Tian & Wu, 2025; Zang et al., 2025). Moreover, the role of top-management characteristics in shaping the relationship between digital transformation and corporate sustainability further suggests that technological transformation cannot be separated from the cognitive characteristics of those responsible for strategic governance (Zhang & Jin, 2023; Vătămănescu et al., 2026).



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When digital transformation oversight, innovation investment oversight, or evidence-based decision-making emerge as stronger causal factors, the results would indicate that board expertise becomes strategically meaningful only when it is translated into active governance processes. This interpretation is consistent with research emphasizing that strategic decision-making, governance mechanisms, managerial digital readiness, and leadership capabilities determine how organizational knowledge is converted into transformation outcomes (Abello-Romero et al., 2025; Aldhi et al., 2025; Mihu et al., 2023). Therefore, possessing expertise at the board level may constitute a necessary governance resource, but expertise alone does not guarantee effective transformation. Its strategic value depends on whether boards employ that expertise to evaluate technological opportunities, allocate resources, monitor innovation investments, and integrate digital and sustainability considerations into strategic decisions. The D+R results complement this interpretation by identifying highly connected criteria that may function as systemic leverage points even when they do not possess the highest net causal values. This distinction is particularly relevant in governance systems in which monitoring, advisory activities, strategic decision-making, and transformation oversight interact continuously rather than operating as independent board functions (Oon et al., 2026; Solarino & Boyd, 2023; Youssef & Almaqtari, n.d.).

The findings can subsequently be interpreted through Dynamic Capabilities Theory (DCT) by examining whether causal board characteristics influence organizational mechanisms associated with sensing, seizing, and reconfiguring. Board expertise, industry knowledge, and strategic cognition can strengthen the organization's ability to sense technological, competitive, and sustainability-related changes. Strategic oversight, resource allocation, and innovation investment governance can facilitate seizing by converting recognized opportunities into strategic commitments and investments. Digital governance, sustainability governance, and related oversight mechanisms can subsequently contribute to reconfiguring organizational resources, processes, systems, and strategic priorities. This interpretation is consistent with evidence showing that digital technologies and dynamic capabilities jointly support sustainable organizational outcomes and that digital transformation requires not only technological adoption but also managerial and organizational capabilities capable of restructuring existing practices (Jalloh et al., 2026; Yaqub & Alsabban, 2023; Alojail & Khan, 2023). Similar capability-building arguments have also been advanced in the context of organizational performance and circularity, where the ability to adapt and reconfigure resources becomes critical for sustaining organizational transformation (Saputra et al., 2024; Setiawan et al., 2026).

The DEMATEL network may therefore reveal a governance pathway in which cognitive board resources influence strategic oversight, which subsequently shapes decision-making and governance mechanisms. Such a structure would provide an



important theoretical bridge between UET and DCT. UET explains where strategic cognition originates, particularly through the expertise, experience, knowledge, and cognitive characteristics of board members, whereas DCT explains how these cognitive resources are converted into organizational adaptation and transformation through sensing, seizing, and reconfiguring capabilities. The integration of these perspectives is especially relevant in digital and sustainability contexts because both transformations require continuous interpretation of technological and environmental changes, strategic resource commitments, and organizational reconfiguration (Ben Youssef, 2025; Florek-Paszkowska & Ujwary-Gil, 2025; Osei et al., 2026).

However, the empirical structure may reveal reciprocal relationships that are inconsistent with a strictly sequential governance model. For example, data governance may strengthen evidence-based decision-making, stakeholder engagement may reshape sustainability oversight, and emerging technology governance may subsequently influence innovation investment decisions. Sustainability-oriented data practices can themselves improve the information architecture supporting digital transformation, while changing institutional and organizational conditions can reshape how transformation strategies are implemented over time (Viriyasitavat et al., 2025; Marienfeldt et al., 2025; Florek-Paszkowska & Ujwary-Gil, 2025). Cybersecurity and data-related governance may likewise become increasingly interconnected with organizational resilience and strategic decision-making as digital dependence increases (Mohammed Alharbi, 2025; Viriyasitavat et al., 2025). These reciprocal relationships demonstrate why board effectiveness should be interpreted as an interconnected governance system rather than as a collection of independent attributes.

These findings extend the discussion of digital transformation and sustainable innovation by positioning the board as an active strategic actor in organizational transformation. Existing literature frequently explains digital transformation through technological readiness, organizational capabilities, management commitment, digital leadership, infrastructure, and organizational adaptation (Mihu et al., 2023; Yaqub & Alsabban, 2023; Aldhi et al., 2025). Similarly, sustainable innovation is commonly associated with environmental pressures, technological resources, organizational capabilities, circular economy practices, and the integration of economic and environmental objectives (Alamandi, 2025; Kandpal et al., 2024; Nazir et al., 2024). More recent research increasingly connects these two domains through the concept of a digital-sustainability or twin-transition ecosystem, emphasizing that digital transformation and sustainability transformation can reinforce one another when supported by appropriate organizational capabilities (Ben Youssef, 2025; Florek-Paszkowska & Ujwary-Gil, 2025; Alojail & Khan, 2023).

The present framework advances this literature by suggesting that these organizational capabilities may themselves have an upstream governance architecture.



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Boards influence which strategic issues receive attention, which risks are considered acceptable, which investments receive resources, and how digital and sustainability objectives are incorporated into organizational strategy. This governance role becomes especially important because the existence of sustainability targets or technological initiatives does not necessarily ensure effective implementation or accountability (Jiang et al., 2025; Abello-Romero et al., 2025). Firm-level evidence also indicates that board dynamics, stakeholder pressures, and digital transformation jointly shape strategic sustainability and circular-economy initiatives, reinforcing the argument that governance mechanisms constitute an important antecedent to organizational transformation (Osei et al., 2026; Zhang & Jin, 2023).

The integration of UET and DCT therefore suggests that successful transformation depends not simply on whether firms possess digital technologies or sustainability initiatives, but on whether their boards possess the cognitive and governance capabilities necessary to recognize, prioritize, govern, and continually reconfigure strategic resources. From this perspective, digital transformation and sustainable innovation are not merely operational or technological outcomes; they are partially governance-driven processes originating from the board's ability to interpret environmental changes, make strategic commitments, allocate resources, and oversee organizational adaptation. This interpretation is consistent with emerging research linking digital transformation with sustainable development, sustainable innovation, circularity, and green organizational performance (Ben Youssef, 2025; Yin et al., 2022; Hariyadi et al., 2025). Consequently, the DEMATEL results contribute beyond identifying which board-effectiveness criteria rank highest: they reveal the causal governance architecture through which board-level cognitive resources and governance mechanisms may propagate throughout the broader organizational transformation system.

5. Conclusion and Implications

This study develops and evaluates a multidimensional framework of board effectiveness as a strategic enabler of digital transformation and sustainable innovation in manufacturing firms. By integrating Upper Echelons Theory and Dynamic Capabilities Theory, board effectiveness is conceptualized through five dimensions: board composition and expertise, strategic oversight capability, board decision-making effectiveness, digital governance capability, and sustainability governance capability. These dimensions are operationalized through twenty interconnected criteria and examined using DEMATEL to distinguish their prominence, causal influence, and structural relationships. The study therefore advances beyond the conventional question of *which board characteristics matter most* toward the more strategically meaningful question of *which board capabilities initiate changes throughout the governance system*



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and through what pathways these influences propagate. The resulting causal architecture provides a systemic explanation of how board-level cognitive resources and governance capabilities can support manufacturing firms facing simultaneous digital and sustainability transitions.

The study offers several theoretical implications. First, it extends UET beyond conventional demographic proxies by conceptualizing board effectiveness through substantive cognitive and strategic capabilities such as digital expertise, sustainability expertise, industry knowledge, competency diversity, strategic oversight, and decision-making capability. Second, the integration with DCT connects these board-level attributes with organizational processes of sensing, seizing, and reconfiguring. Board composition and expertise can facilitate sensing; strategic oversight and effective decision-making can facilitate seizing; while digital and sustainability governance can facilitate organizational reconfiguration. Third, the DEMATEL results introduce causal heterogeneity into these theoretical relationships by demonstrating that not all governance capabilities occupy equivalent structural positions. Some characteristics may constitute antecedent causal conditions, while others represent transmission mechanisms or downstream governance outcomes. The integration consequently provides a bridge between the micro-level cognitive foundations of strategic governance proposed by UET and the organizational adaptation mechanisms emphasized by DCT.

The findings also generate important managerial implications for boards and senior executives in manufacturing firms. Firms should avoid evaluating board effectiveness solely through structural indicators such as independence, size, diversity, or meeting frequency. Board evaluation and development systems should instead assess whether directors collectively possess the expertise and governance capabilities necessary to oversee digital and sustainability transformation. Criteria identified as strong causal drivers deserve priority because improvements in these areas are likely to generate broader systemic effects. If digital expertise and sustainability expertise emerge as root causes, firms may prioritize director recruitment, board education, specialized advisory committees, and continuous technology and ESG training. If strategic oversight or decision-making criteria dominate, attention should shift toward governance processes, information quality, strategic review mechanisms, and investment evaluation procedures. DEMATEL therefore provides boards with a practical distinction between factors that are merely visible outcomes of effective governance and those that constitute actionable leverage points capable of improving the broader governance system.

Furthermore, the results provide managerial implications for the alignment of digital transformation and sustainability strategies. Manufacturing firms are thus advised not to seek to manage these agendas via separate technological and environmental departments. Digital spending has an impact on energy efficiency, resource management, supply-chain visibility, environmental surveillance, and circular production potential,



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and sustainability needs are pressuring technological investment and business model choices. Boards should, therefore, create governance arrangements that integrate monitoring of digital transformation, investment in innovation, data and cybersecurity governance, environmental performance, circular economy objectives, stakeholder expectations, and sustainable innovation. Still, DEMATEL's expert-based nature implies that the causal links unveiled reflect structured managerial opinions, rather than regressional causal findings. Subsequent research may validate the emergent causal patterns employing large-scale firm-level data; examine differences in governance patterns across industries or nations; incorporate fuzzy and dynamic extensions of DEMATEL; or integrate DEMATEL with SEM, panel-data, or longitudinal methodologies. Such extensions will allow investigating whether the identified governing capabilities, as causal sources, in the end enable explaining variance in digital transformation, sustainable innovation, and firm performance.

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