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RECOMMENDATIONS FOR RESPONSIBLE IOT ADOPTION: A HUMAN-CENTERED APPROACH

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ABSTRACT

Objective: To explore how organizations can adopt the Internet of Things (IoT) responsibly and human-centrically, embedding ethical principles throughout the product and service lifecycle.

Method: A mixed-methods approach was employed, combining a comprehensive literature review with semi-structured interviews with ten experts across fields such as engineering, software development, business, and ethics. Thematic analysis was used to identify practical insights and recurring themes.

Results: Findings highlight the importance of transparent data practices, privacy-by-design, human-AI collaboration, and continuous ethical assessments. Experts emphasized technical challenges, user-centered business models, and concerns with fairness, inclusiveness, and sustainability. Based on these insights, a roadmap for responsible IoT adoption was proposed.

Conclusion: Responsible IoT adoption requires a holistic approach that integrates technical innovation with ethical accountability. The proposed roadmap provides practical guidance for human-centered innovation aligned with the core principles of Industry 5.0.

Keywords: IoT Adoption. Responsible Innovation. Human-Centered Design. Industry 5.0.

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RECOMENDAÇÕES PARA A ADOÇÃO RESPONSÁVEL DA INTERNET DAS COISAS: UMA ABORDAGEM CENTRADA NO SER HUMANO

RESUMO

Objetivo: Investigar como as organizações podem adotar a Internet das Coisas (IoT) de maneira responsável e centrada no ser humano, integrando princípios éticos ao longo de todo o ciclo de vida dos produtos e serviços.

Método: O estudo adotou uma abordagem de métodos mistos, combinando uma revisão bibliográfica com entrevistas semiestruturadas com dez especialistas de diversas áreas (engenharia, desenvolvimento de software, negócios e ética). A análise temática das entrevistas foi utilizada para identificar padrões e recomendações práticas.

Resultados: Os resultados apontam a necessidade de práticas transparentes de dados, privacidade desde a concepção (privacy-by-design), colaboração entre humanos e IA, e avaliações éticas contínuas. Especialistas destacaram desafios técnicos, demandas por modelos de negócios centrados no usuário e preocupações com justiça, inclusão e sustentabilidade. Com base nessas evidências, foi proposto um roteiro para adoção responsável da IoT.

Conclusão: A adoção responsável da IoT requer uma abordagem holística que una inovação técnica e responsabilidade ética. O modelo proposto oferece diretrizes práticas que colocam o ser humano no centro do processo de inovação, alinhando-se aos princípios da Indústria 5.0.

Palavras-chave: Adoção de IoT. Inovação Responsável. Design Centrado no Ser Humano. Indústria 5.0.

RECOMENDACIONES PARA LA ADOPCIÓN RESPONSABLE DE LA INTERNET DE LAS COSAS: UN ENFOQUE CENTRADO EN EL SER HUMANO

RESUMEN

Objetivo: Investigar cómo las organizaciones pueden adoptar la Internet de las Cosas (IoT) de manera responsable y centrada en el ser humano, integrando principios éticos a lo largo de todo el ciclo de vida de productos y servicios.

Método: Se utilizó un enfoque de métodos mixtos, que combinó una revisión bibliográfica con entrevistas semiestructuradas a diez expertos en áreas como ingeniería, desarrollo de software, negocios y ética. Se aplicó análisis temático para identificar ideas prácticas y temas recurrentes.

Resultados: Los hallazgos subrayan la necesidad de prácticas de datos transparentes, privacidad desde el diseño, colaboración humano-IA y evaluaciones éticas continuas. Los

expertos destacaron desafíos técnicos, modelos de negocio centrados en el usuario y preocupaciones sobre justicia, inclusión y sostenibilidad. A partir de estos resultados, se propuso una hoja de ruta para la adopción responsable de la IoT.

Conclusión: La adopción responsable de la IoT exige un enfoque holístico que combine innovación técnica con responsabilidad ética. El modelo propuesto proporciona una guía práctica para una innovación centrada en el ser humano, alineada con los principios de la Industria 5.0.

Palabras clave: Adopción de IoT. Innovación Responsible. Diseño Centrado en el Ser Humano. Industria 5.0.

1 INTRODUCTION

The Internet of Things (IoT) is rapidly transforming industries and daily life, promising enhanced efficiency, personalization, and connectivity. The new Industry 5.0 paradigm envisions a future in which humans and intelligent systems collaborate to create value, moving beyond mere automation to achieve human-centric and sustainable industrial transformation (European Commission, 2021). However, the pervasive nature of IoT, characterized by interconnected devices collecting and processing massive amounts of data, poses non-trivial ethical and societal challenges. Concerns about privacy, security, data misuse, and the potential erosion of human agency demand a responsible and human-centered approach to IoT adoption (Weber & Weber, 2010).

The *Responsible Innovation framework* emphasizes anticipating and reflecting on the potential societal and ethical implications of innovation throughout the product lifecycle, promoting inclusivity, responsiveness, and reflexivity (Stilgoe et al., 2013). Furthermore, *stakeholder theory* posits that organizations must consider the interests of all stakeholders affected by their actions, not just shareholders (Freeman, 1984). In the context of IoT, stakeholders include users, employees, communities, and the environment. Applying these frameworks to IoT requires a nuanced understanding of the technology's specific characteristics and impacts, particularly concerning human agency and ethical considerations in product development and business model innovation.

This study aims to address this gap by investigating how organizations can implement IoT in an ethically, responsible and human-centric manner. We extend stakeholder theory and the responsible innovation framework by specifically focusing on IoT product development

and the critical roles of human agency and ethical considerations. Through a mixed-methods approach combining a comprehensive literature review with expert interviews, we identified key challenges and opportunities for responsible IoT adoption. Ultimately, a roadmap is provided to guide organizations in harnessing the transformative potential of IoT while ensuring the integration of ethical principles and prioritizing a human-centered approach in accordance with the core values of Industry 5.0.

1.1 IoT definition

IoT is a transformative paradigm that refers to a network of interconnected devices embedded with sensors, microcontrollers, and communication capabilities. These devices (ranging from everyday household items to industrial machinery) collect and exchange data over both wired and wireless networks, forming an infrastructure that enables advanced services and intelligent decision making.

IoT's characteristics include its large scale, the integration of sophisticated software with hardware for smart, autonomous actions, and the ability to sense and respond to changes in the environment. Modern implementations of IoT have evolved from simple data tracking (originally conceptualized for supply chain management) to complex, interactive ecosystems that support automation and real-time analysis across diverse sectors (Bertino & Islam, 2021; Shin, Lee, & Kim, 2021).

1.2 Stakeholder theory and IoT ecosystems

The stakeholder theory, originally articulated by Freeman (1984), argues that businesses should create value for and consider the interests of a broad range of stakeholders. In the context of IoT, the stakeholder landscape is complex and multi-faceted. Users are primary stakeholders who directly interact with IoT devices and services and are concerned about privacy, security, and control over their data (Solove, 2013). Engineers and developers, as internal stakeholders, play an important role in embedding ethical considerations into the design and development processes (Vallor, 2016). Business development experts must also consider the ethical implications of IoT business models and ensure that they are sustainable and responsible (Bocken et al., 2014). Ethicists provide an important perspective on the broader societal and ethical impacts of the IoT, guiding responsible innovation practices

(Floridi, 2013). It is imperative to recognize the interconnectedness of these stakeholders and develop strategies that address their diverse needs and concerns in a balanced and ethical manner.

Responsible Innovation (RI) provides a guiding framework for navigating the ethical and societal dimensions of IoT. Stilgoe et al. (2013) defined RI in four dimensions: anticipation, reflection, inclusion, and responsiveness. *Anticipation* in the IoT involves proactively assessing the potential future impacts of IoT technologies, both positive and negative (Owen et al., 2012). *Reflection* suggests a critical evaluation of the underlying assumptions and values embedded in the IoT design and deployment (Macnaghten et al. 2014). *Inclusion* emphasizes the importance of engaging diverse stakeholders, including users, experts, and the public in the innovation process to ensure a plurality of perspectives. *Responsiveness* refers to the ability to adapt and modify innovation trajectories based on ongoing learning and stakeholder feedback (Fisher et al., 2006).

1.3 Human-centered design and ethical considerations in IoT

Initiating an IoT project demands addressing a range of ethical considerations, such as privacy, informed consent, data minimization, security, transparency, accountability, and human agency—to ensure that the technology harmonizes with human values and societal well-being. IoT systems routinely collect extensive and sensitive personal data, which require robust privacy measures and clear consent protocols to mitigate the risks of data breaches and misuse (Longo et al., 2020).

Moreover, a security-by-design approach is essential to protect IoT systems from the continuously evolving landscape of cyber threats throughout their operational lifecycle (Bertino & Islam, 2021). Simultaneously, incorporating human-centered design (HCD) principles is instrumental for responsible IoT adoption, as HCD emphasizes a deep understanding of users' diverse needs, contextual factors, and cultural values, thereby broadening the focus beyond mere usability to include ethical dimensions such as fairness, autonomy, and justice (Shin, et al., 2021).

1.4 Industry 5.0 and its human-centric imperatives

Industry 5.0, which represents a paradigm shift from automation-centric models to systems that prioritize human-machine collaboration, societal well-being, and environmental

sustainability (Nahavandi, 2019; Román et al., 2022), integrates IoT, AI, and robotics to augment rather than replace human capabilities. This evolution is based on the design of IoT systems that empower users through intuitive and accessible interfaces (Norman, 2013), promote human control and oversight of automated processes (Lee, 2019), and address ethical concerns, such as data privacy, algorithmic bias, and the digital divide (Dignum, 2019).

IoT technologies serve as the backbone of Industry 5.0 by enabling real-time data exchange, predictive analytics, and autonomous decision making across interconnected devices. However, their deployment in critical domains (e.g., healthcare, agriculture, and smart cities) introduces complex ethical dilemmas. For instance, medical IoT devices must balance data collection for patient monitoring with stringent privacy protection to prevent the misuse of sensitive health information. Similarly, agricultural IoT systems require robust security measures to safeguard production data while ensuring the interoperability between heterogeneous devices.

In healthcare, AI diagnostic tools can process IoT-generated patient data to identify potential anomalies; however, final decisions must remain under clinician supervision to ensure accountability (Ghassemi et al., 2023). This approach, which is increasingly adopted in clinical settings, aligns with ethical frameworks that emphasize the importance of human agency in autonomous systems.

2 METHODOLOGY

This study employed a mixed-methods approach to carefully investigate responsible IoT adoption. The research comprised two primary phases: a comprehensive literature review and ten semi-structured interviews conducted with specialists to gather practical insights and perspectives on responsible IoT adoption. The participants were selected to represent diverse expertise relevant to IoT development and implementation.

- Electrical engineers (n=2): Specialists in IoT device design and security (Subjects 1 and 2).
- Business development experts (n=3): Professionals focused on IoT market evolution and business model innovation (Subjects 3, 4, and 5).
- Software developers (n=2): Professionals with expertise in IoT software development and human-centered design (Subjects 6 and 7).

- Software development managers (n=2): Managers who oversee IoT software development teams (Subjects 8 and 9).
- Ethicist (n=1): An ethics specialist responsible for addressing ethical implications throughout technology development and deployment (Subject 10).

Interviews questions explored multiple facets of the IoT development. The participants discussed the technical challenges in implementing privacy and security measures, balancing data collection with privacy concerns, and maintaining robust security across the IoT lifecycle. They also examined design considerations for creating energy-efficient, sustainable systems, and emerging market trends, highlighting the importance of human-centered approaches and successful business models that prioritize user privacy and ethics.

The interviews lasted an average of 45 minutes and were conducted remotely, audio-recorded with participant consent, and transcribed for subsequent thematic analysis. This technique is a systematic method used to identify, organize, and interpret patterns of meaning in qualitative data (Braun & Clarke, 2006). Interview transcripts were analyzed to identify recurring themes, challenges, and proposed solutions related to responsible IoT adoption. These themes were then synthesized with insights from the literature review to develop comprehensive recommendations.

3 INTERVIEWS INSIGHTS ON RESPONSIBLE IOT ADOPTION

Thematic analysis revealed several key findings, categorized by the perspectives of the different expert groups, and linked back to the themes identified in the literature.

3.1 Engineering perspective: Technical challenges and solutions

Engineers (Subjects 1 and 2) highlighted significant technical challenges in implementing privacy-by-design in IoT devices, primarily owing to resource constraints of devices, heterogeneity and interoperability of the IoT ecosystem, and the difficulty of data minimization and purpose limitation. Both interviewees stressed the importance of privacy through design, data minimization, and transparency and control mechanisms, echoing the principles of Responsible Innovation (Stilgoe et al., 2013) and human-centered design (Norman, 2013). Subject 1, a device specialist, emphasized the trade-offs between security measures, such as encryption, device performance, and energy consumption. Subject 2,

specializing in medical devices, further emphasized real-time data sensitivity and the need to balance privacy with data integrity and availability, which are vital in critical applications, such as healthcare. Both engineers underscored the necessity of robust security measures throughout the device lifecycle, including secure boots, firmware updates, and strong authentication, aligning with the best practices in IoT security (Weber & Weber, 2010). Subject 2 also mentioned federated learning as a potential privacy-preserving technique for medical data analysis, highlighting innovative approaches to data handling.

3.2 Business development perspective: Market orientation and ethics

Business development professionals (Subjects 3, 4, and 5) have focused on the evolving IoT market, growing importance of human-centered approaches, and ethical considerations. Subject 3, from the food and beverage industry, predicted a shift towards human-centered design, where IoT products prioritize user experience and empower consumers. They highlight the need for transparency and control over data, emphasizing that granular control and opt-out options are essential for building trust. Subject 4, a telecom professional, envisioned telecom companies moving beyond basic connectivity to become facilitators of a human-centric IoT ecosystem, focusing on services that enhance user experience and prioritize privacy. Subject 5, in hospitality, suggested transparency-based pricing models offering different pricing tiers based on data access levels, allowing users to choose their desired level of privacy. Across these perspectives, a common theme emerged: Trust is fundamental for successful IoT adoption. Business models that prioritize user privacy, offer transparent data practices, and empower consumers are seen as critical for long-term success, aligning with stakeholder theory (Freeman, 1984) and the ethical imperative of responsible innovation (Stilgoe et al., 2013).

3.3 Software development perspective: ambidextrous aspirations

Software developers (Subjects 6 and 7) provided insights into the technical implementation strategies for human-centered IoT applications. Subject 6, a senior software development professional in manufacturing, recommended an event-driven architecture and microservices for creating responsive and scalable IoT systems. They emphasized the importance of intuitive and accessible interfaces through visual design, natural language

interaction, context-aware interfaces, and accessibility features, reflecting the principles of human-centered design (Norman, 2013). Subject 7, a CX specialist, reiterated the importance of human-centered design and emphasized usability, accessibility, and transparency. They suggested augmented reality for contextualizing data disclosure and improving user perception of threats, and emphasized the need for transparency and control mechanisms to maintain user "surveillance" over connected systems, as the capability of users to monitor the behavior of connected systems. Both developers highlighted the need for robust error handling and fault tolerance in distributed IoT systems, recommending a decentralized architecture, redundancy, and robust monitoring to ensure system resilience and user trust.

3.4 Software development leadership perspective: Responsible innovation

Software development managers (8 and 9) offered a perspective on balancing technical debt[1] reduction while delivering new features. They stressed prioritization and transparency in task management and iterative development, incorporating technical debt reduction using static code analysis. In fostering collaboration among remote teams, they highlighted regular communication, collaborative documentation, and pair programming. For project estimation, they advocated breaking down tasks by using historical data and contingency planning. To measure team productivity, they emphasized outcomes and value delivery over lines of code and suggested software quality metrics such as defect density and code coverage. This perspective underscores practical management considerations in developing and maintaining responsible IoT systems and ensuring innovation and quality.

3.5 Ethics perspective: Design to societal impact

The ethicist (Subject 10) advocated for broader ethical considerations of IoT, emphasizing privacy, autonomy and human agency, justice and fairness, explainable AI, and responsibility and accountability. The professional highlighted the potential for surveillance and loss of privacy as the two most significant ethical concerns, emphasizing the importance of transparency, informed consent, and data minimization. He stressed the importance of maintaining human decision-making power and offered ethical frameworks, such as *Human Rights-Based Approaches* and *Value-Sensitive Design*, to guide AI development in IoT. The

[1] Technical debt: refers to the cost of delaying maintenance or fixing issues with a software solution

ethicist also addressed justice and fairness, highlighting the need to ensure that IoT technologies do not exacerbate social inequalities and are accessible and affordable to all, aligning with the findings of Stilgoe et al. (2013).

4 ROADMAP FOR RESPONSIBLE IOT ADOPTION

Based on the literature review and insights from interviews, we propose a roadmap to guide IoT solution architects in integrating human-centered design principles throughout IoT product development lifecycle. By embedding ethics from conception to decommissioning, prioritizing robust privacy and security measures, fostering human agency, embracing sustainability in line with Industry 5.0, and ensuring corporate accountability and continuous learning, the roadmap aims to support the creation of IoT solutions that enhance user well-being and societal trust (Dignum, 2019; Vallor, 2016; Norman, 2013).

First, organizations should embed ethical considerations from the initial concept through decommissioning by conducting regular ethical impact assessments, establishing clear policies on data handling, and forming dedicated ethical review boards to ensure compliance with relevant regulations.

In parallel, a “privacy-by-design” approach must be adopted, ensuring that IoT systems are developed with privacy as a core tenet—incorporating data minimization, encryption, anonymization, and obtaining explicit user consent—while transparent data practices are implemented through clear, accessible policies that empower users with control over their data. Moreover, IoT solutions should be designed to foster human-AI collaboration; rather than replacing human workers, these systems should augment human capabilities, maintain human decision-making in morally significant choices, and utilize natural language interfaces to reduce barriers to adoption.

As AI components become increasingly integrated, it is critical to ensure ethical AI deployment, with a focus on mitigating bias and upholding fairness. In addition, IoT devices and interfaces must be accessible, inclusive, and designed to accommodate users with diverse abilities, thereby promoting broad digital participation.

The roadmap also advocates for continuous ethical and impact assessments through ongoing audits, ensuring that emerging risks are identified and mitigated in a timely manner.

Finally, leveraging generative AI for personalization and customization can further enhance user engagement by delivering tailored experiences that satisfy individual preferences.

This holistic strategy, which combines rigorous ethical frameworks with human-centered innovation and sustainable design practices, is in line with Industry 5.0 principles and supports the development of IoT technologies that are not only technologically advanced but also aligned with societal values and human well-being.

5 FINAL REMARKS

The responsible and human-centered adoption of IoT technologies demands a holistic approach that harmonizes technical innovation with ethical stewardship. By prioritizing human agency, fostering inclusive design, and institutionalizing ethical governance, organizations can unlock IoT's potential as a force for societal good.

Future research should explore longitudinal studies on the socioeconomic impacts of IoT and the development of standardized metrics for assessing ethical compliance in IoT ecosystems. As Industry 5.0 reshapes the interplay between humans and machines, prioritizing innovation that upholds human dignity remains paramount.

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