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Emerging Trends in Edge-Intelligent Wearables: AI–IoT Convergence for Biotechnology

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ABSTRACT

Wearable technology integrated with artificial intelligence (AI), the Internet of Things (IoT), biotechnology, and edge computing constitutes a distributed, real-time sensing and analytics ecosystem that is reshaping data-driven healthcare and smart systems. Despite rapid technical advances in the adoption of AI- and edge-enabled wearables, this study examines how the convergence of wearable devices, artificial intelligence (AI), the Internet of Things (IoT), biotechnology, and edge computing is reshaping data-driven healthcare and smart systems by enabling real-time sensing, low-latency analytics, and autonomous decision-making. This work highlights the persistent digital divides, especially in Africa, where weak broadband, unreliable power, affordability constraints, and fragmented governance impede adoption. Synthesizing recent evidence and adoption theories, the study finds strong potential for AI-enabled wearables to advance health equity through remote diagnostics and data-guided interventions, while noting unresolved gaps in interoperability, cybersecurity, and standards. It argues for localized edge intelligence, ethical data frameworks, and targeted infrastructure investment, providing a concise roadmap for policymakers, researchers, and industry to align technical innovation with equity, resilience, and responsible, scalable deployment.

Keywords: Artificial Intelligence, Biotechnology, Edge computing, Internet of Things, Wearable devices

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1. INTRODUCTION

The 21st century has ushered in an era of interconnected intelligence where technologies such as wearable devices, artificial intelligence (AI), biotechnology, Internet of Things (IoT), and edge computing are converging to redefine the digital landscape. These technologies

are driving the transition from conventional reactive systems to proactive and predictive frameworks that rely on real-time data collection, analytics, and automated decision-making. In modern economies, this convergence underpins the development of smart environments ranging from intelligent healthcare and smart cities to industrial automation, precision agriculture, and environmental monitoring. As shown in Figure 1, IoT serves as the underlying infrastructure that connects multiple domains, including health monitoring, smart cities, smart grids, retail IoT, transport systems, and smart manufacturing (Alahi et al., 2023; Whaiduzzaman et al., 2022). It is this interconnected ecosystem that enables seamless data exchange and integration between physical and digital systems, thereby creating the foundation for the current wave of digital transformation.

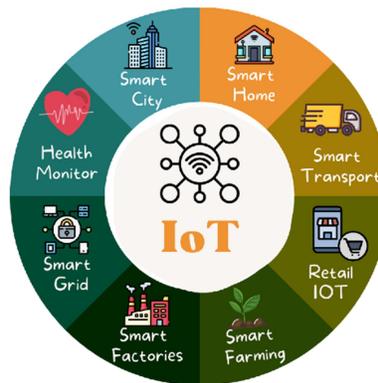


Figure 1. Internet of Things (IoT) Applications Across Sectors (Whaiduzzaman et al., 2022)

The continuous evolution of wearable technology lies at the center of this transformation. Initially designed as consumer fitness trackers and lifestyle accessories, wearable devices have evolved into advanced biosensing systems capable of monitoring vital health parameters such as heart rate, blood oxygen saturation, electrocardiogram (ECG) signals, and sleep cycles. These devices are increasingly integrated with AI algorithms and IoT frameworks to analyze physiological data, detect anomalies, and provide actionable insights. Lu et al. (2020) describe this evolution as a paradigm shift from passive health tracking to ubiquitous healthcare, where the body becomes a data-generating interface connected to intelligent analytics platforms. Abdulmalek et al. (2022) further assert that IoT-based healthcare-monitoring systems have significantly improved the quality of life by facilitating continuous, non-invasive observation and enabling timely clinical intervention. These systems have reduced the need for in-hospital monitoring, allowing patients and clinicians to interact through remote care frameworks that combine efficiency, accessibility, and personalized service delivery through continuous connectivity and distributed computation.

The integration of edge computing has further transformed the architecture of wearable and IoT systems. The powerful conventional cloud-based systems are limited by latency, bandwidth demand, and privacy constraints. Edge computing addresses these challenges by decentralizing data processing, moving analytics closer to the source of data generation. Gill et al. (2025) explain that edge artificial intelligence (Edge AI) allows for real-time decision-making by performing inference directly on local devices or gateways rather than transmitting all data to distant cloud servers. This distributed intelligence enhances responsiveness in time-sensitive applications such as cardiac monitoring and emergency response.



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Pereira et al. (2024) demonstrate that integrating machine learning models into edge computing environments improves system resilience, energy efficiency, and operational scalability. These advancements represent a fundamental shift from static systems to adaptive, self-learning ecosystems capable of autonomous operation, a critical innovation for the next generation of smart health and industrial solutions. Despite their growing prominence, the diffusion and adoption of wearable and IoT technologies remain uneven across global regions. Advanced economies have rapidly integrated these systems into healthcare and industrial operations, while many developing regions face persistent infrastructural and policy-related constraints.

Kuaban et al. (2024) and Kumar et al. (2025) identify unreliable broadband connectivity, inadequate power infrastructure, and limited investment as key barriers to IoT adoption in Africa's Silicon Mountain ecosystem. Additionally, socio-economic and behavioral factors influence technology acceptance. Worlanyo et al. (2023) report that in Ghana, awareness of wearable technologies is relatively high, but affordability and technical literacy challenges hamper adoption. Nielsen et al. (2024) stated that wearable devices are feasible and acceptable among young women in Kampala's informal settlements, the sustainability of use is restricted by charging limitations and cost barriers. Thomas et al. (2025) further highlights that technology readiness and perceived usefulness are significant determinants of wearable adoption in South African workplaces, reinforcing the importance of human, organizational, and cultural factors in driving diffusion.

The need for this study stems from the growing digital divide between technologically advanced and developing economies in the context of wearable and IoT innovation. Although global research and industry investments are propelling advancements in digital health, Africa and other emerging regions continue to experience limited integration due to systemic challenges. Segun-Omosehin et al. (2025) observe that fragmented policy frameworks, weak governance structures, and limited coordination among stakeholders hinder the effective adoption of digital health technologies in sub-Saharan Africa. However, the integration of AI and IoT introduces new ethical and cybersecurity risks. Matekaire and Siriram (2025) reported that the lack of cybersecurity standards and data-protection legislation in African Small and Medium-sized Enterprises (SMEs) undermines trust and prevents full utilization of IoT applications. This highlights the urgent need for holistic research that not only explores the technical aspects of emerging technologies but also examines the socio-economic, ethical, and regulatory contexts that shape their diffusion and impact.

The significance of this study lies in its contribution to both academic scholarship and practical innovation management. The study enhances understanding of how technologies evolve, interact, and diffuse within different socio-economic ecosystems. It integrates insights from multiple theoretical perspectives, including the Diffusion of Innovations (DOI), Technology Acceptance Model (TAM), and Unified Theory of Acceptance and Use of Technology (UTAUT), to provide a multidimensional understanding of adoption behavior. The research provides valuable evidence for governments, healthcare providers, and digital entrepreneurs seeking to leverage emerging technologies for sustainable development. Walter et al. (2024) argue that equitable deployment of wearable and IoT systems can bridge healthcare inequities by decentralizing access to medical resources. However, achieving this vision requires investment in digital infrastructure, interoperability standards, and governance models that safeguard data privacy while promoting inclusion.

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The importance of this work extends beyond healthcare into broader applications of AI and IoT ecosystems in smart cities, manufacturing, and environmental sustainability. As shown in Figure 1, IoT serves as a central enabler across sectors, linking smart homes, transportation systems, energy grids, and industrial processes (Alahi et al., 2023; Whaiduzzaman et al., 2022). The integration of wearables, IoT, and edge computing, this work contributes to the global discourse on Industry 5.0, a movement that prioritizes human-centric, intelligent, and resilient systems. This study also promotes digital sovereignty, local innovation, and data-driven governance. Huang et al. (2025) and Huhn et al. (2022) provide empirical evidence that wearable devices can successfully generate high-quality, individual-level health data even in low-income environments, highlighting the potential for locally adaptable digital ecosystems.

This study aims to provide a comprehensive examination of the evolution, diffusion, acceptance, and uptake of emerging technologies, with a particular focus on the interplay between wearable technology, AI, biotechnology, IoT, and edge computing. It seeks to identify the technological, behavioral, and policy determinants influencing their adoption, especially in developing contexts. The work underscores that technological innovation alone does not guarantee progress, but it is the integration of technology with human readiness, policy support, and ethical governance that ensures inclusive and sustainable digital transformation.

2. RELATED LITERATURE

The convergence of wearable technology, artificial intelligence (AI), the Internet of Things (IoT), biotechnology, and edge computing represents one of the most dynamic transformations in modern technology and healthcare systems. These technologies have evolved from isolated applications into interconnected ecosystems capable of sensing, processing, and analyzing real-time physiological and environmental data. The integration of wearables and IoT networks enables continuous health and environmental monitoring, allowing users and healthcare providers to detect abnormalities early and take preventive action. As global research shows, the combination of AI-driven analytics and IoT architecture has enhanced the predictive and diagnostic capabilities of healthcare technologies, improving not only clinical accuracy but also operational efficiency across sectors (Lu et al., 2020; Ghadi et al., 2025). This paradigm shift signifies the emergence of intelligent, adaptive, and context-aware systems that redefine traditional notions of patient care, data management, and decision support.

The evolution of wearable technologies has been characterized by miniaturization, increased sensor precision, and the embedding of AI algorithms that allow for autonomous data interpretation. According to Lu et al. (2020), wearable health devices have matured from simple activity trackers into complex biomedical systems capable of monitoring vital signs, motion, sleep patterns, and biochemical signals. The authors state that such devices are pivotal in shifting healthcare models from reactive to proactive, emphasizing prevention, early diagnosis, and continuous patient engagement. Abdulmalek et al. (2022) argue that IoT-based healthcare systems have become essential for remote patient monitoring, integrating body area sensors and wireless networks to provide real-time data exchange between patients and medical professionals. These developments facilitate timely clinical interventions and improve overall health outcomes enabled by advanced communication protocols and edge computing. Artificial intelligence and edge computing play a central role in expanding the functionality of wearables and IoT systems.

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Traditionally, healthcare data were transmitted to centralized cloud systems for analysis, but this approach introduced latency, security, and bandwidth challenges. Edge computing mitigates these issues by relocating computation closer to the data source. Gill et al. (2025) emphasized that Edge AI architecture combines the learning capabilities of machine learning models with the responsiveness of localized data processing, thereby supporting real-time analytics and decision-making. Pereira et al. Souza (2024) further highlighted that edge-enabled machine learning models optimize system efficiency by reducing data transmission loads, conserving energy, and ensuring resilience in low-connectivity environments.

These findings reveal how edge computing and AI converge to enhance data privacy, system scalability, and device intelligence, making them critical for the next generation of wearable health systems. Apart from the technical architecture, the diffusion and adoption of wearable and IoT technologies reveal varied patterns across regions. Research in developing economies highlights a complex interaction between technological readiness, socio-economic conditions, and user perception. Worlanyo et al. (2023) observed that awareness of wearable fitness devices among Ghanaians is high, yet adoption remains low due to affordability constraints and limited interoperability. In Uganda, Nielsen et al. (2024) found that wearable devices were both feasible and acceptable among young women in low-income communities, but challenges such as inconsistent charging access and high costs affected sustained use.

Thomas et al. (2025) noted that in South African workplaces, employee acceptance of wearable technology was influenced by perceived usefulness, trust in data handling, and technological self-efficacy factors consistent with behavioral frameworks like the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT). These studies collectively suggest that successful diffusion depends not only on technological advancement but also on institutional trust, cultural fit, and economic accessibility.

Despite their transformative potential, wearable and IoT technologies face persistent barriers that constrain scalability, particularly in Africa and other developing regions. Kumar et al. (2025) identified infrastructural deficiencies such as weak broadband coverage, power instability, and inadequate funding as major obstacles to IoT adoption in Africa's emerging technology ecosystems. Matekaire and Siriram (2025) extended this discussion by highlighting cybersecurity vulnerabilities and weak digital governance as critical impediments to the expansion of IoT-based systems in small and medium enterprises. These challenges with high device costs and limited digital literacy create uneven technology diffusion across socio-economic and geographic lines. Edge-enabled wearables still contend with hardware constraints from a technical perspective, including limited battery capacity, restricted processing power, and non-standardized communication protocols. These factors not only affect performance but also raise concerns about interoperability and data integrity across diverse platforms.

Ethical and privacy considerations have emerged as another important dimension of wearable and IoT deployment. As data collection becomes more pervasive, issues surrounding consent, ownership, and algorithmic bias have gained global attention. Walter et al. (2024) emphasized that wearable devices can democratize healthcare by extending diagnostic access to underserved populations, they also risk reinforcing inequalities if affordability and security data are not adequately addressed.



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Segun-Omosehin et al. (2025) added that in sub-Saharan Africa, fragmented digital-health governance and inconsistent policy enforcement limit progress toward equitable and secure adoption. The author emphasized that establishing harmonized national data protection policies, alongside ethical AI frameworks, is vital to ensuring inclusiveness and sustainability. These insights underscore the need for a multidisciplinary approach that balances innovation with accountability, aligning technological development with human rights and regulatory compliance.

Emerging literature provides a positive outlook for the future of wearable and IoT technologies. Huang et al. (2025) and Huhn et al. (2022) demonstrated that wearable systems could effectively generate reliable, individual-level health data even in low-resource settings, confirming their adaptability beyond high-income regions. Their findings highlight the potential of data-driven healthcare in population health management, epidemiological monitoring, and personalized medicine. Pereira et al. (2024) reinforced this perspective by proposing energy-efficient and context-aware AI algorithms that can improve device longevity and predictive accuracy in dynamic environments. The next frontier for research lies in the development of interoperable standards, energy-efficient computing, and inclusive policy frameworks that address Africa's infrastructural and socio-economic realities.

The integration of biotechnology through biosensors, implantable systems, and nanomaterials will further advance wearable technology, enabling precision diagnostics and seamless human-machine interfaces. Coordinated policy interventions and collaborative research can achieve sustainable impact, and governments should prioritize digital infrastructure investment, regulatory alignment, and cybersecurity resilience to strengthen the adoption of wearable and IoT ecosystems. Academia and industry must collaborate on developing interoperable platforms and open data standards that encourage innovation while maintaining ethical boundaries. Future research should focus on culturally adaptive user-experience design, cross-sector integration, and the measurement of long-term socio-economic benefits of wearable adoption. As the literature describes, wearable technologies are not merely engineering artifacts, but they are socio-technical systems that reflect the intersection of innovation, policy, and human behavior. Their future success will depend on the collective ability to bridge gaps in access, ethics, and governance while fostering inclusive innovation across all regions.

3. EVOLUTION, DIFFUSION, ACCEPTANCE, AND UPTAKE OF THESE TECHNOLOGIES IN AFRICA AND BEYOND

The evolution of wearable technology has been shaped by a growing convergence of artificial intelligence (AI), the Internet of Things (IoT), edge computing, and biotechnology, each contributing to the development of intelligent, networked, and context-aware systems. Early wearable devices, such as fitness trackers and pedometers, primarily focused on activity and heart-rate monitoring. Today, advancements in sensor design, microelectronics, and communication networks have transformed these devices into complex biosensing ecosystems that monitor physiological, biochemical, and behavioral parameters in real time (Vo et al., 2024).

The integration of AI enables predictive analytics and adaptive responses, while IoT connectivity ensures data can be shared seamlessly across platforms and healthcare systems (Abdulmalek et al., 2022). Pereira et al. (2024) stated that the use of machine

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learning within edge-based wearables now allows for faster, localized processing of health data, reducing latency, conserving bandwidth, and improving privacy.

Globally, the diffusion of wearable devices has accelerated due to the proliferation of mobile technologies, improvements in cloud computing, and the deployment of high-speed communication infrastructures. The IoT ecosystem has expanded rapidly, enabling interoperability between wearable sensors, smartphones, and healthcare databases. Gill et al. (2025) emphasize that the evolution of “Edge AI” has been critical in optimizing computational efficiency for these connected systems, allowing devices to make autonomous decisions without heavy dependence on centralized servers. Ghadi et al. (2025) highlight how AI-enhanced IoT frameworks have enabled healthcare wearables to collect, process, and transmit medical data for personalized diagnosis and disease management. These global developments have driven innovation in various sectors beyond health, including manufacturing, defense, sports, and education, thereby accelerating global uptake.

In Africa, diffusion patterns remain more heterogeneous. African nations are experiencing rapid digital transformation characterized by “leapfrog” innovation while developed economies lead in large-scale adoption, where mobile-based and IoT-driven solutions bypass legacy infrastructure constraints (Kuaban et al., 2024). The continent’s growing network coverage and smartphone penetration have become enablers of wearable technology, particularly within healthcare, retail, and education (Matekaire and Siriram, 2025). Studies show that IoT adoption is increasing within local technology ecosystems, yet major barriers such as limited funding, poor infrastructure, and skills gaps persist (Kumar et al., 2025). Despite these challenges, IoT adoption within Africa’s Silicon Mountain region and other tech clusters demonstrates significant potential for scalable, low-cost solutions (Kuaban et al., 2024). The expansion of edge computing architecture further supports distributed processing in low-bandwidth environments, offering sustainable pathways for innovation and data sovereignty across the continent.

Acceptance of wearable technologies is a multifaceted process influenced by cultural context, affordability, trust, and perceived usefulness. Pandey et al. (2022) observed that in developing economies, socio-demographic factors such as gender, income level, and technology readiness significantly shape acceptance behavior. Worlanyo et al. (2023) found that in Ghana, user knowledge, comfort, and perceived health benefits strongly influenced wearable fitness device adoption. Thomas et al. (2025) identified that employee readiness and digital literacy are major determinants of workplace wearable adoption in South Africa. These studies underscore that acceptance is not simply a function of technology design but also of user education, accessibility, and perceived personal value. Huang et al. (2025) and Huhn et al. (2022) demonstrated that wearables can be effectively deployed even among vulnerable populations in low-income settings if devices are culturally adapted and privacy concerns addressed.

The uptake of wearables across Africa has been strongest in health-related applications, where IoT and AI integration are addressing persistent gaps in access to care. Nielsen et al. (2024) reported successful implementation of wearable sleep and activity monitoring among women in informal settlements in Kampala, Uganda, highlighting their feasibility in low-resource environments. Walter et al. (2024) also noted that wearables, when combined with equitable design and accessibility frameworks, can enhance health equity by extending monitoring capabilities to underserved populations. The emergence of AI-enabled biosensors capable of tracking complex physiological indicators such as glucose, lactate, or hydration further expands the potential of these technologies (Vo et al., 2024).

Furthermore, the integration of edge computing and AI in e-health devices is enabling real-time analytics for diagnostics, disease prediction, and rehabilitation (Ghadi et al., 2025). These developments mark a transition from basic fitness monitoring to personalized, preventative, and precision healthcare models. The ongoing digitalization efforts and ecosystem collaboration support Africa's uptake of wearable and associated technologies from a technological perspective. Edge computing is emerging as a crucial enabler, allowing decentralized processing and reducing dependence on unstable internet connections. This is especially relevant in African universities and research centers, where local edge architectures are now being explored to enhance data autonomy and processing speed (Sithole et al., 2025). The combination of IoT and edge intelligence presents a promising path for scalable innovation, offering robust solutions for data management, security, and healthcare delivery, while structural constraints remain significant.

Kumar et al. (2025) emphasize that African IoT ecosystems face technical and governance barriers, including inconsistent standards and weak cybersecurity frameworks, which can undermine long-term scalability. Despite these challenges, the future trajectory for wearable and associated technologies in Africa is optimistic. With the growing investment in connectivity, AI innovation, and local research capacity, the continent is gradually aligning with global trends. Abdulmalek et al. (2022) point out that IoT-based health monitoring systems are already improving patient outcomes and quality of life through continuous remote observation and personalized feedback. As AI, IoT, and biotechnology converge, new opportunities for early diagnosis, preventive care, and telemedicine will emerge to address inequities and strengthen public health systems. Walter et al. (2024) reported that the next decade will witness a paradigm shift in healthcare delivery, where wearable technologies become integral components of inclusive, data-driven, and equitable digital ecosystems across Africa and beyond.

4. THEORETICAL FRAMEWORKS APPLICABLE TO EVOLUTION, DIFFUSION, ACCEPTANCE, AND UPTAKE

Emerging technologies such as wearable devices, edge computing, artificial intelligence (AI), and the Internet of Things (IoT) evolve, diffuse, and achieve sustained acceptance, requiring the application of rigorous theoretical frameworks. These frameworks explain not only the technological trajectory of innovations but also the behavioral, institutional, and socio-technical mechanisms that determine whether such technologies are successfully adopted and integrated into everyday life. The processes of evolution, diffusion, acceptance, and uptake are interconnected phases within the innovation lifecycle, and frameworks such as the Diffusion of Innovations (DOI) theory, the Technology Acceptance Model (TAM) and its extensions (UTAUT/UTAUT2), the Technology Organization Environment (TOE) framework, and the Normalization Process Theory (NPT) together offer a comprehensive theoretical foundation to analyze these dynamics.

The Diffusion of Innovations (DOI) theory, first developed by Everett Rogers, provides the conceptual basis for understanding how innovations evolve and spread across populations or organizations. The theory posits that diffusion occurs through communication channels over time among members of a social system, and that adoption decisions are influenced by five key attributes, which are relative advantages, compatibility, complexity, trialability, and observability. The evolution phase reflects the technical maturation of innovations such as miniaturized sensors,

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AI integration and edge computing, while the diffusion phase represents the spread of these technologies across users, industries, and regions. Jeilani and Hussein (2025) demonstrate, digital health innovations follow a diffusion trajectory that depends heavily on organizational readiness, policy alignment, and user awareness. Zhang et al. (2022) utilized an agent-based modeling approach to show how social influence, network effects, and communication dynamics accelerate or inhibit the diffusion of smart wearables, revealing that adoption rates are not solely determined by technical performance but by social interactions and perceptions of relative advantage. This theoretical lens bridges the technical and sociological dimensions of innovation, providing insight into how technological evolution translates into adoption across populations.

The DOI explains the macro-level diffusion process, the Technology Acceptance Model (TAM), and the Unified Theory of Acceptance and Use of Technology (UTAUT/UTAUT2) focus on the individual and organizational determinants of technology acceptance. According to TAM, perceived usefulness (PU) and perceived ease of use (PEOU) are the primary factors influencing users' behavioral intentions toward adopting a new technology. The UTAUT model extends this framework by integrating social influence, performance expectancy, effort expectancy, facilitating conditions, and hedonic motivation as key determinants of intention and usage. Malarvizhi et al. (2025) adopted an extended UTAUT model to IoT-enabled healthcare devices among elderly users and found that perceived product value and technological accuracy significantly influenced acceptance intentions.

These findings highlight that, in health and wearable technologies, acceptance is driven not only by usability and functionality but also by trust in device reliability and data accuracy. Thomas et al. (2025) observed that employee readiness and perceived benefits were strong predictors of wearable technology acceptance in South African workplaces, confirming that behavioral and psychological readiness mediate adoption outcomes. Furthermore, Suhluli and Ali Khan (2022) emphasized that social norms and privacy concerns play a pivotal role in moderating the relationship between perceived usefulness and behavioral intention in the adoption of wearable IoT devices. These models provide a robust understanding of how cognitive, affective, and contextual factors shape individual and organizational technology acceptance.

The Technology Organization Environment (TOE) framework provides a comprehensive structure for analyzing how contextual factors influence technology adoption and long-term uptake. The TOE model posits that adoption is shaped by three interdependent domains which are technological (relative advantage, complexity, compatibility), organizational (resources, size, culture, management support), and environment (competition, regulatory policies, and infrastructure). This perspective is particularly useful in understanding institutional adoption and diffusion of IoT and edge technologies in developing economies. Kuaban et al. (2024) employed the TOE framework to examine IoT adoption in African technology ecosystems, concluding that infrastructural readiness, regulatory clarity, and organizational capacity significantly determine successful diffusion.

The study revealed that while awareness of IoT technologies is high, structural constraints such as unreliable power supply and inadequate digital infrastructure remain substantial barriers to sustained uptake. TOE offers an integrative explanation of how macro-level environmental conditions and micro-level organizational factors jointly influence adoption outcomes. The Normalization Process Theory (NPT) elucidates how new technologies transition from experimental tools to normalized, routine practices.



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NPT focuses on the collective and organizational processes that embed technologies into everyday workflows through four mechanisms such as coherence (sense-making), cognitive participation (engagement), collective action (operational work), and reflexive monitoring (evaluation). NPT also helps explain the uptake phase, where users, professionals, and organizations integrate innovations into regular activities. For instance, in healthcare settings, NPT clarifies how the successful normalization of digital monitoring systems depends not only on training and usability but also on continuous evaluation, user engagement, and workflow integration. NPT extends the analytical reach of TAM and TOE from initial adoption toward sustained, meaningful use by emphasizing social processes and feedback mechanisms.

Integrating these frameworks provides a multi-stage theoretical architecture that captures the full innovation lifecycle. The evolution stage represents the technical advancement and design optimization of technologies, as the diffusion stage involves their propagation through social and institutional networks (DOI), the acceptance stage focuses on cognitive and behavioral determinants influencing user intention (TAM/UTAUT), while the uptake or institutionalization stage addresses the embedding of technology into organizational routines and social systems (TOE and NPT). These frameworks offer a comprehensive approach to understanding how technological innovations mature, spread, and sustain within diverse environments. This model is especially relevant to Africa and other emerging regions, where technological innovation often outpaces infrastructural, policy, and human readiness.

These frameworks reveal that successful technology diffusion and uptake require not only technical evolution but also supportive ecosystems, cultural acceptance, and institutional integration. The theoretically grounded understanding of evolution, diffusion, acceptance, and uptake can guide policymakers, researchers, and practitioners in designing strategies that foster sustainable technological transformation. These frameworks collectively underscore that innovation is not a linear process, but a multi-dimensional phenomenon shaped by the interaction of technology, people, organizations, and environments. Emerging technologies such as wearables and IoT systems, embedding these theories into policy and implementation design, ensure that advancements translate into real societal impact, bridging the gap between invention and equitable adoption.

5. FINDINGS ON THE USEFULNESS OF TECHNOLOGY AND TECHNOLOGY GAPS/LIMITATIONS IN AFRICA AND BEYOND

Recent developments in wearable devices, artificial intelligence (AI), Internet of Things (IoT), and edge computing have significantly transformed the global digital health ecosystem. Studies consistently emphasize their usefulness in enhancing healthcare delivery, promoting real-time monitoring, and supporting preventive care. According to Abdulmalek et al. (2022), IoT-based healthcare systems have revolutionized patient monitoring by enabling continuous tracking of physiological data, which improves diagnostic accuracy and overall quality of life. Pereira et al. (2024) add that integrating machine learning with edge computing has created robust architectures for localized analytics, reducing latency and enhancing data security while enabling continuous operation even in low-connectivity environments. Ghadi et al. (2025) demonstrate that the convergence of AI, IoT, and edge computing in wearable devices optimizes medical data collection, analysis, and predictive health modeling paving the way for personalized medicine and efficient telehealth interventions.

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Segun-Omosehin et al. (2025) reported a comprehensive evaluation of Africa's digital health landscape, observing that while the adoption of wearables, telemedicine, and mobile health (mHealth) technologies has accelerated, the region's ecosystem still requires structural investments in interoperability, governance, and equity. The study notes that AI-driven and IoT-enabled systems are already improving healthcare coordination in countries such as Kenya, Nigeria, and South Africa, yet scalability is constrained by infrastructure readiness and digital policy maturity. This reinforces global findings that technology usefulness depends not only on technical innovation but also on systemic readiness and institutional frameworks. The usefulness of wearable and IoT technologies extends beyond healthcare. Gill et al. (2025) highlighted that Edge AI systems significantly enhance computational efficiency by decentralizing processing, allowing smart devices and wearables to function autonomously and securely without relying heavily on cloud servers.

These technologies have also begun addressing local challenges in Africa. Huang et al. (2025) and Huhn et al. (2022) found that wearable devices can successfully generate individual-level data among vulnerable populations in low- and middle-income countries, demonstrating their value for inclusive research and public health management. Nielsen et al. (2024) confirmed the feasibility and acceptability of wearable sleep and activity monitors among young women in the informal settlements of Kampala, Uganda, underscoring the adaptability of these tools in low-resource contexts. Worlanyo et al. (2023) also observed that wearable fitness devices increased self-awareness and improved healthy lifestyles among Ghanaians, providing evidence of their behavioral and preventive health benefits. These findings affirm that wearable and IoT-enabled systems are not only useful for individual health tracking but are also enabling data-driven decision-making for community health interventions in resource-constrained environments.

Despite these benefits, the literature identifies critical technology gaps and limitations that constrain the full realization of these innovations, particularly in Africa. Kuaban et al. (2024) and Kumar et al. (2025) both observed that weak broadband infrastructure, poor power supply, and inadequate funding remain primary barriers to IoT and wearable diffusion within African ecosystems. Infrastructure fragility limits the scalability of digital health projects that rely on continuous connectivity and cloud integration. Segun-Omosehin et al. (2025) further emphasize that fragmentation in digital health policies and data frameworks across sub-Saharan Africa creates interoperability challenges and reduces cross-country collaboration potential. The issue of affordability and accessibility also persists. Worlanyo et al. (2023) reported that despite high awareness of wearable technologies, adoption rates remain low due to cost barriers and limited device availability.

Pandey et al. (2022) similarly demonstrated that socio-economic status, gender, and technology readiness significantly influence wearable adoption rates in developing countries, revealing the digital divide between demographics and income groups. At the technical level, interoperability, data governance, and device performance remain pressing issues. Abdulmalek et al. (2022) and Ghadi et al. (2025) both identified a lack of unified standards for data interoperability, raising privacy and integration concerns for IoT-based health systems. Edge computing, while promising, also faces hardware limitations, including energy constraints, short battery lifespans, and inadequate on-device computational power (Gill et al., 2025). Matekaire and Siriram (2025) revealed that cybersecurity vulnerabilities and weak digital governance frameworks among African small and medium enterprises (SMEs) hinder IoT adoption.



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These structural weaknesses reinforce the need for national digital transformation policies emphasizing resilience, security, and inclusiveness. Beyond infrastructure and policy gaps, there is a contextual limitation in the existing literature, which is that most African studies are urban-centric, leaving rural populations underrepresented in digital adoption research (Nielsen et al., 2024). This highlights a gap in understanding rural user behavior, health outcomes, and device usability under diverse socio-economic conditions. Nevertheless, emerging evidence suggests that Africa is positioned to benefit substantially from these technologies if the identified barriers are addressed. Walter et al. (2024) argue, the equitable design and deployment of wearables and IoT systems can bridge healthcare inequities by decentralizing health access and democratizing data. Pereira et al. (2024) further advocate for localized edge computing models that allow African innovators to process health data on-site, reducing dependency on foreign infrastructure while improving data sovereignty. Investment in broadband networks, power infrastructure, regulatory frameworks, and human capital, Africa can leverage these technologies to achieve greater efficiency, inclusion, and sustainability in healthcare and beyond.

6. RECOMMENDATION FOR POLICY, RESEARCH, AND PRACTICES IN THE USE OF THESE TECHNOLOGIES

The global diffusion of wearable devices, artificial intelligence (AI), the Internet of Things (IoT), edge computing, and biotechnology has created unprecedented opportunities to improve health systems, economic productivity, and scientific innovation. Yet, realizing these benefits, particularly in developing and emerging economies, requires coordinated action across policy, research, and practice. For Africa and other low-resource regions, aligning these three pillars is essential to ensure that technological advances translate into inclusive, sustainable, and equitable outcomes.

Governments and regional institutions must establish coherent digital-health governance frameworks that address infrastructure, regulation, data privacy, and affordability from the policy perspective. According to Mamuye et al. (2022), the absence of standardized health information exchange (HIE) systems in Africa creates inefficiencies, data silos, and duplication of digital efforts. Policymakers must adopt globally recognized interoperability standards such as HL7 FHIR, ISO/IEC 27001, and open-API architectures to facilitate seamless data integration between wearable devices, hospitals, and cloud-edge systems. Segun-Omosehin et al. (2025) reports that although digital-health innovations are expanding across sub-Saharan Africa, inconsistent policy enforcement and fragmented strategies undermine their scalability. Establishing regional digital-health coordination agencies could foster synergy between ministries of health, innovation hubs, and private telecom operators.

Furthermore, digital-health policies must embed data sovereignty, cybersecurity, and ethical AI governance to protect users from algorithmic bias and privacy violations. Qoseem et al. (2024) emphasize that digital technologies should be deployed within equity-driven frameworks to prevent deepening existing health disparities. Governments should therefore implement legislation mandating transparency in algorithmic decision-making, consent-based data usage, and localized data storage compliant with regional privacy laws. In addition, fiscal incentives such as innovation grants, tax reliefs, and public and private partnerships should be structured to promote affordable access to wearables and IoT devices, especially in healthcare, agriculture, and education sectors.



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A stronger evidence base is required in the domain of research to understand the contextual, technical, and behavioral factors that influence technology uptake in emerging economies. Olusanya et al. (2022) observe that while digital-health initiatives have proliferated in Africa, most remain pilot-based and lack long-term evaluation of health outcomes or cost-effectiveness. Future research should therefore emphasize longitudinal and comparative studies that assess scalability, sustainability, and societal impact. Celesti et al. (2025) highlight the importance of developing low-power, fault-tolerant edge-computing architectures capable of operating in unstable energy and network conditions typical of rural regions. Canali et al. (2022) recommend refining wearable-AI algorithms using demographically diverse datasets to enhance fairness, accuracy, and inclusivity in digital diagnostics.

Recent evidence also suggests that socio-organizational and behavioral factors are central to technology adoption. Díaz-Arancibia et al. (2024) provide a systematic review demonstrating that adoption of digital technologies in developing-country SMEs is shaped by organizational readiness, leadership support, and external market pressures. In a related study, Faiz et al. (2024) show that digital adoption in emerging economies depends on technological, organizational, and environmental determinants, particularly access to skills, digital infrastructure, and trust in innovative ecosystems. Sagala et al. (2024) reinforce these findings, arguing that successful digital transformation requires alignment between technological capability, financial investment, and human capital. Researchers should adopt interdisciplinary approaches that integrate behavioral science, economics, and human-computer interaction, enabling a holistic understanding of adoption barriers and enablers.

Developing regional open-data repositories for biomedical and behavioral datasets can foster African algorithmic innovation and reduce reliance on imported technologies. The real-world deployment of wearable, IoT, and AI technologies, from a practice standpoint, must prioritize usability, sustainability, and inclusiveness. Walter et al. (2024) observed, equitable design and deployment of wearables can help close health gaps by delivering continuous diagnostics to populations with limited clinical access. Practitioners spanning government agencies, such as NGOs and technology firms, should therefore employ human-centered design principles that reflect local language, culture, and literacy levels. Devices must be designed for ruggedness, energy efficiency, and offline functionality to suit the African environment. Training programs should accompany deployments to build the technical literacy of healthcare workers and end users, enabling correct device usage, data interpretation, and maintenance.

Operational frameworks should also emphasize integration into existing workflows. For instance, IoT and wearable data streams should feed directly into national electronic-health records and decision-support systems to avoid data fragmentation. Continuous monitoring and evaluation mechanisms should measure real-time system performance, clinical outcomes, user satisfaction, and equity indicators. Such feedback loops will allow iterative improvement and adaptation of technology in diverse contexts. Furthermore, governments and private organizations should collaborate to develop local manufacturing and repair ecosystems that reduce dependence on imported devices and strengthen economic sustainability. An integrated readiness framework is critical for the long-term success of these technologies.



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This framework should encompass three interdependent dimensions: infrastructure readiness, which ensures reliable power, broadband, and data centers; institutional readiness, which strengthens governance, financing, and regulatory mechanisms; and human readiness, which develops digital literacy, behavioral adaptability, and user inclusion. Emerging technologies can evolve from experimental tools to foundational components of sustainable health and economic systems when these pillars are well-aligned. Celesti et al. (2025) and Canali et al. (2022) conclude, the true promise of digital transformation lies not only in technological innovation but also in the social systems that sustain and scale it. Africa and other developing regions should coordinate action across policy, research, and practice will determine the trajectory toward inclusive and resilient digital futures aligned with the Sustainable Development Goals, particularly SDG 3 (Good Health and Well-Being), SDG 9 (Industry, Innovation and Infrastructure), and SDG 10 (Reduced Inequalities).

7. CONCLUSION

The rapid integration of wearable technology, artificial intelligence (AI), Internet of Things (IoT), biotechnology, and edge computing is revolutionizing how data is collected, analyzed, and utilized across industries. These technologies collectively enable real-time health monitoring, intelligent automation, and predictive analytics that enhance efficiency, accuracy, and personalization in healthcare, manufacturing, and urban systems. Through AI-driven algorithms and edge-enabled architectures, wearable devices now function as intelligent nodes within distributed IoT ecosystems, capable of autonomous decision-making and adaptive feedback. This convergence marks a shift toward decentralized digital systems where computation and analytics occur closer to the data source, thereby reducing latency, improving security, and optimizing resource utilization.

Despite these advancements, the global diffusion and adoption of such technologies remain uneven, especially across developing regions like Africa. Challenges such as limited broadband infrastructure, unstable power supply, high device costs, cybersecurity vulnerabilities, and weak policy frameworks impede large-scale implementation. Stakeholders must prioritize inclusive innovation, emphasize affordability, interoperability, and ethical data governance to achieve sustainable digital transformation. Integrating robust edge intelligence, localized AI applications, and resilient infrastructure will be essential to overcoming these barriers. Furthermore, the technological future will depend not only on advancing digital sophistication but also on embedding equity, transparency, and adaptability into the core design of smart, connected systems that enhance both human and societal well-being.

8. FUTURE DIRECTIONS WITH TECHNOLOGIES

The next decade will see tight convergence of wearables, AI, IoT, edge computing, and biotechnology into autonomous, context-adaptive systems that execute analytics at or near the data source. Edge AI and federated learning will push inference and model updates onto devices and gateways, minimizing latency, bandwidth use, and cloud dependency while enhancing privacy. In parallel, bio-integrated wearables and implantable devices capable of tracking biochemical and physiological markers with medical-grade fidelity will enable noninvasive, predictive, and personalized care. As connectivity scales, multi-device, multi-modal sensing will extend from individual monitoring to population-level surveillance and preparedness, with digital twins and real-time situational awareness supporting proactive responses across health, environment, and infrastructure.

Delivering this vision requires as much attention to sustainability, interoperability, and governance as to engineering. Long-life, energy-efficient designs and green IoT strategies are essential for durable deployments in low-resource settings. At the same time, robust cybersecurity, data-protection, and standards-based integration are prerequisites for trusted scale-up. The path forward prioritizes localized edge intelligence, privacy-preserving learning, and workflow-aligned implementation, strategically demands coordinated policy, investment in broadband and reliable power, and sustained capacity-building. Together, these measures translate technical potential into equitable, resilient, and scalable systems across healthcare and adjacent sectors.

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