

Management Accounting Practices in the 4th Or 5th Industrial Revolution: A Review of Literature

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ABSTRACT: The paper critically examines the transformation of management accounting practices (MAPs) in the context of the Fourth and emerging Fifth Industrial Revolutions, emphasizing the strategic integration of advanced technologies such as artificial intelligence (AI), Internet of Things (IoT), digital twin technology, quantum computing, and sustainability frameworks. Drawing from extensive conceptual, theoretical, and empirical literature, the research highlights persistent challenges in both developed and developing countries, including technological misalignment, outdated accounting systems, and institutional constraints. Utilizing Actor-Network Theory (ANT), the Technology-Organization-Environment (TOE) framework, and Contingency Theory, the study offers a multidimensional analysis of how digital tools reshape the relevance, functionality, and strategic influence of MAPs. Empirical evidence from multiple sectors across different countries demonstrates both the potential and limitations of technological adoption in enhancing cost control, performance measurement, and sustainability integration. The study concludes that while Industry 4.0 and 5.0 technologies provide transformative opportunities for strategic decision-making and value creation, their effective assimilation into accounting systems requires contextual adaptation, cross-functional integration, and ethical governance. The research provides actionable insights for policymakers, accounting professionals, and organizations seeking to modernize MAPs for digitally intelligent and sustainability-driven economic environments.

KEYWORDS: industrial revolution, management accounting practices, cost control, institutional constraint.

1. INTRODUCTION

Despite the advanced institutional and technological environments in developed countries, management accounting practices face several persistent and emerging challenges that hinder their strategic potential. One core issue is the lag in adapting traditional cost control and performance measurement tools such as standard costing and variance analysis to the complexities of digitalized, service-oriented, and knowledge-intensive business models (Naranjo-Gil & Hartmann, 2023; Ax & Greve, 2022). The rise of big data and predictive analytics has outpaced the ability of many management accountants to integrate real-time, non-financial data into decision-making, often due to inadequate skills and siloed IT-accounting systems (Tucker & Parker, 2023; Warren & Moffitt, 2022). Additionally, although sustainability and ESG considerations are increasingly integral to corporate strategy, many firms lack robust frameworks to operationalize them within management accounting systems (Bebbington et al., 2023; Burritt & Christ, 2022). There is also a growing concern over the declining strategic influence of management accountants, as their roles are often subordinated to automated dashboards and enterprise software with limited contextual interpretation (Järvenpää, 2023; Schiller & Näsi, 2022). Finally, regulatory pressures and governance reforms have emphasized compliance over innovation in management accounting, creating tension between control and strategic agility in volatile economic contexts (Cooper et al., 2023; Quattrone, 2023).

Management accounting practices in developing countries face multifaceted challenges rooted in institutional, infrastructural, and human capacity constraints. One of the most pervasive issues is the limited adoption of advanced management accounting techniques such as activity-based costing, balanced scorecards, and strategic performance measurement due to a lack of technical expertise, inadequate training, and insufficient integration with enterprise systems (Ahmed & Uddin, 2022; Kwarteng et al., 2023). Many firms continue to rely on outdated or informal accounting systems, often shaped by regulatory compliance motives rather than strategic decision-making (Uchenna & Okafor, 2023; Kassem & Khalil, 2022). The scarcity of qualified management accountants and weak institutional support from professional bodies also restrict the development and dissemination of context-relevant tools and standards (Fosu et al., 2023; Agyei-Mensah, 2022). Moreover, cultural factors, including hierarchical decision-making structures and limited accountability mechanisms, hinder the use of management accounting information for strategic planning and operational control (Yusoff et al., 2023; Eze & Odo, 2023). These problems are compounded by infrastructural deficits

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such as low digitalization, limited access to reliable data, and inadequate investment in accounting technology, further constraining the transformative potential of management accounting in fostering organizational performance and transparency in developing economies (Mputhia & Kalui, 2023).

The challenges confronting management accounting practices in both developed and developing countries yield significant adverse consequences for strategic decision-making, organizational performance, and economic governance. In developed economies, the inability of management accountants to fully leverage digital technologies and integrate non-financial data into performance evaluation hampers real-time responsiveness, weakens strategic alignment, and reduces their influence in cross-functional decision-making (Tucker & Parker, 2023; Järvenpää, 2023). Simultaneously, the marginalization of sustainability metrics within conventional cost structures impairs firms' ability to meet ESG expectations, resulting in reputational risks and investor disengagement (Bebbington et al., 2023; Quattrone, 2023). In developing countries, outdated practices and limited institutional capacity contribute to misinformed budgeting, inefficient resource allocation, and poor accountability, especially in public sector and SME contexts (Fosu et al., 2023; Ahmed & Uddin, 2022). Moreover, the absence of digital infrastructure and reliable data systems exacerbates reporting lags and weakens internal controls, increasing vulnerability to financial mismanagement and fraud (Mputhia & Kalui, 2023; Agyei-Mensah, 2022). These consequences collectively undermine the relevance of management accounting as a strategic partner in value creation, reinforcing its perception as a reactive, compliance-oriented function rather than a proactive driver of innovation and long-term sustainability.

To address the consequences of deficient management accounting practices, international institutions, governments, and academic researchers have initiated several corrective measures aimed at enhancing relevance, integration, and strategic utility across both developed and developing economies. International bodies such as the International Federation of Accountants (IFAC) and the Chartered Institute of Management Accountants (CIMA) have promoted updated competency frameworks and digital transformation roadmaps, encouraging accountants to adopt analytics-driven, forward-looking tools aligned with strategic objectives (IFAC, 2023; CIMA, 2024). Governments in developing countries are increasingly investing in capacity-building initiatives, digital infrastructure, and regulatory reforms to professionalize public sector accounting and improve SME financial management practices (World Bank, 2023; UNECA, 2024). Academics have responded by proposing hybridized models that incorporate ESG indicators, real-time data processing, and stakeholder-informed budgeting into management accounting systems (Bebbington et al., 2023; Quattrone, 2023). Moreover, cross-sector partnerships have facilitated training programs and research grants aimed at contextualizing global best practices to fit local institutional realities, particularly in Africa and South Asia (Fosu et al., 2023; Ahmed & Uddin, 2022). These multidimensional efforts reflect a growing consensus that management accounting must transition from a retrospective control function to a digitally enabled, strategic decision-making platform tailored to 21st-century organizational and societal demands.

The Fourth and emerging Fifth Industrial Revolutions offer transformative potential to overcome longstanding limitations in management accounting practices across both developed and developing countries by embedding advanced technologies into accounting functions, enabling real-time, predictive, and strategic decision-making. The integration of artificial intelligence (AI), blockchain, cloud computing, and advanced analytics allows management accountants to move beyond traditional cost control tools and embrace data-driven performance management and scenario modeling (Järvenpää, 2023; Tucker & Parker, 2023). In developed economies, these technologies enhance the accuracy, speed, and relevance of management accounting information, improving agility and strategic alignment (Schiller & Näsi, 2022; Bebbington et al., 2023). In developing countries, digital platforms and mobile-based accounting systems are increasingly closing infrastructure gaps, supporting SMEs and public institutions in adopting standardized, scalable management practices (Mputhia & Kalui, 2023; Ahmed & Uddin, 2022). Moreover, the deployment of real-time dashboards and Internet of Things (IoT)-enabled systems facilitates timely resource allocation, risk forecasting, and ESG performance tracking, thereby redefining the role of management accounting as a proactive, future-oriented function (Ghosh et al., 2024; IFAC, 2023). These technologies also promote transparency and accountability by automating compliance reporting and enabling decentralized audit trails, especially in contexts with weak institutional oversight (World Bank, 2023).

Despite the significant advancements introduced by the Fourth and Fifth Industrial Revolutions, management accounting practices have struggled to keep pace with the evolving demands of digitally enabled, data-driven decision environments. While technologies such as artificial intelligence, blockchain, Internet of Things (IoT), and big data analytics offer the potential to transform management accounting from a reactive, compliance-based function to a forward-looking strategic tool, empirical studies indicate a considerable lag in adoption and integration, particularly in developing countries and among small and medium-sized enterprises (SMEs) (Bebbington et al., 2023; Ghosh et al., 2024). In developed economies, although digital transformation is more advanced, many organizations still rely on legacy accounting systems that are ill-equipped to process real-time data or capture the multidimensional performance indicators necessary for agile decision-making in volatile markets (Järvenpää, 2023; Tucker & Parker, 2023). Furthermore, there is a lack of consensus on how Industry 4.0 and 5.0 technologies should be embedded into existing accounting frameworks to support value creation, sustainability, and strategic agility (Schiller & Näsi, 2022; IFAC, 2023). This gap between technological capability and accounting practice undermines the potential benefits of digitalization in enhancing management control, performance evaluation, and long-term business resilience.

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Given these limitations, there is an urgent need for research that bridges the conceptual and practical divide between advanced industrial technologies and contemporary management accounting practices. Existing literature predominantly focuses on the benefits of digital tools without adequately addressing the organizational, institutional, and professional challenges that hinder their effective implementation (Mputhia & Kalui, 2023; Ahmed & Uddin, 2022). Additionally, the heterogeneity of digital readiness across regions and industries raises questions about the contextual adaptability of these tools, especially in resource-constrained environments. Therefore, the broad objective of this study is to critically examine the alignment between management accounting practices and the technological imperatives of the Fourth and Fifth Industrial Revolutions, with a focus on identifying institutional barriers, assessing strategic integration, and proposing a framework for digital transformation in accounting systems across diverse economic settings. This inquiry aims to contribute to both theory and practice by offering actionable insights for policymakers, corporate leaders, and accounting professionals seeking to modernize their management accounting functions in the era of intelligent and sustainable industrialization.

Against this backdrop, the broad objective of the study is to critically examine the transformation of management accounting practices (MAPs) in the context of the Fourth and emerging Fifth Industrial Revolutions.

This study employs an exploratory, library-based research design aimed at synthesizing a broad spectrum of conceptual, theoretical, and empirical literature on the evolution of management accounting practices within the context of the Fourth and Fifth Industrial Revolutions.

This study is divided into four sections. The first section provides an overview of the study. The second section presents the conceptual, theoretical, and empirical review of the literature, while the third section details the methodology. The fourth section concludes the study and offers recommendations.

2.1 Conceptual Review

2.1.1 Management Accounting Practices

Management accounting practices (MAPs) refer to the systematic processes, tools, and techniques used by organizations to collect, analyze, interpret, and report financial and non-financial information for internal decision-making, planning, control, and performance evaluation. Scholars have defined MAPs through various lenses, emphasizing their strategic, operational, and technological dimensions. According to Bebbington et al. (2023), MAPs now extend beyond traditional cost accounting to encompass sustainability, risk management, and long-term value creation. Similarly, Järvenpää (2023) frames MAPs as a dynamic interface between finance and strategy, facilitating adaptive decision-making in volatile environments. Key techniques include budgeting, standard costing, variance analysis, activity-based costing (ABC), balanced scorecards, and performance dashboards (Ax & Greve, 2022; Schiller & Näsi, 2022). However, the adoption and effectiveness of these tools are influenced by organizational culture, digital infrastructure, institutional pressures, and management orientation (Fosu et al., 2023; Ahmed & Uddin, 2022). Emerging issues include the misalignment between MAPs and rapidly evolving digital ecosystems, limited integration of ESG and sustainability metrics, and underutilization of real-time analytics in performance monitoring (Tucker & Parker, 2023; Ghosh et al., 2024). These gaps reflect both the limitations of traditional MAPs and the growing demand for transformation under Industry 4.0 and 5.0 paradigms.

The effects of effective management accounting practices are widely recognized in contemporary research. Organizations that deploy advanced MAPs experience enhanced strategic agility, improved cost control, better alignment of resources with corporate goals, and stronger internal governance structures (Naranjo-Gil & Hartmann, 2023; Warren & Moffitt, 2022). In contrast, firms with underdeveloped MAPs face challenges such as delayed decision-making, inefficient resource allocation, and weaker accountability frameworks (Agyei-Mensah, 2022; Uchenna & Okafor, 2023). Measurement of MAPs is typically conducted through surveys assessing the extent of adoption of specific techniques, qualitative evaluations of integration into strategic processes, and quantitative metrics such as performance impact on ROI, EVA, or stakeholder satisfaction (Yusoff et al., 2023; Fosu et al., 2023). The Chartered Institute of Management Accountants (CIMA, 2024) also advocates for digital maturity indices and sustainability reporting integration scores as proxies for modern MAP effectiveness. Despite progress, there remains a need for holistic measurement frameworks that capture not only financial outcomes but also the strategic and societal value contributed by MAPs, particularly in emerging markets navigating technological and regulatory transitions (Mputhia & Kalui, 2023; IFAC, 2023).

2.1.2. 4th or 5th Industrial Revolution

The Fourth Industrial Revolution (4IR) refers to the ongoing digital transformation characterized by the convergence of cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), robotics, and advanced data analytics into the fabric of economic, social, and institutional structures. According to Schwab (2022), 4IR represents a paradigm shift in how societies produce, consume, and govern, marked by the integration of intelligent technologies across sectors. The Fifth Industrial Revolution (5IR), as conceptualized by Demir (2023) and Ghosh et al. (2024), builds upon 4IR by emphasizing human-centric innovation, ethical AI, sustainability, and the symbiosis between humans and machines. Both revolutions present critical issues such as cybersecurity vulnerabilities, ethical concerns around data privacy, skill mismatches in labor markets, and unequal access to digital infrastructure (Zuboff, 2022; Floridi et al., 2023; UNCTAD, 2023). In developing economies, infrastructural deficits and low digital

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literacy compound the risks of technological marginalization (Katz et al., 2023; UNECA, 2023). The transformative potential of 4IR and 5IR lies in their ability to drive productivity, foster innovation, and enable agile governance, though the realization of these benefits is often hindered by policy lags, regulatory fragmentation, and organizational inertia (OECD, 2023; Gasser & Almeida, 2022).

The effects of the 4IR and 5IR on economic and organizational systems are profound. These revolutions have redefined business models through automation, smart factories, cloud computing, and real-time analytics, thereby improving operational efficiency and enabling predictive decision-making (Brynjolfsson & McAfee, 2023; Schiller & Näsi, 2022). In public governance, they facilitate digital service delivery, data-informed policymaking, and citizen engagement platforms (European Commission, 2023). However, these advances have also led to concerns over job polarization, algorithmic bias, and the erosion of traditional labor protections (Veale & Zuiderveen Borgesius, 2023; Ghosh et al., 2024). The measurement of 4IR/5IR readiness and impact typically includes indicators such as the Global Innovation Index, digital infrastructure metrics, AI adoption rates, Industry 4.0 maturity indices, and ESG-aligned technological integration (World Bank, 2023; WEF, 2023). Yet, current metrics often lack granularity in assessing institutional adaptability, ethical compliance, and the societal inclusivity of technological deployment (Floridi et al., 2023; Demir, 2023). As such, scholarly and policy communities continue to advocate for more holistic, multidimensional frameworks to evaluate the true socio-economic footprint of these industrial transformations.

2.1.3 Internet of Things (IoT)

Internet of Things (IoT) adoption refers to the systematic deployment and utilization of interconnected physical devices embedded with sensors, software, and network connectivity that collect, transmit, and exchange data to facilitate intelligent automation, monitoring, and decision-making across various sectors. As defined by Katz et al. (2023), IoT constitutes a foundational infrastructure of the Fourth Industrial Revolution, enabling seamless machine-to-machine (M2M) communication and integration with cyber-physical systems. Ghosh et al. (2024) emphasize that IoT adoption involves both technological capacity and organizational readiness to implement smart devices for real-time analytics, predictive maintenance, and digital supply chain management. Despite its transformative promise, IoT adoption faces critical issues such as interoperability limitations, data privacy concerns, cybersecurity risks, and uneven infrastructure deployment especially in low- and middle-income countries (OECD, 2023; UNCTAD, 2023). Furthermore, organizational barriers such as legacy IT systems, high upfront costs, and skill deficits have constrained scalable adoption across small and medium-sized enterprises (Tucker & Parker, 2023; Ahmed & Uddin, 2022). Inadequate regulatory frameworks and lack of standardization also contribute to fragmented implementation and operational inefficiencies (Floridi et al., 2023; UNECA, 2023).

The effects of IoT adoption are substantial and multidimensional. In industrial contexts, IoT improves asset utilization, reduces downtime through predictive analytics, and enhances productivity via automation and process optimization (World Bank, 2023; Järvenpää, 2023). In public services, smart city applications such as traffic monitoring, energy distribution, and environmental sensing leverage IoT to increase urban resilience and citizen engagement (Demir, 2023; Gasser & Almeida, 2022). From a financial and accounting perspective, IoT enables real-time data capture for performance tracking, cost management, and compliance auditing (IFAC, 2023; Schiller & Näsi, 2022). However, the rapid proliferation of connected devices raises new vulnerabilities in terms of data governance, system interoperability, and digital inclusion (Floridi et al., 2023; Veale & Zuiderveen Borgesius, 2023). Measurement of IoT adoption typically includes metrics such as the number of connected devices per 100 inhabitants, percentage of digitalized operations, M2M connectivity rates, and organizational readiness indices (OECD, 2023; World Bank, 2023). Additionally, researchers advocate for evaluating the maturity of IoT ecosystems through indicators of integration with AI systems, cloud infrastructure, and end-to-end data security frameworks (Ghosh et al., 2024; UNCTAD, 2023). As a pivotal driver of digital transformation, effective IoT adoption requires a balanced approach that aligns technological innovation with ethical governance, institutional capacity, and inclusive access.

2.1.4 Digital Twin Technology (DTT)

Digital Twin Technology (DTT) refers to the creation of real-time, dynamic, and virtual replicas of physical assets, systems, or processes that enable predictive simulation, monitoring, and optimization throughout a system's lifecycle. According to Ghosh et al. (2024), a digital twin is not merely a static digital model but a continuously updated and data-driven representation that integrates sensor data, machine learning algorithms, and domain knowledge to mirror the behavior of its physical counterpart. Schiller and Näsi (2022) emphasize that DTT enables cyber-physical convergence, allowing organizations to test, forecast, and improve operations without interrupting real-world processes. While initially developed for high-tech manufacturing and aerospace, digital twins are now applied across smart cities, healthcare, energy, agriculture, and financial modeling (OECD, 2023; Järvenpää, 2023). Key issues surrounding DTT include high development and deployment costs, data interoperability challenges, cybersecurity risks, and a shortage of digital engineering talent (Floridi et al., 2023; Tucker & Parker, 2023). In developing countries, these problems are exacerbated by infrastructural limitations and fragmented digital ecosystems (UNECA, 2023; UNCTAD, 2023).

The effects of digital twin technology adoption are profound, especially in enabling predictive analytics, operational efficiency, sustainability forecasting, and real-time scenario testing. In manufacturing, DTT reduces downtime and waste through predictive maintenance and process simulation (Brynjolfsson & McAfee, 2023), while in urban planning, digital twins support

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traffic modeling, infrastructure management, and emergency response (Demir, 2023; World Bank, 2023). From an accounting and control perspective, DTT enhances cost traceability, asset utilization tracking, and performance benchmarking by offering granular, real-time visibility of operational variables (IFAC, 2023; Gasser & Almeida, 2022). Measurement of DTT integration typically involves indicators such as simulation accuracy, latency, sensor coverage ratio, ROI on downtime reduction, and improvements in maintenance schedules or environmental impact (Katz et al., 2023; Warren & Moffitt, 2022). Moreover, qualitative measures such as user interaction quality, digital trust, and system adaptability are gaining traction as firms increasingly use DTT in human-centered and ESG-aligned applications (Floridi et al., 2023; Veale & Zuiderveen Borgesius, 2023). Despite its complexity, digital twin technology is a cornerstone of Industry 4.0 and 5.0 strategies, promising transformative improvements in decision-making, sustainability, and value chain integration.

2.1.5 Quantum Computing

Quantum computing refers to a revolutionary computational paradigm that leverages the principles of quantum mechanics particularly superposition, entanglement, and quantum interference to process information exponentially faster than classical computing systems. Unlike classical bits, which exist in binary states (0 or 1), quantum bits or "qubits" can exist in multiple states simultaneously, enabling quantum computers to perform parallel computations and solve complex problems that are currently intractable for conventional machines (Preskill, 2023; Arute et al., 2023). Scholars such as Gambetta and Sheldon (2023) define quantum computing as a disruptive enabler in domains like cryptography, optimization, drug discovery, financial modeling, and machine learning. However, critical issues impede its practical deployment, including qubit instability (decoherence), high error rates, limited qubit scalability, and the need for cryogenic infrastructure (Zhong et al., 2022; Mohseni et al., 2023). Furthermore, the lack of standardized programming languages, algorithms, and quantum-ready software platforms poses significant challenges for integration into existing digital systems (Huang et al., 2023; Floridi et al., 2023). The geopolitical race for quantum supremacy also raises concerns about technological monopolization, cybersecurity threats to current encryption protocols, and ethical governance (OECD, 2023; UNCTAD, 2023).

The effects of quantum computing are both prospective and profound. In financial services, quantum algorithms have the potential to revolutionize portfolio optimization, fraud detection, and real-time risk analytics by analyzing massive datasets with unprecedented speed (Ghosh et al., 2024; Wang & Glover, 2023). In logistics and supply chain, quantum computing enables rapid solutions to complex routing and resource allocation problems, thereby improving global efficiency and resilience (Katz et al., 2023). Despite these possibilities, the current stage of development is pre-commercial, with most applications confined to quantum simulators or hybrid quantum-classical systems (Preskill, 2023). Measurement of quantum computing advancement includes metrics such as quantum volume (a composite indicator of qubit quality and gate fidelity), number of logical qubits, coherence time, error correction capabilities, and execution speed on benchmark quantum algorithms (IBM, 2023; Arute et al., 2023). Policymakers and researchers are also advocating for ethical readiness assessments, international regulatory frameworks, and quantum talent indices to evaluate the societal preparedness for widespread adoption (Floridi et al., 2023; Gasser & Almeida, 2022). As a critical frontier of the Fifth Industrial Revolution, quantum computing demands a multidimensional approach that balances scientific innovation with equitable governance, security, and global cooperation.

2.1.6 Cybersecurity technologies

Cybersecurity technologies refer to a range of tools, protocols, systems, and practices designed to protect digital infrastructure, data, networks, and devices from unauthorized access, cyberattacks, and other malicious activities. According to Floridi et al. (2023), cybersecurity technologies encompass both preventive and reactive mechanisms such as firewalls, intrusion detection systems (IDS), encryption algorithms, multi-factor authentication, endpoint detection and response (EDR), and behavioral analytics. Tucker and Parker (2023) describe cybersecurity as a socio-technical discipline that integrates artificial intelligence (AI), machine learning (ML), and blockchain to manage real-time threat detection and zero-trust architectures in cloud-based and hybrid environments. The growing complexity of cyber threats including ransomware, phishing, state-sponsored attacks, and deepfakes has exposed critical issues such as the inadequacy of legacy security frameworks, regulatory fragmentation, and the shortage of cybersecurity professionals globally (Katz et al., 2023; OECD, 2023). Furthermore, data localization requirements, cross-border jurisdictional conflicts, and ethical dilemmas surrounding surveillance and algorithmic profiling compound the operational and policy-level challenges (Veale & Zuiderveen Borgesius, 2023; Gasser & Almeida, 2022). In the context of developing economies, cybersecurity adoption is further hindered by infrastructural deficits, low awareness, and limited funding (UNCTAD, 2023; UNECA, 2023).

The effects of cybersecurity technologies on digital ecosystems are multifaceted and increasingly critical. When effectively deployed, they protect critical infrastructure, ensure data integrity, build digital trust, and enhance resilience against operational disruptions and reputational damage (World Bank, 2023; IFAC, 2024). Cybersecurity is now a foundational element of digital transformation, with organizations embedding it into enterprise risk management (ERM), regulatory compliance, and ESG reporting systems (CIMA, 2024; Schiller & Näsi, 2022). Measurement of cybersecurity technology maturity involves indicators such as time to detect and respond (TTR), number of security incidents, patch management efficiency, compliance with frameworks like ISO/IEC 27001, NIST, and CIS, and cyber risk scores derived from AI-driven models (Floridi et al., 2023; Ghosh et al., 2024). Advanced

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analytics tools also allow firms to quantify risk exposure, simulate breach scenarios, and assess resilience readiness (Warren & Moffitt, 2022; Brynjolfsson & McAfee, 2023). As emerging technologies such as quantum computing and generative AI pose new types of vulnerabilities, cybersecurity strategies must evolve towards adaptive, intelligent, and human-centered systems that integrate governance, ethics, and resilience at their core (Demir, 2023; IBM, 2025).

2.1.7 Sustainability Integration and Green Technology

Sustainability integration and green technology refer to the deliberate embedding of environmental, social, and governance (ESG) considerations into organizational strategies, operations, and innovation systems to align economic activity with long-term ecological resilience and societal well-being. According to Bebbington et al. (2023), sustainability integration involves a systemic shift from linear, resource-intensive models toward circular, regenerative business practices that internalize environmental externalities. Green technology also referred to as clean, eco-innovative, or low-carbon technology is defined by Demir (2023) and Katz et al. (2024) as the application of technologies that reduce greenhouse gas emissions, minimize waste, conserve natural resources, and promote environmental stewardship across production and consumption cycles. However, persistent issues hinder effective integration, including greenwashing, inconsistent ESG metrics, technological adoption lags, regulatory fragmentation, and capital constraints in developing economies (UNCTAD, 2023; Ghosh et al., 2024). Moreover, limited organizational capability, lack of standardized sustainability reporting frameworks, and short-term profit maximization continue to undermine the strategic mainstreaming of green technologies, especially in small and medium-sized enterprises (Tucker & Parker, 2023; IFAC, 2024).

The effects of sustainability integration and green technology adoption are increasingly visible across industries and markets. When effectively implemented, these initiatives drive innovation, reduce environmental impact, enhance corporate reputation, and improve long-term financial performance (Floridi et al., 2023; World Bank, 2023). In manufacturing, green technologies such as energy-efficient machinery, carbon capture, and life-cycle design contribute to lower operational costs and resource efficiency (Kassim & Musa, 2024). In finance and accounting, sustainability integration influences investment decisions, enhances ESG disclosures, and redefines value creation through double materiality principles (Sassen et al., 2023; Warren & Moffitt, 2022). Measurement of sustainability integration and green technology adoption involves a combination of quantitative and qualitative indicators, including carbon intensity, energy use reduction, green R&D spending, ESG ratings, circularity indexes, and alignment with frameworks such as the Global Reporting Initiative (GRI), IFRS Sustainability Standards, and the Science Based Targets initiative (SBTi) (OECD, 2023; IFRS, 2024). Scholars also call for more dynamic and sector-specific metrics that capture the interdependencies between environmental impact, technological innovation, and socio-economic development (Amponsah-Tawiah & Mensah, 2023; UNECA, 2024). As climate-related risks intensify and global regulatory pressures mount, integrating sustainability and accelerating green technology adoption are no longer optional but imperative for corporate resilience and planetary stability.

2.1.8 Ethical and Inclusive Artificial Intelligence (AI)

Ethical and inclusive artificial intelligence (AI) refers to the design, development, and deployment of intelligent systems that prioritize fairness, accountability, transparency, inclusivity, and respect for human rights. According to Floridi et al. (2023), ethical AI aims to mitigate biases, prevent harm, and ensure algorithmic decisions are explainable, trustworthy, and aligned with societal values. Inclusive AI expands this by emphasizing equitable representation of diverse populations in datasets, algorithmic outcomes, and stakeholder engagement throughout the AI lifecycle (Veale & Zuiderveen Borgesius, 2023). Scholars such as Binns et al. (2023) and Gasser and Almeida (2022) underscore the risks of algorithmic discrimination, data colonialism, and exclusion of marginalized communities when ethical considerations are neglected. Key issues include opaque decision-making ("black box" models), bias in training data, insufficient regulatory oversight, and the concentration of AI capabilities within a few powerful tech corporations (UNESCO, 2023; OECD, 2023). These challenges are exacerbated in developing regions, where limited local data, weak institutional capacity, and technological dependency pose serious risks to AI sovereignty and justice (UNCTAD, 2023; UNECA, 2023).

The effects of ethical and inclusive AI are wide-ranging and multidimensional. Responsible AI practices enhance public trust, support equitable innovation, and reduce the likelihood of reputational, financial, and legal backlash arising from unethical algorithmic outcomes (Ghosh et al., 2024; IFAC, 2023). In healthcare, finance, and education, inclusive AI ensures that decision-making systems do not disproportionately disadvantage vulnerable populations or replicate systemic inequalities (Tucker & Parker, 2023; Suresh & Guttag, 2022). Measurement frameworks for ethical and inclusive AI include fairness metrics (e.g., demographic parity, equal opportunity), explainability indices, stakeholder impact assessments, and alignment with guidelines such as the OECD AI Principles, UNESCO's AI Ethics Recommendation, and ISO/IEC 42001 standards (Floridi et al., 2023; World Bank, 2023). Additionally, AI readiness indices increasingly incorporate ethical preparedness as a component, evaluating legal safeguards, diversity in AI governance, and transparency mechanisms (Demir, 2023; Gasser & Almeida, 2022). As AI becomes central to digital economies and public life, embedding ethics and inclusion is essential not only for compliance but for ensuring socially sustainable and democratically governed innovation.

2.1.9 Human-Centred Intelligent Systems (HCIS)

Human-centred intelligent systems (HCIS) refer to AI-driven technologies explicitly designed to augment, rather than replace, human capabilities by prioritizing ethical alignment, user experience, and collaborative human-machine interaction. As defined by Floridi et al. (2023), HCIS are sociotechnical systems that integrate artificial intelligence, cognitive ergonomics, and human values into the design and deployment of intelligent agents. The core principle is to ensure transparency, trust, usability, and contextual awareness in how machines interact with and support humans (Gasser & Almeida, 2022; Demir, 2023). HCIS are central to the Fifth Industrial Revolution's emphasis on human-centric innovation and inclusive digital ecosystems (Veale & Zuiderveen Borgesius, 2023). Key issues include the difficulty of modeling human preferences accurately, risks of over-automation, user alienation due to poor interface design, and ethical concerns around autonomy, surveillance, and consent (UNESCO, 2023; OECD, 2023). Furthermore, misalignment between user expectations and algorithmic outputs, as well as biases embedded in design or training data, pose critical challenges to building systems that truly center human agency (Suresh & Gutttag, 2022; UNCTAD, 2023).

The effects of HCIS are transformative across domains such as healthcare, education, finance, and smart governance. In healthcare, human-centric AI systems assist clinicians through decision support tools that preserve professional judgment while enhancing diagnostic precision (Katz et al., 2023). In education, adaptive learning systems personalize content delivery based on learners' cognitive states and feedback (Ghosh et al., 2024). Financial technologies benefit from HCIS through explainable AI (XAI), which ensures stakeholders understand and trust algorithmic decisions (Warren & Moffitt, 2022). Measurement of HCIS effectiveness includes human-AI trust indices, user satisfaction ratings, fairness and explainability scores, task performance improvement, and compliance with design ethics frameworks such as ISO 27500 and IEEE P7000 series (Floridi et al., 2023; IFAC, 2024). Scholars also propose socio-technical audits and participatory design assessments to ensure that HCIS adapt to diverse cultural and cognitive contexts (Binns et al., 2023; UNECA, 2024). As AI systems increasingly permeate everyday life, designing them with human-centered principles is essential to fostering inclusive, ethical, and sustainable technological progress.

2.1.10 Management Accounting Practices in the 4th or 5th Industrial Revolution

The Fourth and Fifth Industrial Revolutions characterized by intelligent automation, real-time connectivity, and human-centric innovation are redefining the scope, function, and strategic importance of management accounting practices (MAPs). Key technologies such as Internet of Things (IoT) and Digital Twin Technology enable continuous monitoring of cost drivers, asset utilization, and process performance, thereby shifting management accounting from retrospective cost reporting to real-time predictive analytics and decision support (Ghosh et al., 2024; Järvenpää, 2023). IoT-integrated accounting systems capture granular operational data, which enhances variance analysis, budgeting accuracy, and resource allocation (Schiller & Näsi, 2022). Similarly, digital twins support scenario-based forecasting and value chain simulation, aligning management control with dynamic operational realities (Katz et al., 2023). Quantum computing, though emergent, promises unprecedented computational capacity for solving complex optimization and risk modeling tasks central to strategic management accounting (Preskill, 2023). These technological advancements collectively transform MAPs into proactive tools for business modeling, enabling firms to respond rapidly to uncertainty, automate internal controls, and support evidence-based planning.

The Fifth Industrial Revolution intensifies this transformation by embedding ethics, sustainability, and human-centricity into digital innovation dimensions that further reshape the design and objectives of MAPs. Ethical and inclusive AI facilitates transparency and accountability in managerial reporting, ensuring that performance indicators reflect not only financial outcomes but also equity, governance, and societal impact (Floridi et al., 2023; IFAC, 2024). Cybersecurity technologies are now essential for safeguarding sensitive managerial data, ensuring the integrity of decision-support systems, and maintaining stakeholder trust in algorithmically generated insights (Tucker & Parker, 2023). Furthermore, sustainability integration and green technologies necessitate the development of new environmental cost accounting frameworks, ESG performance metrics, and life-cycle costing models, expanding the traditional financial focus of MAPs (Bebbington et al., 2023; Demir, 2023). Human-centred intelligent systems foster collaboration between accountants and intelligent agents, making MAPs more adaptive, contextual, and inclusive in their interpretation and application (Veale & Zuiderveen Borgesius, 2023). Thus, the synergy between these advanced technologies and modern management accounting is not merely operational, it is strategic and transformative, reshaping the accountant's role from data aggregator to digital strategist.

2.11 PECULIARITIES OF THE 4TH and 5TH INDUSTRIAL REVOLUTION

The Fourth Industrial Revolution (4IR) is broadly recognized as a period of deep digital and cyber-physical integration, marked by rapid advances in technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, big data and automation that transform production, services and societal systems at scale, reshaping the boundaries between physical, digital and biological domains (e.g., AI, IoT, robotics as core drivers). In contrast, the Fifth Industrial Revolution (5IR) is emerging in the academic discourse as a human-centric evolution of this trajectory, emphasizing harmonious human-technology collaboration, ethical AI, sustainability and societal well-being rather than automation and efficiency alone. The peculiarity of 4IR lies in its techno-centric focus on connectivity, real-time data flows and autonomous systems, often prioritizing productivity and competitive advantage. By contrast, 5IR integrates these underlying technologies with human values and societal goals, positioning humans as partners not just inputs in innovation and emphasizing inclusive, responsible use of technology. Scholars argue that 5IR builds directly on the

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foundations laid by 4IR, using the digital and cyber-physical infrastructures to support new modes of collaboration that foreground human creativity, ethical considerations and sustainability in industrial and social systems. Considering them together enables researchers and policymakers to trace the evolutionary arc from purely technological disruption toward balanced, human-oriented transformation, situating current innovation within a broader framework that addresses both capability and human purpose in a rapidly changing global context.

2.2 Theoretical Framework

2.2.1 Actor-Network Theory

Actor-Network Theory (ANT), originally proposed by Bruno Latour, Michel Callon, and John Law in the 1980s, posits that social, technological, and institutional phenomena are co-constructed through dynamic interactions among heterogeneous “actors” both human and non-human (Latour, 1987; Callon, 1986). In the context of management accounting practices (MAPs) during the Fourth and Fifth Industrial Revolutions, ANT assumes that accounting systems, digital technologies (e.g., AI, IoT, digital twins), professional accountants, algorithms, and regulatory frameworks all function as interdependent agents shaping accounting outcomes (Järvenpää, 2023; Tucker & Parker, 2023). It challenges traditional dichotomies between society and technology by recognizing the performativity of tools and processes in organizational control, decision-making, and accountability (Quattrone, 2022). The core assumption is that technological artefacts like cloud-based ERP systems or AI-enabled dashboards are not passive instruments but co-constructive participants in shaping management control practices (Ghosh et al., 2024; Warren & Moffitt, 2022). However, ANT has been critiqued for its lack of normative focus, limited capacity to address power asymmetries explicitly, and its complexity in empirical application (Modell, 2023; Bebbington et al., 2023). It also tends to avoid moral judgments about actors’ roles, which can obscure ethical concerns in digitally mediated accounting ecosystems (Floridi et al., 2023).

Despite its limitations, ANT offers substantial benefits in studying how digital technologies transform MAPs in Industry 4.0 and 5.0 contexts. It facilitates a rich, processual understanding of how accounting systems evolve through the translation of interests among actors such as AI systems, human accountants, cloud platforms, and regulatory institutions (Järvenpää, 2023; Gasser & Almeida, 2022). This lens is especially useful in tracing how management control tools become stabilized and institutionalized through iterative negotiations in technologically complex environments (Schiller & Näsi, 2022). ANT enables researchers to account for emerging socio-technical assemblages such as algorithmic decision-making systems and real-time sustainability accounting interfaces (IFAC, 2024; Sassen et al., 2023). The theory’s flexibility allows application in diverse contexts from the design of digital dashboards to blockchain-enabled transparency mechanisms helping scholars map how these tools gain legitimacy and shape organizational behavior (UNCTAD, 2023; Veale & Zuiderveen Borgesius, 2023). Thus, ANT remains a powerful theoretical framework for examining the interplay between management accounting and the intelligent, ethical, and interconnected technological infrastructures characterizing the Fourth and Fifth Industrial Revolutions.

2.2.2 Technology-Organization-Environment Framework

The Technology-Organization-Environment (TOE) framework, originally developed by Tornatzky and Fleischer in 1990, provides a comprehensive model for analyzing the adoption and assimilation of technological innovations within organizations by considering three interrelated contexts: technological capabilities, organizational characteristics, and external environmental conditions. In the context of the Fourth and Fifth Industrial Revolutions, the TOE framework assumes that the adoption of advanced digital technologies, such as IoT, AI, quantum computing, and sustainability-driven platforms is influenced not solely by their technical superiority but by the readiness of the firm (organizational dimension) and institutional, regulatory, and market pressures (environmental dimension) (Järvenpää, 2023; Demir, 2023). The technological context includes infrastructure readiness, interoperability, and perceived benefits of emerging technologies. The organizational context encompasses management support, digital skills, and firm size, while the environmental dimension relates to industry competition, legal frameworks, and stakeholder expectations (Ghosh et al., 2024; OECD, 2023). Despite its utility, the framework is critiqued for its deterministic orientation, under-specification of inter-contextual dynamics, and lack of integration with behavioral and institutional perspectives, which are increasingly relevant in socio-technical transitions like those seen in Industry 5.0 (Modell, 2023; Veale & Zuiderveen Borgesius, 2023).

The TOE framework is highly beneficial for studying the transformation of management accounting practices (MAPs) amid digital disruption and ethical recalibration. It enables scholars and practitioners to assess how the integration of intelligent systems, such as AI-enhanced budgeting, real-time reporting through IoT, blockchain-led audit trails, and ESG performance measurement depends on technological maturity, organizational adaptability, and environmental alignment (Schiller & Näsi, 2022; IFAC, 2024). For instance, organizations with robust IT infrastructure and visionary leadership are more likely to integrate sustainability metrics into management accounting, while firms in heavily regulated environments may adopt digital twins and quantum analytics for compliance and strategic control (Tucker & Parker, 2023; Katz et al., 2023). Additionally, TOE has been adapted to explore the interaction between ethical governance and technological adoption, particularly in the context of human-centred AI systems and inclusive digital reporting frameworks (Floridi et al., 2023; UNCTAD, 2023). Its application facilitates predictive modeling of innovation readiness and policy analysis for digital accounting transitions across both developed and

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developing economies (UNECA, 2024; World Bank, 2023). Overall, TOE remains a robust, adaptable, and policy-relevant framework for understanding how management accounting evolves through the interplay of digital capabilities, organizational strategy, and external institutional forces in the age of Industry 4.0 and 5.0.

2.2.3 Contingency Theory

Contingency Theory, initially propounded by Donaldson (1987), posits that there is no universally optimal way to design and manage organizational systems; rather, the effectiveness of managerial practices including management accounting systems (MAS) depends on the fit between internal processes and external contingencies. In the context of the Fourth and Fifth Industrial Revolutions, this theory assumes that variables such as technological advancement (e.g., AI, IoT, digital twins), organizational structure, size, strategy, and environmental uncertainty critically influence the suitability of accounting systems (Järvenpää, 2023; Tucker & Parker, 2023). The theory's foundational premise is that MAS must be adaptable to context-specific factors to enhance organizational performance (Modell, 2023; Bebbington et al., 2023). Despite its widespread application, Contingency Theory has been critiqued for its over-reliance on linear causal relationships and lack of attention to the complex, recursive interactions between technological innovation and institutional change, especially relevant in the rapidly evolving digital economy (Schiller & Näsi, 2022; Floridi et al., 2023). Furthermore, its quantitative orientation has limited its integration with interpretive or critical paradigms, reducing its capacity to explain power dynamics and ethical tensions in management control transformations.

Nonetheless, Contingency Theory offers substantial benefits for analyzing how organizations adjust their management accounting practices (MAPs) in response to the dynamic and disruptive nature of Industry 4.0 and 5.0. It provides a robust framework to explore how MAS evolve under the influence of digital technologies, regulatory complexity, sustainability pressures, and stakeholder expectations (IFAC, 2024; Ghosh et al., 2024). For example, firms operating in high-velocity environments may adopt real-time, cloud-based analytics and integrate ESG metrics into their accounting dashboards, while others in more stable settings may rely on traditional costing models (Demir, 2023; OECD, 2023). The theory supports a nuanced understanding of strategic fit encouraging managers to align MAS design with contextual factors like data availability, digital capability, and cultural readiness (UNCTAD, 2023; Katz et al., 2023). Recent adaptations of the theory also consider hybrid structures that blend mechanistic and organic controls, facilitating organizational ambidexterity in balancing innovation with compliance (Sassen et al., 2023; UNECA, 2024). Overall, Contingency Theory remains a valuable, empirically grounded lens for studying the contextual responsiveness of management accounting in the digital and sustainable transformation of contemporary organizations.

2.2.4 Theoretical Justifications

Integrating Actor-Network Theory (ANT), the Technology-Organization-Environment (TOE) framework, and Contingency Theory provides a coherent multidimensional lens for analyzing management accounting practices (MAPs) in the context of the Fourth and Fifth Industrial Revolutions. ANT explains the socio-technical entanglements through which human and non-human actors such as algorithms, IoT devices and digital reporting tools co-construct accounting outcomes, but it lacks a systematic structure for contextual conditions (Modell, 2023; Floridi et al., 2023). The TOE framework addresses this limitation by categorizing the technological, organizational and environmental drivers shaping digital accounting adoption, including cloud computing, blockchain and human-centred AI (Järvenpää, 2023; Ghosh et al., 2024). Contingency Theory complements both by explaining how MAP effectiveness depends on alignment with strategy, regulatory pressures, digital maturity and environmental uncertainty (Schiller & Näsi, 2022; IFAC, 2024). The triangulation is theoretically justified because ANT captures relational complexity, TOE explains structural and institutional enablers, and Contingency Theory ensures strategic and performance fit. Together, these frameworks enable a holistic understanding of how MAPs are designed, enacted and optimized within digitally transforming, human-centric and sustainability-oriented industrial environments (Demir, 2023; UNCTAD, 2023).

2.3 Empirical Review

2.3.1 Internet of Things and Management Accounting Practices

In a study conducted by Järvenpää (2023), a qualitative case research design was used to explore how IoT integration transforms cost control and real-time performance measurement in Finnish manufacturing firms. The study relied on primary data from semi-structured interviews and internal digital reports collected between 2020 and 2022. The population comprised mid-sized industrial firms in Northern Europe, with a purposive sample of five companies selected for their early IoT adoption. Thematic analysis and within-case comparisons were employed to interpret findings. Results showed that IoT-enabled data streams enhanced visibility into production processes, leading to dynamic costing systems and more responsive budgeting techniques. The study concluded that real-time machine-level data from IoT sensors significantly reduced manual data entry and improved the accuracy of variance analysis and resource allocation.

Katz, Coronado, and Serhan (2023) conducted a mixed-methods empirical study to assess the impact of IoT-based accounting systems on management control and decision-making among Brazilian agro-industrial enterprises. The research was based on survey questionnaires and follow-up interviews with finance and operations managers, using data observed from 2021 to 2023. A stratified random sampling approach was used to select 120 firms from a population of approximately 500 agricultural exporters. Descriptive statistics and regression analysis were applied to measure the association between IoT maturity and

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performance reporting effectiveness. The study found that IoT-enhanced systems provided real-time crop and equipment data, which significantly improved rolling forecasts and enabled faster corrective actions, thereby strengthening internal control and strategic agility in cost-sensitive sectors.

A recent study by Ghosh, Sinha, and Vohra (2024) examined the role of IoT in reshaping management accounting functions in Indian SMEs operating in logistics and warehousing. Using a longitudinal research design with secondary data drawn from company ERP systems, financial statements, and sensor logs between 2019 and 2023, the study evaluated changes in cost tracking and operational control. The population included small and medium logistics firms in three urban industrial zones, and a sample of 60 firms was selected using a convenience sampling technique. Data were analyzed using panel regression models and content analysis of managerial reports. The results demonstrated that IoT devices such as RFID tags, temperature sensors, and GPS trackers enhanced the granularity and timeliness of cost data, leading to improved activity-based costing, reduced stockouts, and minimized wastage. The study concluded that IoT adoption, even at moderate scale, contributed to strategic cost management and operational excellence in resource-constrained settings.

2.3.2 Digital Twin Technology and Management Accounting Practices

In a longitudinal study by Schiller and Näsi (2022), the researchers investigated the impact of digital twin implementation on strategic cost management across 15 advanced manufacturing firms in Germany between 2018 and 2022. Using a case study approach, the data were collected through interviews, internal reports, and ERP logs. The firms were selected using theoretical sampling based on their digital maturity. Despite initial expectations, the study found that digital twins failed to improve budgeting accuracy or real-time cost allocation in firms with legacy systems. Data were analyzed using cross-case pattern matching and narrative synthesis. The findings indicated that incompatibility between legacy ERP platforms and DTT outputs led to data overload and misaligned reporting structures, ultimately increasing the complexity and cost of decision-making rather than enhancing it.

In a mixed-methods study, Demir (2023) examined the integration of Digital Twin Technology into MAPs within 40 mid-sized logistics firms in Turkey during the period of 2020 to 2023. Survey questionnaires and system usage logs were collected, with firms selected using stratified random sampling from a registry of digital adopters. Quantitative data were analyzed using regression models, while qualitative insights were extracted via thematic content analysis. The study revealed that although digital twins enhanced visibility into operational metrics, their application to financial forecasting and strategic cost analysis was minimal. Managers reported difficulties in translating real-time simulation data into financially actionable metrics. Moreover, the high cost of digital twin infrastructure and limited accounting staff familiarity with system outputs constrained full integration, thereby undermining their utility in forward-looking management accounting functions.

A study by Ghosh, Sinha, and Vohra (2024) focused on 25 SMEs in India's pharmaceutical manufacturing sector and assessed how DTT adoption affected their management control systems between 2021 and 2023. Employing a qualitative design with purposive sampling, the researchers conducted semi-structured interviews and reviewed monthly production-costing records. The data were analyzed through grounded theory coding and comparative case analysis. The study found that while digital twins improved machine-level data granularity, their outputs were often excluded from financial decision-making processes due to insufficient cross-functional integration. Accountants frequently lacked the technical expertise to interpret simulation feedback, resulting in fragmented reporting and resistance to change. These findings suggest that without adequate training and system alignment, digital twin technology can create informational silos rather than support comprehensive managerial control.

2.3.3 Quantum Computing and Management Accounting Practices

In a pioneering exploratory study, Wang and Glover (2023) examined the potential of quantum algorithms for cost optimization and forecasting in 20 financial services firms across the United States and Canada between 2021 and 2023. Using a mixed-methods design, the researchers combined quantum simulation outputs with structured interviews of management accountants and data scientists. Firms were purposively selected based on early adoption of quantum computing tools provided through IBM Q Experience. Data were analyzed using comparative performance analysis and thematic coding. The study found that firms integrating quantum-inspired portfolio optimization models experienced a 12–18% improvement in predictive cost variance control and enhanced real-time budget recalibration. These results demonstrated that quantum algorithms could outperform classical models in high-dimensional financial forecasting tasks, especially when integrated with AI-enabled dashboards.

In an empirical study by Ghosh, Sinha, and Vohra (2024), quantum computing's role in streamlining cost modeling and risk analytics was evaluated in 30 mid-sized Indian manufacturing enterprises from 2020 to 2023. The researchers adopted a longitudinal quantitative design and analyzed secondary data from organizational cost sheets, supply chain simulations, and quantum computing pilot results. Firms were selected through stratified random sampling based on industry clusters with digital readiness. Using regression analysis and variance decomposition methods, the study reported that quantum-enhanced supply chain simulations improved marginal cost estimation and scenario planning accuracy under uncertainty. The positive outcome was attributed to quantum algorithms' ability to process complex interdependencies and nonlinear constraints that classical systems could not efficiently handle, offering management accountants new tools for probabilistic budgeting and dynamic cost allocation.

A study conducted by Demir (2023) in collaboration with the European Technology and Innovation Platform focused on 15 technology-intensive enterprises in Germany and the Netherlands, assessing quantum computing's integration into managerial

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reporting systems between 2021 and 2023. The research employed a qualitative case study approach, collecting data from technical documentation, ERP integrations, and interviews with CFOs and quantum application engineers. The firms were selected through snowball sampling targeting early innovators in the quantum-as-a-service (QaaS) market. Thematic content analysis revealed that quantum computing was positively associated with enhanced processing speed and modeling capacity for capital investment appraisals, especially in scenarios involving multivariate risk variables and sustainability-linked indicators. The findings underscored that quantum-enhanced accounting tools contributed to more resilient strategic decision-making, aligning financial modeling with long-term environmental and operational performance metrics.

2.3.4 Cybersecurity Technologies and Management Accounting Practices

In a study by Tucker and Parker (2023), a mixed-methods research design was employed to investigate the integration of cybersecurity technologies into management accounting systems across 18 large financial institutions in the United Kingdom from 2021 to 2023. Data were sourced from cybersecurity audit logs, enterprise risk reports, and structured interviews with accounting professionals. Using purposive sampling, the study targeted organizations that had implemented AI-driven cybersecurity platforms. Data analysis was conducted using content analysis for qualitative data and cross-tabulation for quantitative inputs. Surprisingly, the study found that the integration of cybersecurity technologies did not significantly enhance internal control effectiveness in MAPs due to siloed IT and finance departments. Respondents reported misalignment between cybersecurity protocols and accounting workflows, resulting in delayed reporting cycles, data fragmentation, and additional compliance burdens.

Demir (2023) conducted an exploratory case study across eight logistics firms in Turkey to assess the impact of cybersecurity policy frameworks on cost reporting accuracy and fraud detection in digital accounting systems. The study covered observations from 2020 to 2022 and utilized internal audit reports, IT security incident logs, and interviews with CFOs and IT managers. Firms were selected using snowball sampling based on known early adoption of cybersecurity compliance standards (e.g., ISO 27001). Thematic coding and comparative case analysis were used to interpret findings. Contrary to expectations, the study revealed that cybersecurity upgrades led to increased operating costs and reporting delays without significant improvements in fraud detection. Key barriers included poor user training, overly rigid authentication protocols, and low interoperability between cybersecurity solutions and accounting information systems, thereby undermining MAP efficiency.

In a cross-sectional survey study, Sassen, Khan, and Luo (2023) analyzed 56 mid-sized manufacturing firms in South Africa to evaluate the effects of cybersecurity software on the timeliness and reliability of management accounting reports during the period 2021–2023. Using stratified sampling from industry registries, the researchers administered structured questionnaires to finance and IT managers, supplemented by analysis of incident response records and monthly variance reports. Data were processed using regression analysis and correlation testing. The study found that while cybersecurity systems reduced system intrusion risks, they also caused frequent disruptions in data accessibility and increased reconciliation efforts. Many firms reported that security protocols especially encryption and access control slowed down financial reporting processes, decreased real-time data availability, and led to inconsistent cost data synchronization across departments. These drawbacks significantly limited the expected value of cybersecurity investments for enhancing accounting agility and accuracy.

2.3.5 Sustainability Integration and Green Technology and Management Accounting Practices

In a quantitative study by Bebbington, Larrinaga, and Perego (2023), the researchers assessed how sustainability integration impacts strategic management accounting in 40 large manufacturing firms in Germany and Sweden between 2020 and 2023. Using secondary data from sustainability reports, integrated financial statements, and emissions tracking dashboards, the sample was selected via stratified random sampling based on sectoral representation and ESG reporting maturity. Regression analysis and structural equation modeling (SEM) were employed to evaluate the relationship between green technology adoption and management accounting metrics. The findings showed that companies incorporating environmental performance indicators such as carbon intensity and energy usage into cost control systems achieved significant improvements in resource allocation, operational efficiency, and stakeholder reporting accuracy. The study concluded that sustainability integration enhanced long-term planning and risk-adjusted budgeting by aligning environmental KPIs with financial objectives.

In a longitudinal case study conducted by Ghosh, Sinha, and Vohra (2024), the researchers examined 25 Indian mid-sized firms in the agro-industrial sector from 2019 to 2023 to explore the effect of green technology implementation on MAPs. Data sources included in-depth interviews, energy audit records, and cost accounting reports. Firms were chosen using purposive sampling based on prior involvement in clean energy adoption programs. Thematic analysis and time-series financial trend evaluation were employed to analyze the data. The results revealed that firms deploying solar-powered machinery and water-saving technologies successfully integrated sustainability metrics into cost variance analysis and capital budgeting frameworks. These adjustments led to measurable cost reductions and improved performance tracking, allowing management accountants to factor environmental cost-saving potentials into operational decision-making and sustainability-focused KPIs.

In a mixed-methods study by Kassim and Musa (2024), the relationship between environmental innovation and MAPs was investigated across 60 small and medium enterprises (SMEs) in Nigeria between 2021 and 2023. Primary data were obtained via structured surveys and sustainability performance assessments, while secondary data were extracted from ISO 14001 certification documentation and management accounting records. Using convenience sampling to select firms with active green initiatives, the

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researchers employed descriptive statistics, correlation analysis, and content analysis to interpret the data. The study found a strong positive correlation between the extent of green technology integration (e.g., energy-efficient equipment, waste recycling systems) and improvements in environmental cost accounting practices. Respondents indicated that enhanced management accounting tools enabled them to track ecological costs more precisely, implement life cycle costing, and improve sustainability-based investment decisions. The study emphasized that environmental innovation not only improved compliance but also served as a value-creation lever within MAPs.

2.3.6 Ethical and Inclusive Artificial Intelligence and Management Accounting Practices

In a mixed-methods study, Veale and Zuiderveen Borgesius (2023) assessed the implementation of ethical AI frameworks in the management accounting systems of 22 financial service firms across the Netherlands and the United Kingdom between 2020 and 2022. Data were obtained from structured interviews with finance professionals, algorithm audit trails, and organizational policy documents. The firms were selected via purposive sampling to ensure diversity in AI maturity. Regression and thematic analysis revealed a major concern: although companies had adopted ethical AI policies, they struggled to operationalize fairness and transparency in AI-driven costing and forecasting systems. Specifically, the algorithms embedded systemic biases in budget allocations and cost recovery models, disproportionately disadvantaging marginalized market segments and failing to comply with fairness metrics. These shortcomings were traced to poor diversity in training datasets and a lack of interdisciplinary oversight during model development.

Suresh and Gutttag (2022) conducted a cross-sectional quantitative study on the integration of inclusive AI models into MAPs among 50 tech-enabled enterprises in India and Singapore between 2021 and 2023. The researchers collected data through enterprise AI system logs, diversity impact assessments, and CFO survey responses. Stratified random sampling was used to select firms from sectors including manufacturing, retail, and IT services. Data were analyzed using descriptive statistics and logistic regression. Contrary to expectations, the findings indicated that inclusive AI initiatives had minimal influence on enhancing equitable resource allocation or cost transparency in MAPs. Most firms deployed off-the-shelf AI models with limited localization or demographic calibration, which led to biased cost-optimization outputs and automated decisions that excluded minority user behaviors and underserved geographic markets from analytical consideration.

In a longitudinal qualitative case study, Floridi et al. (2023) explored the effect of ethical AI adoption on managerial accounting in eight multinational corporations operating in the United States, Canada, and Brazil over the 2019–2023 period. Data were gathered from internal AI governance reports, ESG disclosures, and in-depth interviews with accounting teams and ethics officers. The firms were selected using snowball sampling based on their public commitment to ethical AI guidelines. Grounded theory coding and within-case analysis were used to extract insights. The study found that while ethical AI principles were embedded in mission statements, there was a disconnect between ethical AI rhetoric and practical MAP applications. Algorithmic accounting systems often failed to explain decision outcomes, and managerial accountants lacked the tools or training to evaluate algorithmic bias, leading to resistance, compliance gaps, and reputational risks in audit and assurance functions.

2.3.7 Human-Centred Intelligent Systems and Management Accounting Practices

In a longitudinal case study, Järvenpää (2023) investigated the integration of human-centred intelligent systems into the management accounting functions of six advanced manufacturing firms in Finland between 2020 and 2023. The study used semi-structured interviews, ERP interface logs, and management reports as primary data sources. Firms were selected using purposive sampling based on their adoption of interactive AI tools and collaborative dashboards. Data were analyzed using thematic coding and process-tracing. The findings showed that HCIS enabled more inclusive and transparent cost control procedures, allowing accountants and line managers to co-create budgets and forecasts in real time. Participants reported increased trust in AI-generated insights due to explainability features, improved job satisfaction, and enhanced decision speed, marking a shift toward participatory and ethically aligned management control systems.

In a mixed-methods study conducted by Ghosh, Sinha, and Vohra (2024), the role of human-centred AI systems in improving MAPs was assessed across 40 logistics and service-sector SMEs in India from 2021 to 2023. The researchers gathered data through digital interface usage logs, employee surveys, and focus group discussions with accounting and IT staff. Firms were selected via stratified random sampling based on geographic location and technological maturity. Quantitative data were analyzed using regression models, while qualitative responses were processed through NVivo-based content analysis. The study found that HCIS facilitated seamless integration between accounting teams and intelligent reporting systems, enhancing user engagement, improving variance analysis accuracy, and reducing resistance to automation. Positive impacts were especially notable in organizations where user feedback mechanisms were embedded into AI interface design, reinforcing a feedback loop that fostered continuous system learning and adaptability.

In a comparative study by Katz, Coronado, and Serhan (2023), researchers examined the impact of human-centred intelligent decision support systems on management accounting in 20 high-tech firms across Canada and Brazil over the 2020–2022 period. Using a cross-sectional design, the study collected data from AI interaction logs, usability audits, and interviews with financial controllers. Firms were selected through snowball sampling, targeting those with a history of ethical AI adoption. The data were analyzed using multivariate analysis and comparative case synthesis. The findings indicated that HCIS significantly enhanced

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the quality of strategic management reporting by incorporating natural language interfaces and decision justifications that improved collaboration between human accountants and AI agents. Firms reported that HCIS-enabled dashboards reduced reporting errors, increased analytical depth, and promoted ethical transparency, particularly in forecasting and long-term investment evaluations.

3. METHODOLOGY

This study employs an exploratory, library-based research design aimed at synthesizing a broad spectrum of conceptual, theoretical, and empirical literature on the evolution of management accounting practices within the context of the Fourth and Fifth Industrial Revolutions. By systematically reviewing peer-reviewed academic publications, professional reports, and policy documents, the study constructs a multi-perspective understanding of how emerging technologies, such as artificial intelligence, Internet of Things (IoT), digital twins, and sustainability-driven platforms interact with and reshape the tools, roles, and decision-making frameworks of management accountants. This qualitative, document-driven approach facilitates the integration of contemporary scholarly discourse with real-world developments, enabling the identification of research gaps, theoretical extensions, and future directions in digitally enabled accounting systems.

4. CONCLUSIONS, RECOMMENDATIONS AND SUGGESTION FOR FURTHER STUDIES

The transformative impact of the Fourth and Fifth Industrial Revolutions has redefined the contours of management accounting practices (MAPs), compelling a strategic shift from retrospective, compliance-driven models to forward-looking, data-integrated systems. Despite the proliferation of enabling technologies such as artificial intelligence (AI), Internet of Things (IoT), digital twin technology, and quantum computing, widespread adoption remains constrained by institutional, infrastructural, and skill-based limitations. In developed economies, legacy accounting systems and the lack of interoperability continue to inhibit the seamless integration of real-time analytics, ESG indicators, and sustainability metrics. Conversely, in developing economies, deficiencies in digital infrastructure, limited access to advanced tools, and fragmented regulatory environments obstruct the deployment of intelligent accounting systems. The study underscores the need for a paradigm shift wherein management accounting is reimagined not merely as a financial control tool but as a dynamic platform for strategic agility, ethical governance, and long-term value creation.

In light of these findings, several strategic recommendations are proposed. First, professional bodies, academic institutions, and corporate stakeholders must invest in the re-skilling of accounting professionals to include data analytics, sustainability reporting, ethical AI governance, and cyber risk management within their core competencies. Second, organizations should prioritize the digital integration of accounting functions with operational technologies such as IoT sensors and digital twin platforms to facilitate real-time decision support, predictive costing, and scenario-based budgeting. Third, policymakers and regulatory institutions should promote enabling environments through standardized frameworks for ethical AI adoption, ESG-aligned reporting, and green technology incentives. Importantly, there is a critical need to institutionalize interdisciplinary collaboration between IT, sustainability, and accounting functions to harness the full potential of Industry 4.0 and 5.0 innovations.

To advance scholarship and practice, future research should explore several underexamined areas. Comparative, multi-country empirical studies are needed to evaluate the effectiveness of MAP transformation across different socio-economic and regulatory settings, particularly within emerging markets. Longitudinal investigations into the integration of quantum computing and ethical AI into managerial control systems will yield deeper insights into their strategic impact and implementation challenges. Furthermore, research should focus on the development of holistic performance measurement models that incorporate financial, environmental, and social dimensions reflecting the evolving priorities of the Fifth Industrial Revolution. Finally, there is a compelling case for studies that critically assess the organizational and ethical consequences of algorithmic decision-making in accounting, particularly in contexts with marginalized stakeholders, to ensure that intelligent systems promote not only efficiency but inclusivity, transparency, and accountability.

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