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Transformative capabilities of MedTech organizations in driving circularity in the healthcare industry: Insights from multiple cases

Shamaila Ishaq [a], Thinh Gia Hoang [b], Umair Tanveer [c,*], Thu-Hang Hoang [b], Huy Quang Truong [b,d]

[a] Derby Business School, University of Derby, Kedleston Road, Derby, DE22 1GB, UK
[b] School of International Business – Marketing, University of Economics Ho Chi Minh City, Ho Chi Minh City, Viet Nam
[c] Exeter Business School, University of Exeter, 77 Streatham Court, Rennes Drive, Exeter, EX4 4PU, UK
[d] The Business School (TBS), RMIT International University, Ho Chi Minh City, Viet Nam

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ABSTRACT

The healthcare industry's significant environmental impact has prompted the urgent need for sustainable practices. MedTech companies play a crucial role in advancing circularity within the sector by adopting sustainable approaches to product design, resource management, and waste reduction. This research aims to explore how MedTech companies initiate and drive transformation towards circular practices and the key factors influencing their successful transition. Using a qualitative approach, four multinational MedTech companies' case studies are conducted, employing semi-structured interviews with 33 managers and healthcare professionals. The results reveal a model grounded in dynamic capabilities, comprising three stages: sensing, seizing, and transforming, guided by adaptability and flexibility. The study extends the understanding of how MedTech companies can proactively respond to environmental challenges and embrace circular economy practices. Furthermore, the model offers practical implications for MedTech companies to foster sustainable practices, optimize resources, and enhance circularity in the healthcare industry.

1. Introduction

The healthcare industry is a vital pillar of modern society, providing essential services to promote human health and well-being. However, its significant environmental impact, particularly in terms of greenhouse gas emissions and medical waste generation (Chen et al., 2021), has raised concerns about its sustainability and contribution to global environmental challenges (Healthcare Without Harm, 2019; Saadat et al., 2020). The urgency to address the environmental impact of healthcare has been highlighted by initiatives like the COP26 UN climate conference, which calls for climate-resilient and low-carbon health systems to mitigate the effects of climate change on global citizens' health and well-being (Bhopal and Norheim, 2021).

Medical technology (MedTech) companies, as key stakeholders in the healthcare industry, play a critical role in driving the transformation towards a circular economy within the sector (Knapp, 2021). Circular practices in MedTech involve the adoption of sustainable and environmentally responsible approaches to product design, resource management, and waste reduction (Luthra et al., 2022). By embracing circularity, MedTech companies can contribute to minimizing their environmental footprint, promoting resource efficiency, and reducing medical waste generation, thus advancing the healthcare sector's sustainability agenda (Lehoux et al., 2016; McDermott et al., 2022a,b). In the realm of sustainable healthcare development, the limited scholarly attention towards sustainability efforts in MedTech companies is evident (Rattan et al., 2022; Görçün et al., 2023). Despite being pivotal players influencing patient care and healthcare efficiency through innovative solutions, the sustainability initiatives of MedTech remain underexplored in the existing literature (Chowdhury et al., 2022; Tushar et al., 2023). This gap includes a lack of exploration into the technological, managerial, and strategic implications of adopting circular models within MedTech organizations (Leppälä et al., 2023). Recognizing the critical role of MedTech in healthcare, understanding and addressing the sustainability landscape of MedTech becomes imperative (Bhopal and Norheim, 2021). The existing literature inadequately explores the potential impact and implications of circular practices adopted by

* Corresponding author.
E-mail addresses: s.ishaq@derby.ac.uk (S. Ishaq), giathinhhoang@gmail.com (T.G. Hoang), u.tanveer@exeter.ac.uk (U. Tanveer), hanght@ueh.edu.vn (T.-H. Hoang), huytruong.quang@rmit.edu.vn (H.Q. Truong).

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MedTech companies, creating a significant void in understanding the industry's ecological responsibility (Xu et al., 2021; van Straten et al., 2021; Nguyen et al., 2022). This research aims to bridge this gap by focusing on the transformative capabilities of MedTech companies, emphasizing their sustainability initiatives and elucidating their critical role in steering the healthcare industry towards a greener and more sustainable future. Through this exploration, we seek to unravel the strategic initiatives and factors influencing the successful transition of MedTech firms toward the adoption of circular practices, contributing valuable insights to the broader discourse on sustainability in the healthcare sector. Thereby, this study will address two key research questions.

RQ1 In what ways do MedTech companies strategically initiate and propel transformation towards circularity in their operations?

RQ2 What specific factors play a pivotal role in influencing the successful transition of MedTech firms towards the adoption of circular practices?

In understanding the transformation process in MedTech firms towards circularity, the theoretical lens of dynamic capabilities offers valuable insights. Dynamic capabilities refer to an organization's capacity to adapt, integrate, and reconfigure its internal and external resources in response to dynamic and evolving environments (Chari, et al., 2022; Walker et al., 2023). By incorporating the concept of dynamic capabilities, this study aims to explore how MedTech companies initiate and drive the transformation towards circular practices. Besides, by employing the lens of dynamic capabilities, this research also aim to shed light on the mechanisms and processes that drive the adoption of circular practices in the healthcare industry.

This research is based on four MedTech cases that have established circular systems of reprocessing, remanufacturing, and recycling in collaboration with partnering hospitals, clinics, and other medical and healthcare organizations. These circular initiatives represent a significant step towards achieving sustainability and environmental responsibility in the healthcare sector. This research will adopt a qualitative approach, conducting in-depth case studies of four MedTech companies. Semi-structured interviews will be conducted with 33 managers and healthcare professionals in four cases. Through a comprehensive analysis of the circular initiatives in these organizations, this research aims to contribute to the broader fields of cleaner production and sustainability, while also advancing our understanding of circularity in the healthcare industry. The findings of this research will have practical implications for shaping sustainable healthcare practices and policies, promoting environmental responsibility, and fostering circular economy principles within the healthcare sector.

The structure of this manuscript is organized into six sections. Section 2 provides a comprehensive discussion of the theoretical background, laying the foundation for understanding the concept of circularity in the healthcare industry and its relevance to MedTech companies. In Section 3, the research method employed in this study is presented. Section 4 presents an in-depth examination of the results from four multinational MedTech companies. Building on the results, Section 5 discusses the research findings of MedTech companies in driving circular practices. Section 6 highlights the theoretical and practical contributions of this study, emphasizing its implications for sustainable healthcare practices. Additionally, this section identifies the limitations of the research and suggests potential avenues for further exploration in the field of circularity in the healthcare industry.

2. Literature review

2.1. Sustainable development in healthcare and circular initiatives in MedTech

The importance of sustainable development in healthcare has been underscored by the global impact of the Covid-19 pandemic. The pandemic has not only brought about unprecedented challenges to the healthcare system but has also shed light on the significance of green healthcare practices during and after the crisis (Xu et al., 2021). The surge in medical waste generation due to the increased use of disposable personal protective equipment (PPE) during the pandemic has heightened concerns over the environmental sustainability of healthcare (Chen et al., 2021; McDermott et al., 2022a,b). However, it has also highlighted the urgent need to find innovative solutions to manage medical waste sustainably while ensuring patient safety. Moreover, the pandemic has reinforced the interconnectedness between human health and the environment, emphasizing the necessity of building a greener healthcare system that minimizes its environmental impact (Xu et al., 2021). As the world looks towards a post-pandemic era, the role of sustainable development in healthcare becomes even more critical in fostering climate-resilient and low-carbon health systems. Embracing net-zero policies and circular initiatives in the healthcare industry, including the MedTech sector, can play a crucial role in not only mitigating environmental damage but also enhancing overall public health and well-being (Khan et al., 2022; Kholaif et al., 2023)).

The pursuit of sustainable development in the healthcare industry has garnered increasing attention as the world faces growing environmental challenges (Liu et al., 2021; Chen et al., 2021; McDermott et al., 2022a,b). Within the context of healthcare, efforts are being made to build a greener healthcare system that minimizes its ecological footprint and contributes positively to the environment. A prominent example of circular initiatives in healthcare involves the adoption of design for circularity principles (Eisenreich et al., 2022). This approach emphasizes the intentional design of medical devices to facilitate multiple cycles of use, repair, and remanufacturing without compromising safety or performance (Aguiar and Jugend, 2022). By incorporating modular components and standardized interfaces, these devices allow for easy disassembly and part replacement, thereby reducing the need for entirely new devices and minimizing waste generation. Additionally, the implementation of closed-loop supply chains is a pivotal circular initiative in healthcare (Simonetto et al., 2022; Ngo et al., 2023). This practice enables the reclamation and reuse of materials from end-of-life devices through reverse logistics and recovery processes (Duong et al., 2023).

The literature on sustainable development in healthcare explores various strategies and initiatives aimed at reducing the industry's environmental impact (Hildebrandt, et al., 2021; Kholaif et al., 2023). Scholars have also examined the adoption of net-zero policies in healthcare, which entail reducing carbon emissions and striving for carbon neutrality. This includes exploring the potential technological advancements, such as energy-efficient medical devices and sustainable healthcare infrastructure, to achieve these sustainability goals (Natarajan et al., 2023). Additionally, the economic implications of sustainable healthcare practices, including cost-effectiveness and long-term financial benefits, have also been discussed (Chauhan et al., 2022). Strategic approaches, such as stakeholder engagement and policy implementation, are examined in the context of fostering sustainable practices in healthcare (Ertz and Patrick, 2020). MedTech firms play a significant role in achieving these sustainability goals, as they are instrumental in developing innovative medical technologies and solutions that can reduce the industry's environmental impact (Liu et al., 2021; Vishwakarma et al., 2023).

Despite the growing body of literature on sustainable development in the healthcare field, a crucial facet that demands scholarly attention is the sustainability efforts within MedTech companies (Bamakan et al., 2022; Leppälä et al., 2023). As a cornerstone in the healthcare industry, MedTech plays a vital role in driving transformative changes, with its innovative solutions spanning medical devices to digital health technologies significantly impacting patient care, disease prevention, and the overall efficiency of healthcare delivery (Görçün et al., 2023; Leppälä et al., 2023). However, a noticeable gap exists in the current literature concerning the sustainability initiatives undertaken by MedTech companies, reflecting a lack of comprehensive exploration into the technological, managerial, and strategic implications of adopting circular models in these organizations. Understanding and addressing the sustainability landscape of MedTech is imperative not only for the industry itself but also for the broader healthcare sector. By embracing circular practices, MedTech companies have the potential to minimize their environmental footprint, enhance resource efficiency, and significantly contribute to reducing medical waste (Rattan et al., 2022; Bamakan et al., 2022). This not only aligns with global sustainability goals but also ensures the long-term resilience and ecological responsibility of the healthcare industry as a whole (Lehoux et al., 2016; Knapp, 2021; Xu et al., 2021; Kholaif et al., 2023). Therefore, this research endeavours to fill this void by focusing on the transformative capabilities of MedTech companies, shedding light on their sustainability initiatives and elucidating their critical role in steering the healthcare industry towards a greener and more sustainable future.

2.2. Dynamic capabilities and circular transition in MedTech

The dynamic capabilities theoretical lens provides insights into their critical role in driving organizational transformation. Dynamic capabilities refer to an organization's ability to adapt, seize opportunities, and transform its business models to respond to changing environments (Teece et al., 1997; Chari et al., 2022; Walker et al., 2023). In the context of the circular shift in MedTech firms, dynamic capabilities are essential for companies to effectively sense emerging trends, seize circular opportunities, and transform their operational practices towards sustainability (Marrucci, et al., 2022). Research has demonstrated how dynamic capabilities enable firms to innovate, collaborate, and optimize resource utilization, which are all key components of successful organizational transformation (Teece, 2007; Neri et al., 2023). Design for circularity is a fundamental aspect that drives the implementation of circular initiatives in the MedTech industry. This approach involves designing medical devices with the intention of enabling multiple cycles of use, repair, and remanufacturing without compromising safety or performance. By designing products with modular components and standardized interfaces, MedTech companies can facilitate easy disassembly and replacement of parts, reducing the need for entirely new devices and minimizing waste generation (Seles et al., 2022). Through the application of circular design principles, medical devices can be refurbished, repaired, and remanufactured to extend their useful life, thereby reducing the demand for new resources and minimizing the environmental impact associated with the production of new devices (van Straten et al., 2021). This approach not only conserves valuable resources but also contributes to cost savings for healthcare facilities and patients (Khan et al., 2022). Moreover, circular initiatives in MedTech encompass the adoption of closed-loop supply chains, which enable the reclamation and reuse of materials from end-of-life devices (Kholaif et al., 2023). By implementing reverse logistics and recovery processes, MedTech companies can recover valuable components and materials from discarded devices, redirecting them back into the production cycle. This approach significantly reduces the need for virgin resources and lowers the environmental burden associated with material extraction and manufacturing (Chauhan et al., 2022; Natarajan et al., 2023).

The existing literature also highlights technological advancements as a significant driver in enabling circularity in the healthcare industry (McDermott et al., 2022a,b). Advanced technologies such as artificial intelligence (AI), Internet of Things, and 3D printing have the potential to revolutionize medical device design, manufacturing, and waste management. Additionally, logistics and supply chain capabilities play a crucial role in facilitating circular practices (Lehoux et al., 2016; Xu et al., 2021). Efficient material flow, traceability, and collaboration with stakeholders are essential for closing the loop and achieving circular goals. Furthermore, collaboration and cooperation among MedTech firms, healthcare institutions, policymakers, and recycling facilities are key enablers for circular transition (Lehoux et al., 2016). Organizational culture, leadership commitment, and stakeholder engagement are also significant organizational factors that influence the successful adoption of circular practices in MedTech firms (Ertz and Patrick, 2020; Neri et al., 2023; Vishwakarma et al., 2023).

Despite the growing body of literature on sustainable development and circular economy in the healthcare industry (Lehoux et al., 2016; van Straten et al., 2021; Neri et al., 2023; Vishwakarma et al., 2023), there are still gaps in understanding how MedTech companies initiate and drive transformation towards circularity in their operations. Further research is needed to explore the strategies, challenges, and best practices adopted by MedTech firms as they transition towards circular business models. Additionally, the key factors that facilitate or hinder the successful circular transition in the MedTech industry require more comprehensive investigation (Khan, et al., 2022; Kholaif et al., 2023). This includes identifying specific technological advancements and supply chain capabilities that contribute to circularity. Moreover, the role of collaboration and cooperation in fostering circular practices in the MedTech ecosystem needs further exploration (Chauhan et al., 2022). Addressing these gaps can contribute to a deeper understanding of the circular transition in MedTech and inform evidence-based strategies for sustainable development in the healthcare sector.

Moreover, central to the implementation of circular initiatives in the MedTech industry is the concept of design for circularity (Aguiar and Jugend, 2022; Eisenreich et al., 2022). This approach involves designing medical devices for multiple cycles of use, repair, and remanufacturing without compromising safety or performance. By incorporating modular components and standardized interfaces, MedTech companies facilitate easy disassembly, part replacement, and waste reduction (Seles et al., 2022). Circular design principles not only conserve resources but also contribute to cost savings for healthcare facilities and patients (Khan et al., 2022; Görçün et al., 2023). Circular initiatives extend to closed-loop supply chains, enabling the reclamation and reuse of materials from end-of-life devices (Rattan et al., 2022; Kholaif et al., 2023). While technological advancements, logistics, and supply chain capabilities are recognized as drivers of circularity in healthcare, the role of adaptability and flexibility in MedTech firms remains underexplored. Understanding how these firms strategically initiate and propel circular transformation, as well as the factors influencing their successful transition, requires comprehensive investigation (Khan et al., 2022; Kholaif et al., 2023). Specific technological advancements and supply chain capabilities contributing to circularity, along with the collaborative aspects in the MedTech ecosystem, demand further exploration to inform evidence-based strategies for sustainable development in the healthcare sector (Chauhan et al., 2022). Bridging these gaps can enhance the theoretical perspective of dynamic capabilities in understanding the transition toward circularity in MedTech firms.

3. Methodology

3.1. Research settings and sample

This study is based on an interpretive approach and a multiple-case research design (Stake, 2013; Yin, 2017), drawing empirical data from four MedTech companies. These companies have proactively embarked on transformative journeys and formed collaborations with various institutions to establish three circular operation systems – reprocessing, remanufacturing and recycling into their practices. The selected cases represent organizations that have undergone significant operational transformations, involving the adoption of relevant technologies, the development of novel activities, and a fundamental shift in their organizational mindset. Each case presents unique insights into how MedTech companies initiate and drive the transition towards circularity in their operations. The strategic partnerships formed with healthcare stakeholders, such as hospitals, clinics, and other medical organizations, play a pivotal role in shaping their circular initiatives.

By employing a multiple-case design, this research enhances the robustness of its findings, allowing for the comparison and contrast of outcomes and insights from diverse contexts (Yin, 2011). Analysing the circular practices of these MedTech companies provides valuable data to understand the key factors influencing successful adoption in different situations. Moreover, this study specifically focuses on MedTech companies. Through this lens, the research explores the challenges and opportunities they face as they embrace circular economy principles in the healthcare industry. The aim is to provide a comprehensive understanding of the circular transition and its impact in diverse healthcare settings.

See Table 1 for further descriptions of each case organization.

3.2. Data collection

The four selected MedTech companies were chosen based on their active engagement in circular initiatives and their collaboration with healthcare institutions. These companies have undergone significant transformations in their operations and supply chain management to embrace circularity. Their circular initiatives involve the adoption of appropriate technologies, the development of new operational activities, and a shift in organizational mindset towards sustainability and circularity.

The data collection process commenced by contacting the managers of the case organizations to gauge their interest, contribution, and willingness to participate in the study. The lead researcher introduced the research objectives and emphasized the importance of their insights in advancing our understanding of circular practices in the healthcare industry. The managers' positive responses demonstrated their willingness to engage in the research, ensuring that the data collection process could proceed effectively. In the second stage of data collection, online meetings and conversations were conducted with managers and staff from various roles within the four case firms. These interactions allowed the researchers to gain valuable insights into the organizations' transition processes, challenges encountered, and strategies implemented. Additionally, these conversations provided an opportunity to assess the companies' capacity to provide relevant and meaningful data for the study. Ensuring that the selected companies could offer substantial insights was crucial in maximizing the research's value and validity. The third stage of data collection involved semi-structured interviews with key personnel from the case organizations. A total of 33 interviews were conducted, including leaders, senior managers, and middle managers involved in the circular development and transformation process. The interviews were focused on those who played pivotal roles in decision-making, resource allocation, and policy implementation related to circular practices. These participants could provide rich and detailed accounts of the challenges faced, the motivations driving the circular initiatives, and the outcomes achieved.

To enhance the breadth and depth of the data collection, the snowball sampling technique was employed. Middle managers and team leaders, who played critical roles in the transition process, were contacted first. These individuals were asked to recommend additional interviewees who could provide valuable insights into the circular initiatives. This method proved effective in identifying key stakeholders and decision-makers within the organizations and ensured a diverse and comprehensive pool of interviewees. The data collection stages spanned from January 2023 to June 2023. During this period, online communication platforms such as Zoom, Skype, and telephone calls were utilized to conduct the interviews. Each interview lasted between 80 and 120 min, providing ample time for participants to share their perspectives and experiences related to the research aim. The interviews were semi-structured, allowing for both predetermined questions based on the theoretical lens of dynamic capabilities and spontaneous exploration of emerging themes.

The interviews were conducted in an open and non-directive manner, granting the participants the freedom to share their insights

Table 1
Background of case studies.

Case	Number of employees (approximately)	Circular operation approaches	Circular economy narratives
A	40,000	recycling approach, remanufacturing approach	Case A has been actively involved in circular economy initiatives by adopting a closed-loop approach in its medical equipment manufacturing. They focus on designing products for longevity and easy repair, ensuring that devices have a longer life span and can be refurbished or remanufactured when needed. Moreover, GE Healthcare implements take-back and recycling programs to responsibly manage end-of-life medical devices, minimizing waste generation and promoting the recovery of valuable materials.
B	31,000	Reprocessing approach, remanufacturing approach	Case B has been taking significant steps towards circular economy practices in the healthcare sector. They emphasize the reprocessing and remanufacturing of certain medical devices, enabling the products to undergo multiple life cycles. By refurbishing and reusing medical devices, Medtronic reduces resource consumption and waste generation, contributing to a more sustainable healthcare system.
C	48,000	reprocessing approach, remanufacturing approach, recycling approach	Case C has shown a commitment to circular economy principles by integrating sustainable design practices into its product development process. They prioritize the use of eco-friendly materials and incorporate modular designs that facilitate easier repair and component replacement. Additionally, this firm has established collaborations with healthcare institutions to implement take-back and recycling schemes for end-of-life medical equipment.
D	34,000	remanufacturing approach, recycling approach	Case D is actively engaged in circular economy initiatives, focusing on product refurbishment and recycling. They collaborate with healthcare facilities to implement circular supply chains, enabling the recovery and reuse of

(continued on next page)

Table 1 (*continued*)

Case	Number of employees (approximately)	Circular operation approaches	Circular economy narratives
			materials from used medical devices. This company also emphasizes sustainable material sourcing and manufacturing processes to minimize the environmental impact of their products.

and experiences without being guided in any specific direction. This approach enabled the researchers to capture authentic and candid responses, fostering a deeper understanding of the organizations' circular initiatives and their impact on operational practices. Throughout the interviews, the researchers employed an inquiry topics list based on the theoretical framework of dynamic capabilities, including.

i. Interviewees' understanding, knowledge, and experience with circular business models in their organizations, specifically focusing on reprocessing, remanufacturing, and recycling approaches.
ii. The design and implementation of circular business models in the healthcare industry, including the client interface, intra and inter-organizational collaboration, and service delivery systems for circular practices.
iii. The utilization of technologies and innovation management to support the transition towards circular business models in MedTech firms, with a particular emphasis on optimizing resource efficiency and waste reduction.
iv. Implications of adopting circular business models in the MedTech industry, including the impact on operational efficiency, environmental sustainability, and cost-effectiveness.
v. Challenges faced by MedTech companies during the transition towards circular business models, such as logistical complexities, regulatory considerations, and the need for collaboration with healthcare institutions.
vi. Value creation opportunities arising from the adoption of circular business models in the MedTech sector, including the potential for extended product lifespan, reduced environmental impact, and enhanced customer satisfaction.

To complement the insights gathered from the interviews, follow-up emails and phone conversations were conducted with some participants. This additional engagement provided an opportunity to clarify certain points, seek elaboration on specific topics, and gather any additional important insights that may not have been covered during the initial interviews. All interviews were recorded with the participants' consent, and notes were taken from the recordings to facilitate data analysis. Archival documents, such as published reports, presentations, and other publicly available sources, were also collected to compare and validate the interview data. This process of triangulating the data from multiple sources enhanced the reliability and credibility of the study findings. Table 2 summarises the interview details.

3.3. Data analysis

The data analysis process in this research study adopted a systematic and rigorous deductive approach to derive meaningful insights from the collected data (Gioia et al., 2013). It involved a combination of in-depth interviews and examination of archival documents to explore the circular transformation processes, the design and development of circular initiatives, and the key factors influencing the successful transition in the MedTech firms. Thematic analysis was utilized to identify recurring ideas, concepts, and perspectives from the interview transcripts and archival data (Gioia et al., 2013; Yin, 2017). The researchers carefully scrutinized the data to identify common themes and sub-themes that captured the essence of the participants' experiences and viewpoints. This in-depth exploration allowed for a comprehensive understanding of the complexities and intricacies involved in transitioning towards circular operations in the healthcare sector. The identified themes were systematically organized to highlight the characteristics and components of the transformation, the design and development of circular practices, and the factors influencing the transition. This categorization

Table 2
Interview details.

No.	Interviewees' positions	Experience (years)	Education	Interview time (min)
Case A				
1	Chief Operating Officer	25	MBA	120
2	Director of Product Development	22	BA	85
3	Operation Development Manager	18	MBA	80
4	Strategy Development Manager	23	MBA	95
5	Business Intelligence Manager	20	MA	90
6	Quality Control Specialist	19	MBA	95
7	Product Development Engineer	20	BA	90
8	Senior Health Economics Analyst	15	PhD	85
Case B				
9	Vice President	30	MBA	90
10	Quality Control Manager	28	MA	115
11	Operations Manager	25	MA	110
12	Director of Clinical Research	27	PhD	85
13	Business Development Manager	21	BA	95
14	Director of Manufacturing	26	MBA	90
15	Senior Clinical Application Specialist	23	PhD	85
16	Senior Biomedical Engineer	22	PhD	85
17	Operations Coordinator	27	BA	90
18	Senior User Experience (UX) Designer	21	MA	100
Case C				
19	Chief Technology Officer	31	MA	110
20	Director of Quality Assurance	22	BA	80
21	Operation Director	28	MA	85
22	Director of Supply Chain Management	27	MBA	80
23	Business Development Manager	20	MA	85
24	Senior Quality Assurance Specialist	18	MA	85
25	Service Development Manager	18	MBA	90
Case D				
26	Deputy General Manager	32	MBA	100
27	Quality Control Manager	28	MA	95
28	Health Informatics Specialist	13	PhD	85
29	Core Technologies Operation Manager	17	MA	95
30	Technology Operation Manager	20	MA	90
31	Engineering Services Manager	20	BA	120
32	Design Operations Manager	17	BA	90
33	Quality Control Specialist	21	MA	95

facilitated a structured and insightful analysis of the various aspects of the circular initiatives undertaken by the MedTech companies.

To ensure the trustworthiness and credibility of the findings, the research team employed several validation techniques. Constant comparison was applied throughout the data analysis process to identify similarities and differences across the cases, enhancing the rigor of the analysis. Peer debriefing sessions were conducted to provide opportunities for multiple researchers to critically review and validate the data analysis process. These sessions fostered constructive discussions and feedback, ensuring the accuracy and coherence of the interpretations. Furthermore, member-checking was conducted to involve the participants in the analysis process. The respondents were invited to review the initial findings and provide feedback, ensuring that their perspectives were accurately represented and increasing the credibility of the conclusions. By adhering to these rigorous data analysis procedures and involving multiple researchers in the process, the research team bolstered the credibility and validity of the study's outcomes. The data analysis yielded valuable insights into the characteristics, implications, and challenges associated with the circular transformation initiatives in the MedTech firms. Fig. 1 visually represents the data structure of the research.

4. Findings

4.1. Sensing

Sensing refers to the capability to identify and understand emerging trends, challenges, and opportunities related to circularity (Marrucci et al., 2022). This involves monitoring changes in customer demands and sustainability concerns that impact the MedTech sector. Sensing also entails gathering data and insights on resource usage, waste generation, and the environmental impact of medical devices throughout their life cycles (Walker, et al., 2023). The empirical findings from the four MedTech companies shed light on their sensing capabilities concerning the circular shift in the industry, several key themes have emerged.

MedTech companies demonstrate awareness of the limited recycling options for Single Use Disposable (SUD) devices, primarily relying on incineration. This recognition highlights the environmental impact of SUD waste management and underscores the need for alternative approaches to improve circularity. The findings also reveal a heightened awareness of the negative environmental effects arising from the collection, sorting, and transportation of SUDs. This prompts companies to explore more sustainable waste management practices to minimize environmental damage associated with SUDs.

> "*SUDs are designed for single-patient use and are typically discarded after each procedure, leading to a significant waste stream in healthcare settings. The burden on waste management systems and the environmental consequences of disposing of SUDs often through incineration or landfilling. This awareness has prompted us to proactively explore more sustainable waste management practices …*" (Quality Control Specialist, Case A)

Besides, the research findings indicate that MedTech companies are cognizant of the prevailing focus of Original Equipment Manufacturers (OEMs) on selling medical devices rather than extending their lifespan. This awareness signals the need for collaboration between MedTech companies and OEMs to explore circular business models. Prioritizing device refurbishment, remanufacturing, or leasing emerges as a potential solution to extend the lifecycle of medical devices and promote circularity. Additionally, the findings demonstrate the companies' recognition of the resource-intensive production processes employed by OEMs, prompting them to seek greener sourcing and manufacturing practices to minimize their environmental impact.

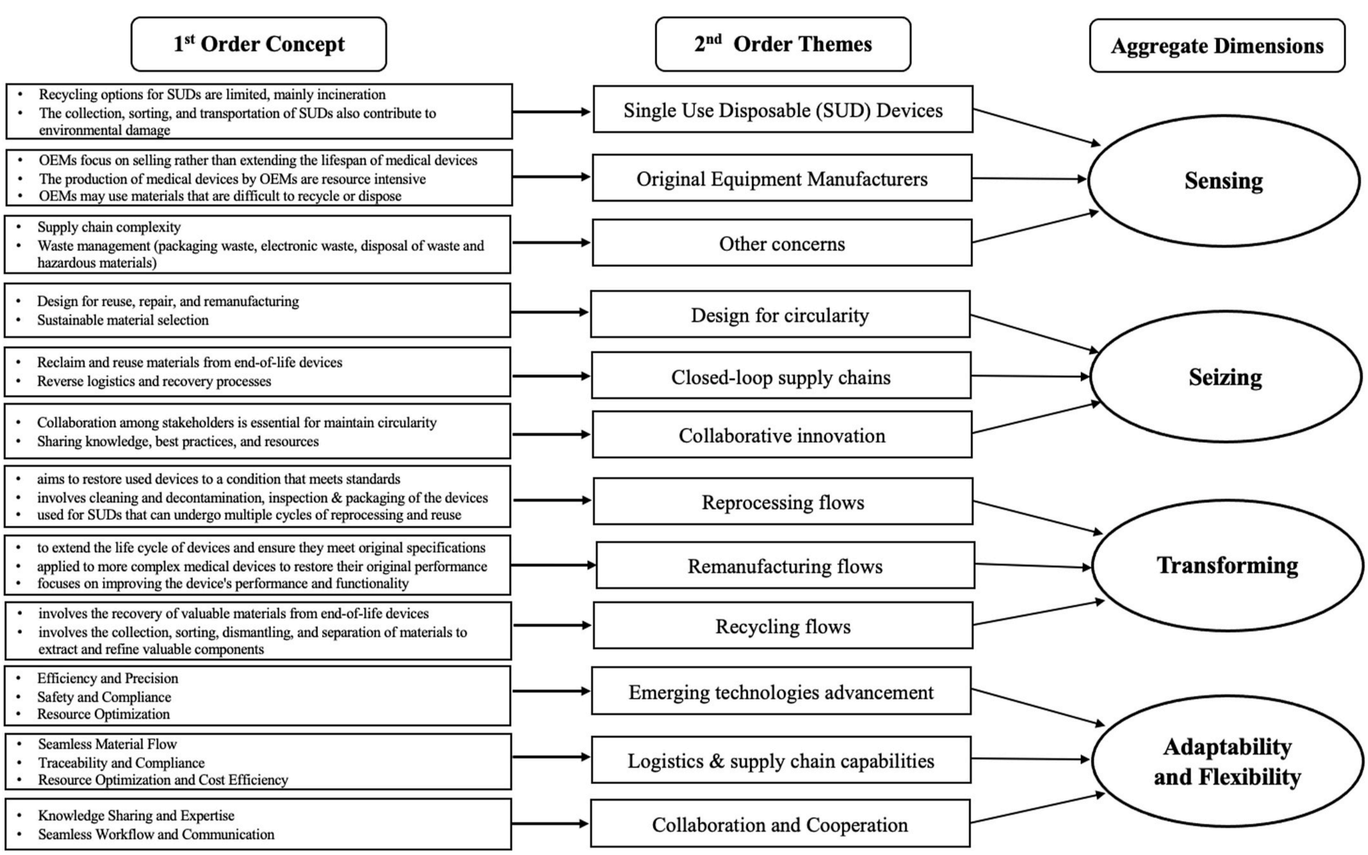

Fig. 1. Data structure.

“*OEMs traditionally focus on selling new medical devices rather than extending the lifespan of their products. We now see the urgency in seeking more sustainable alternatives in sourcing and manufacturing practices …*” (Business Development Manager, Case C)

Additionally, the findings show that MedTech companies are sensing supply chain complexity, signifying awareness of challenges in the flow of materials and products within the circular MedTech ecosystem. This awareness may prompt companies to explore ways to optimize supply chain efficiency and traceability. The findings also indicate that companies are sensing waste management concerns related to packaging waste, electronic waste, and disposal of hazardous materials as illustrated by Business Development Manager, Case B “*Our interactions with stakeholders such as hospitals and clinics have revealed a shared concern for responsible waste management. We recognize the environmental impacts of packaging waste, electronic waste, and hazardous materials disposal*”. This awareness highlights the significance of responsible waste management practices and motivates companies to seek environmentally friendly packaging alternatives and recycling initiatives.

4.2. Seizing

Seizing involves taking action based on the insights gained from sensing (Portillo-Tarragona et al., 2022; Marrucci et al., 2023). It refers to the proactive steps taken by MedTech companies to capitalize on circular opportunities and address potential challenges that hamper the circularity. This includes designing for circularity, investing and developing closed-loop supply chains through embracing collaborations with other stakeholders, such as healthcare providers, suppliers, and recycling partners, also plays a crucial role in seizing circularity opportunities. The research findings provide valuable insights into the seizing capabilities of MedTech companies as they embark on the circular shift in the industry. The following key themes emerged.

The first major theme centres around MedTech companies’ proactive approach to incorporating circularity principles into their product design processes. By emphasizing design for reuse, repair, and remanufacturing, these companies are demonstrating their commitment to extending the lifespan of medical devices and reducing the generation of waste. This strategic focus on circular design principles aligns with the principles of a circular economy, where the goal is to maintain products and materials in use for as long as possible. Furthermore, the findings reveal a strong emphasis on sustainable material selection, indicating that MedTech companies are mindful of the environmental impact of their products throughout their lifecycle. Such design choices reflect a desire to minimize the ecological footprint and facilitate the seamless integration of devices into the circular economy when they reach the end of their useful life.

"*we are proactively integrating circularity principles into our product design and production processes. We aim to extend the lifespan of our medical devices and reduce waste generation … sustainable material selection is a key aspect of our design choices … We also aim to seamlessly integrate our products and production process into the recycling and reprocessing flows ensuring a more sustainable business operation*" (Operations Coordinator, case B).

The second theme emphasizes the adoption of closed-loop supply chain practices as an integral part of the circular shift in MedTech. MedTech companies are seizing the opportunity to implement reverse logistics and recovery processes, enabling the reclamation and reuse of materials from end-of-life devices. By adopting closed-loop supply chains, these companies aim to minimize resource extraction from finite sources and foster a more sustainable approach to material use. The findings underscore the significance of resource efficiency and waste reduction in closed-loop supply chains, thereby reinforcing the circularity objectives of the industry.

"*Adopting closed-loop supply chain practices is integral to our circular shift in our organization. By reclaiming and reusing materials from end-of-life devices, we strive to achieve resource efficiency and waste reduction … closed-loop supply chains enable us to contribute to a more sustainable approach to material use, minimizing ecological footprint*". (Design Operations Manager, case D)

The third prominent theme revolves around the importance of collaboration among stakeholders to achieve and maintain circularity in the MedTech industry. MedTech companies are actively seeking partnerships and engagement with various stakeholders, including "*healthcare institutions such as hospitals, clinic, policymakers, and recycling facilities*" (Quality Control Manager, case D). This collaborative approach allows for the "*sharing of knowledge, best practices, and resources, fostering an environment of collective responsibility towards sustainable practices*" (Director of Product Development, case A). The findings underscore the role of collaborative innovation in overcoming barriers to circularity and driving collective efforts towards a more sustainable and circular healthcare ecosystem.

4.3. Transforming

Transforming denotes the larger-scale shift towards a circular economy in the MedTech industry. It involves the fundamental and systemic changes that companies must make to transition from linear, single-use approaches to circular, resource-efficient models. Organizations may need to adopt new circularity approaches and engage in partnerships that support the transformation towards circularity. The findings from the four MedTech companies shed light on their "transforming" capabilities in response to the circular shift in MedTech. The companies’ efforts in reprocessing, remanufacturing, and recycling flows demonstrate their commitment to sustainable practices and circularity.

Reprocessing flows involve restoring used devices to a condition that meets standards. This process encompasses cleaning, decontamination, inspection, and packaging of the devices, allowing for multiple cycles of reprocessing and reuse. By adopting reprocessing practices, MedTech companies contribute to waste reduction and extend the lifespan of single-use disposable (SUD) devices, aligning with circular economy principles. Fig. 2 illustrates the reprocessing flow from cases B and C.

Remanufacturing flows aim to extend the life cycle of medical devices and ensure they meet original specifications. Particularly applied to complex devices, remanufacturing involves restoring the devices’ original performance and functionality. This process not only reduces waste but also enables companies to maintain the value and usability of their products, promoting circularity in the MedTech industry. Fig. 3 illustrates the remanufacturing flow from all of four cases A, B, C, and D.

Recycling flows involve the recovery of valuable materials from end-of-life devices. This entails a comprehensive process of collection, sorting, dismantling, and material separation to extract and refine valuable components. By embracing recycling practices, MedTech companies contribute to the efficient use of resources and the reduction of environmental impact, supporting circular economy principles. Fig. 4 illustrates the recycling flow from cases A, C, and D.

The findings suggest that MedTech companies are proactively transforming their processes to align with circularity requirements. Through reprocessing, remanufacturing, and recycling flows, these companies exhibit their commitment to sustainable practices and play an essential role in fostering a circular healthcare ecosystem.

4.4. Adaptability and flexibility

The adaptability and flexibility are crucial for MedTech firms as they transition towards circularity in the healthcare industry. They must be adaptable to patient expectations, emerging technologies, and logistics & supply chain capabilities that facilitate circular practices. Integrating

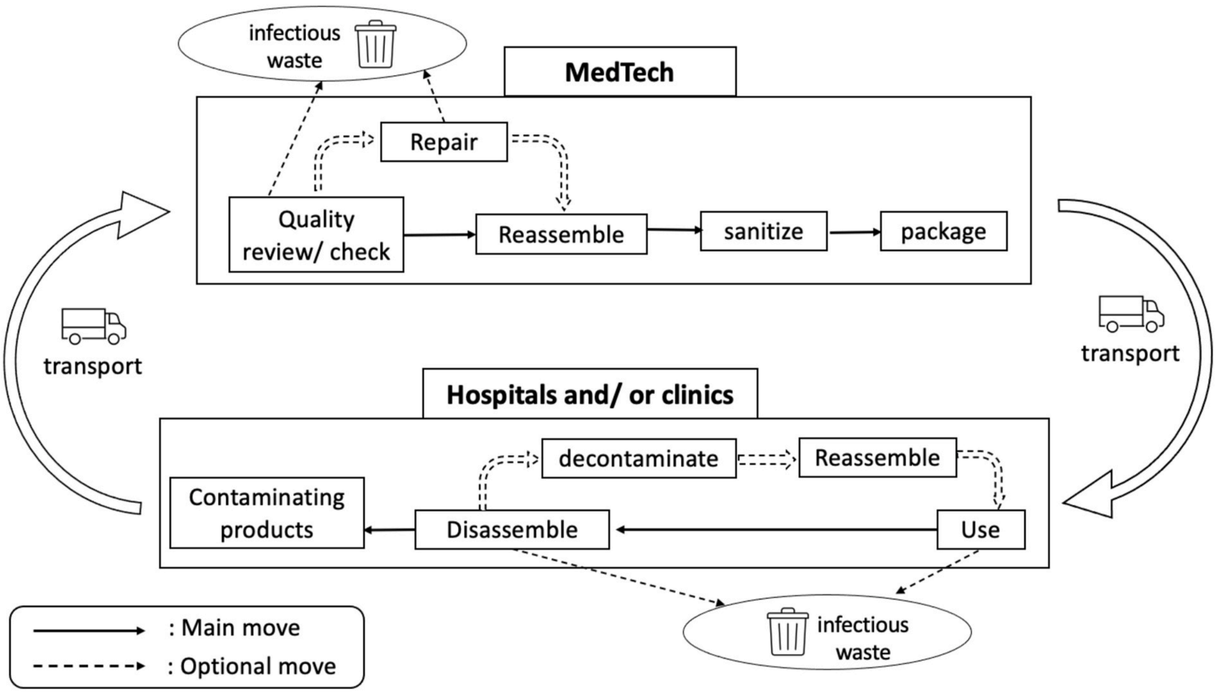

Fig. 2. The reprocessing flow.

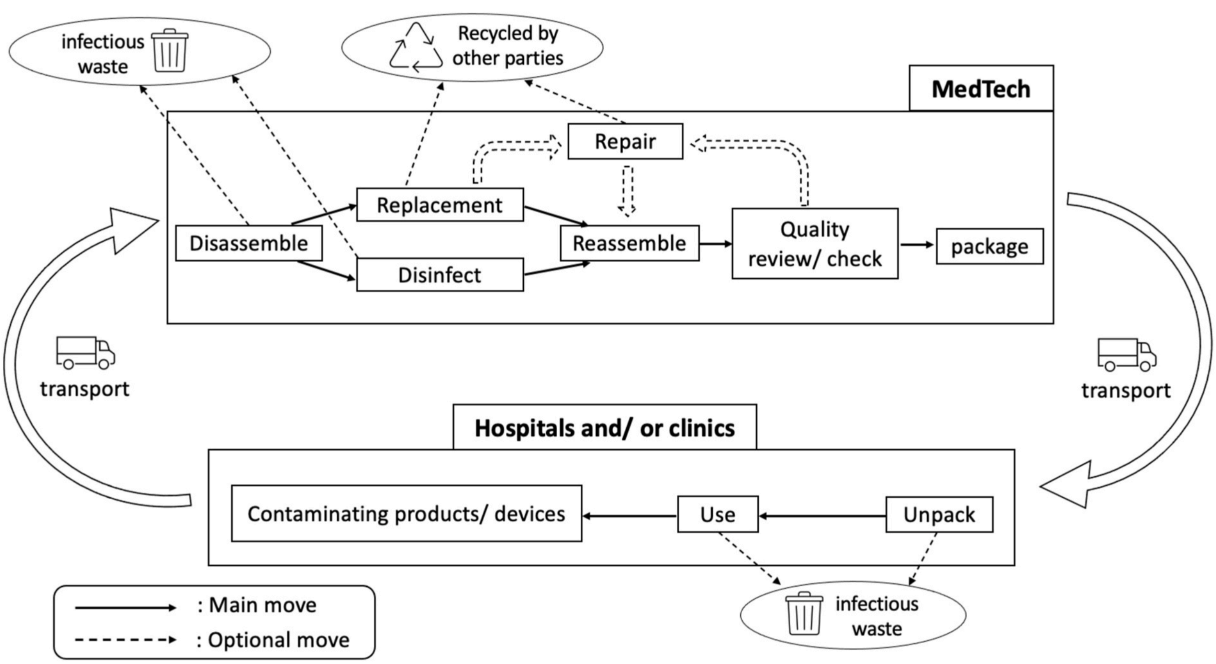

Fig. 3. The remanufacturing flow.

advanced technologies enables sustainable and circular solutions. Robust logistics and supply chain capabilities are essential for efficient material flow, waste management, and closed-loop systems. Collaborative efforts with OEMs, hospitals, clinics and other parties promote knowledge sharing and resource pooling to address challenges and seize circular opportunities.

The findings from the four MedTech companies highlight their "adaptability and flexibility" capabilities in response to the circular shift in MedTech. These capabilities revolve around the incorporation and utilization of emerging technologies, optimization of logistics and supply chain processes, and the fostering of collaboration and cooperation with various stakeholders. In terms of emerging technologies advancement, the companies focus on three key aspects. Firstly, they emphasize efficiency and precision in medical device design, manufacturing, and operations, enabling the development of sustainable and circular products. Secondly, they prioritize safety and compliance to meet regulatory requirements and ensure the seamless integration of innovative technologies into the circular MedTech ecosystem. Lastly, they emphasize resource optimization, leveraging technology to minimize material waste, energy consumption, and environmental impact throughout the product life cycle.

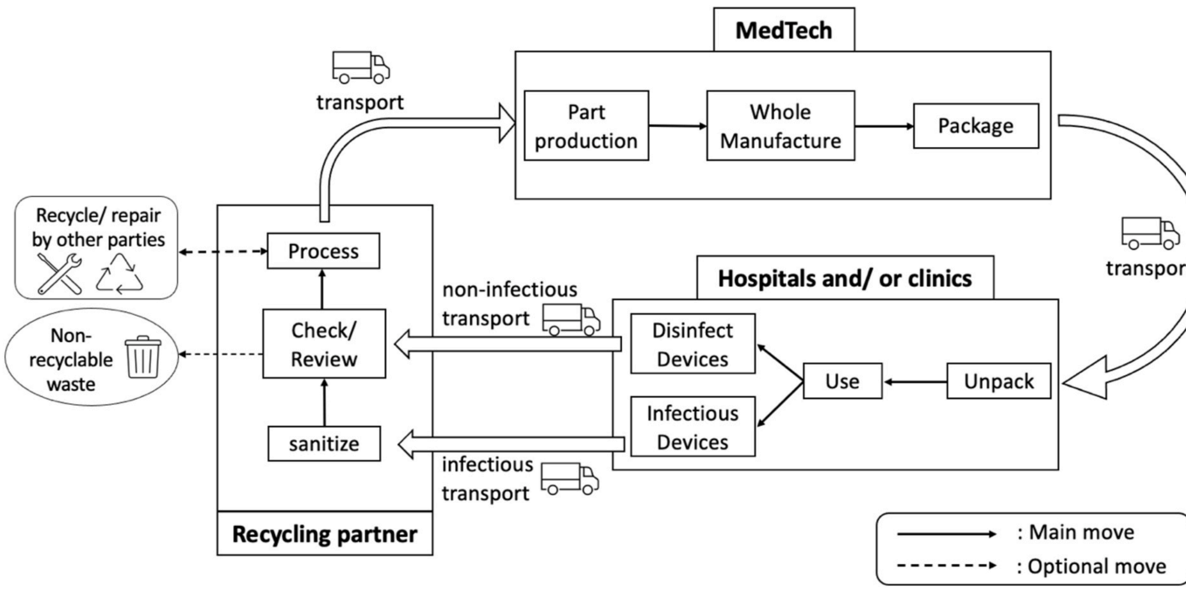

Fig. 4. The recycling flow.

"*we use AI-driven simulations to reduce material waste during the design phase and implement 3D printing technologies to customize medical devices, ensuring precise and efficient resource utilization. Besides, advanced energy monitoring technologies are used to identify areas of energy inefficiency, leading to reduced energy consumption*" (Chief Technology Officer, case C)

Regarding logistics and supply chain capabilities, the companies demonstrate adaptability and flexibility through three fundamental areas. Firstly, they ensure seamless material flow within their supply chains, streamlining processes to reduce delays and enhance circularity. Secondly, they prioritize traceability and compliance, utilizing technology to track materials, products, and waste, ensuring responsible practices and circularity standards. Lastly, they focus on resource optimization and cost efficiency, optimizing supply chain operations to minimize resource consumption and overall expenses while supporting circular initiatives.

"*an RFID-based tracking system was employed for medical supplies and devices, ensuring seamless material flow within their supply chain.*" (Core Technologies Operation Manager, case D)

" *we focus on resource optimization and cost efficiency by partnering with local recycling facilities. we collect and return used medical devices to these facilities for refurbishment and remanufacturing, reducing the consumption of new materials and lowering operational costs*." (Operation Director, case C)

Collaboration and cooperation are critical aspects of MedTech companies' adaptability and flexibility. They foster knowledge sharing and expertise exchange with stakeholders, such as other companies, healthcare institutions, policymakers, and recycling facilities. This collaborative approach ensures the implementation of best practices and innovative solutions to promote circularity effectively. Furthermore, the companies emphasize seamless workflow and communication with stakeholders, facilitating efficient decision-making processes and the realization of circularity goals.

"*Many hospitals, and clinics have collaborated with us to pilot a device leasing program. This initiative allows the hospital to lease certain medical devices instead of purchasing them outright. At the end of the lease, the devices are returned to the manufacturer for refurbishment and reuse, thus reducing waste.*" (Business Intelligence Manager, case A)

5. Discussion

The model proposed in this research is grounded on the principles of dynamic capabilities. The model consists of three stages: sensing, seizing, and transforming, all of which are influenced by the overarching element of adaptability and flexibility. These stages encompass various elements that contribute to the circularity of the MedTech industry.

The first stage, sensing, involves the identification and awareness of critical factors that influence circularity in MedTech. The findings highlight that MedTech companies are actively sensing the limited recycling options for SUDs, the focus of OEMs on selling rather than extending the lifespan of devices, waste management concerns, and the complexities of the supply chain. These findings are aligned with existing literature that emphasizes the challenges and opportunities associated with waste management and sustainable supply chain practices in the healthcare industry (Chari et al., 2022; Kholaif et al., 2023). The second stage, seizing, focuses on the proactive actions taken by MedTech companies to capitalize on circularity opportunities. The findings illustrate that companies are indeed seizing opportunities by prioritizing circular design principles, implementing closed-loop supply chains, and fostering collaboration among stakeholders. Existing research supports the importance of circular design and collaborative innovation for achieving circularity goals in the MedTech sector (Hildebrandt, et al., 2021; Chauhan et al., 2022; Natarajan et al., 2023). The final stage, transforming, involves the adoption of circular economy practices to optimize resource utilization and minimize waste generation. The findings demonstrate that companies are actively transforming their processes to incorporate circular economy principles, such as reprocessing used devices, remanufacturing complex devices, and recycling end-of-life devices. These transformative efforts align with existing literature that emphasizes the potential of circular economy practices to reduce waste and enhance resource efficiency in the healthcare industry (Lehoux et al., 2016; McDermott et al., 2022a,b).

The proposed model, illustrated in Fig. 5, provides a comprehensive framework for comprehending and promoting circularity within the MedTech industry. This model integrates dynamic capabilities and circular economy practices, enabling MedTech companies to sense opportunities, seize advantages, and transform their operations toward a more sustainable and circular ecosystem. The adoption of adaptability and flexibility, facilitated by emerging technologies, logistics capabilities, and collaboration, empowers companies to navigate the circular shift in the healthcare sector successfully. Our research consistently

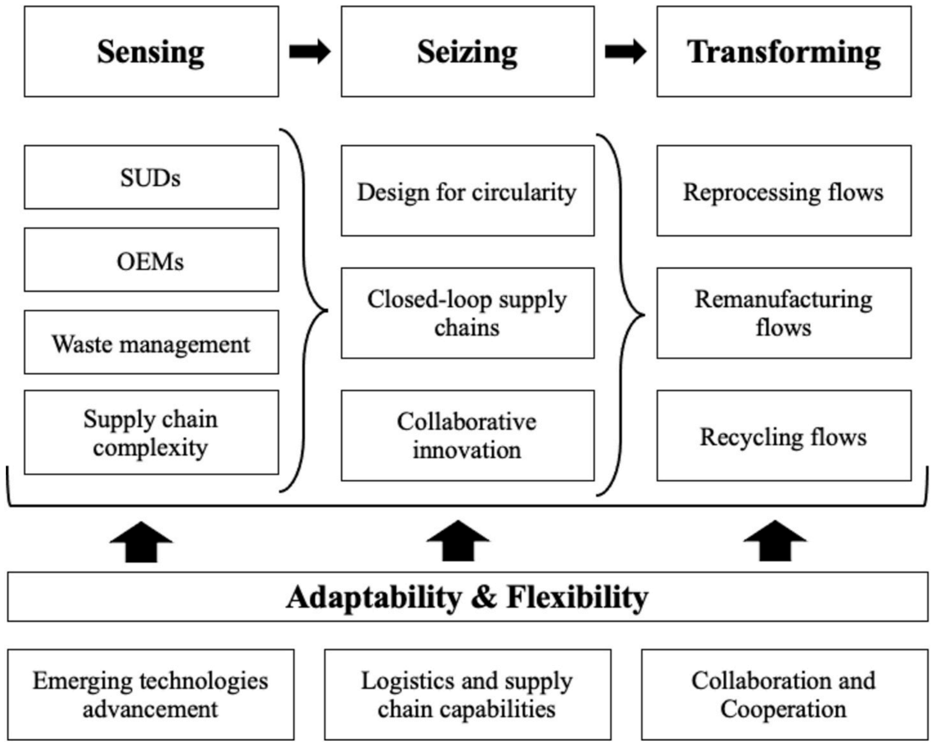

Fig. 5. The circular transformation in MedTech.

emphasizes the crucial role of adaptability and flexibility throughout all three stages. The findings illuminate how MedTech companies leverage emerging technologies, optimize supply chain capabilities, and actively collaborate with stakeholders to drive sustainable initiatives. These insights align with existing scholarly works that stress the significance of adaptability and technology in achieving circularity goals across various industries (Hildebrandt et al., 2021; van Straten et al., 2021; Liu et al., 2021).

Our propositions below encapsulate these insights, offering a nuanced understanding of how adaptability and flexibility, spanning emerging technologies, logistics, and collaboration, advance dynamic capabilities and facilitate the MedTech industry's transition to a more sustainable and circular ecosystem. First, in the MedTech industry, the adaptability to emerging technologies significantly augments not only sensing but also seizing and transforming capabilities, for instance, the integration of AI-driven simulations and 3D printing exemplifies flexibility in response to identified challenges in waste management and sustainable practices. This adaptability allows MedTech companies to actively monitor and understand trends (e.g., sensing), design for circularity (e.g., seizing), and ultimately transform their operations through innovative, technology-driven solutions (e.g., transforming). The adoption of new technologies enhance awareness of limited recycling options, guiding companies in exploring sustainable waste management practices and demonstrating the dynamic adaptabilities required across all stages of the circular transition. Thus, the first proposition can be drawn.

Proposition 1. *Adaptability to emerging technologies in MedTech enhances dynamic capabilities, actively guiding companies in responding to sustainability challenges and advancing the circular transition.*

Second, efficient logistics and supply chain capabilities contribute significantly to seizing and transforming stages, showcasing adaptability across the dynamic capabilities spectrum. The implementation of RFID-based tracking systems and an emphasis on seamless material flow demonstrate adaptability. This logistics flexibility aligns not only with the dynamic capability of seizing by optimizing supply chain operations but also supports *transforming capabilities through the efficient reprocessing, remanufacturing, and recycling flows. For instance, the RFID-based tracking system ensures seamless material flow, streamlining processes and minimizing delays, contributing to both seizing and transforming dynamic capabilities. Therefore, the second proposition can be concluded.*

Proposition 2. *Adaptability in logistics and supply chain capabilities in MedTech enhances both seizing and transforming capabilities, optimizing operations and supporting dynamic capabilities across the circular transition.*

Third, collaboration and cooperation with stakeholders significantly contribute to Transforming capabilities in MedTech, showcasing adaptability across sensing, seizing, and transforming stages. This collaborative approach signifies adaptability and flexibility in fostering a larger-scale shift towards a circular economy. Engaging with healthcare institutions and recycling facilities demonstrates flexibility not only in relationships but also in driving collective efforts, facilitating dynamic capabilities throughout the circular transition. The adaptability in collaboration allows MedTech companies to transform their processes by actively engaging with external entities, supporting *seizing capabilities through collaborative innovation, and facilitating sensing capabilities by staying attuned to external trends and challenges. As a result, the third proposition can be determined.*

Proposition 3. *Collaboration and cooperation enhance transforming capabilities in MedTech, reflecting adaptability and flexibility in relationships, driving collective efforts, and facilitating dynamic capabilities across the circular transition.*

6. Concluding remark

6.1. Theoretical contribution

The present study makes several significant theoretical contributions to the existing literature on circularity in the MedTech industry. By adopting the dynamic capabilities framework (Teece et al., 1997; Teece, 2007), the model highlights the importance of adaptability and flexibility in driving the circular shift (Marrucci et al., 2022; Neri et al., 2023). This emphasis aligns with the dynamic capabilities theory, which emphasizes the ability of organizations to sense, seize, and transform in response to changing environments (Teece, 2007; Seles et al., 2022). By applying this framework to the context of circularity in MedTech, the study extends the understanding of how companies can proactively respond to environmental challenges and embrace circular economy practices (Portillo-Tarragona et al., 2022; Natarajan et al., 2023). Another theoretical contribution lies in the identification of key elements within the sensing stage, such as SUDs, OEMs, waste management, and supply chain complexity. These elements are crucial for MedTech companies to sense opportunities and challenges related to circularity. By grounding these findings in the dynamic capabilities framework, the study enhances our understanding of how organizations can develop a heightened awareness of circular opportunities and environmental impacts (Khan et al., 2022; Kholaif et al., 2023).

Besides, another theoretical contribution stems from the insights into the seizing stage, focusing on design for circularity, closed-loop supply chains, and collaborative innovation. By recognizing these elements as essential for driving circularity, the study offers valuable insights into the operational aspects of circular practices in the MedTech industry. Additionally, the study integrates the dynamic capabilities framework with circular economy forms, such as reprocessing flows, Remanufacturing flows, and Recycling flows, contributing to the literature on the application of dynamic capabilities in circular business models (Horbach and Rammer, 2020; McDermott et al., 2022a,b; Luthra et al., 2022). Finally, this study also contribute to the exploration of adaptability and flexibility, influenced by emerging technologies advancement, logistics and supply chain capabilities, and collaboration and cooperation (Chari et al., 2022; Kholaif et al., 2023). By examining how these factors impact MedTech companies' circularity efforts, the study advances our understanding of how technological advancements, efficient supply chain practices, and collaborative partnerships are critical enablers of circularity in the healthcare sector (Khan et al., 2022; Chauhan et al., 2022; Natarajan et al., 2023).

Finally, the propositions generated in this study contribute to the theoretical landscape by delineating specific relationships or phenomena within the context of MedTech firms transitioning to circular practices (Görçün et al., 2023; Leppälä et al., 2023). Our propositions offer a structured framework for understanding how key elements, such as emerging technologies, logistics, and collaboration, can function as drivers of adaptability and flexibility, thereby influencing dynamic capabilities. Another theoretical contribution also arises from the potential to test and validate these propositions empirically, adding depth to our understanding of the complex interplay between dynamic capabilities (Teece et al., 1997; Teece, 2007), adaptability and flexibility in the MedTech industry's circular transition. In essence, these propositions extend theoretical boundaries and pave the way for continued scholarly exploration and refinement of circularity theories within MedTech.

6.2. Practical implications

The practical implications of this research are also noteworthy. The proposed model provides a roadmap for MedTech companies to strategically incorporate circularity principles into their business operations. By emphasizing adaptability and flexibility, organizations can respond proactively to emerging challenges and opportunities, fostering sustainable practices and resilience in the face of evolving regulatory and market demands. Moreover, the model's focus on closed-loop supply chains, collaborative innovation, and sustainable material selection highlights concrete actions that MedTech companies can take to drive circularity in their products and operations. By adopting circular economy practices such as reprocessing, remanufacturing, and recycling flows, organizations can reduce waste generation, optimize resource use, and enhance the circularity of medical devices.

6.3. Limitation and future research direction

This qualitative research, based on four cases of multinational MedTech companies and employing a semi-structured interview approach, offers valuable insights into circularity efforts within the industry. However, certain limitations should be acknowledged. Firstly, the small sample size of four companies may limit the generalizability of findings to the broader MedTech industry. The focus on multinational firms might not fully capture variations in circularity practices among smaller companies and different geographic regions. Additionally, subjective researcher biases may have influenced data interpretation, despite efforts to maintain objectivity. The study's contextual specificity might restrict the applicability of findings to diverse organizational cultures and regulatory environments. Moreover, the use of semi-structured interviews could have limitations in depth of exploration and potential for socially desirable responses.

To enhance the knowledge generated, future research could consider the following directions. Firstly, conducting larger-scale studies with diverse samples, including small and medium-sized enterprises, would improve the generalizability of findings. A mixed-methods approach combining qualitative interviews with quantitative data from surveys or performance metrics would provide a more comprehensive understanding of circularity efforts. Longitudinal studies tracking circularity initiatives over time would reveal progress and sustainability. Engaging multi-stakeholder perspectives, such as healthcare professionals and policymakers, could offer comprehensive insights into challenges and opportunities. Analysing the influence of regulatory policies on circularity adoption would inform policy recommendations. Comparing circularity practices across industries would enable knowledge exchange and identify best practices.

CRediT authorship contribution statement

Shamaila Ishaq: Conceptualization, Writing – original draft. **Thinh Gia Hoang:** Conceptualization, Methodology, Writing – original draft. **Umair Tanveer:** Conceptualization, Formal analysis, Methodology, Writing – review & editing. **Thu-Hang Hoang:** Investigation, Resources, Visualization. **Huy Quang Truong:** Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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