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Healthcare 4.0 value creation – The interconnectedness of hybrid value propositions

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ABSTRACT

Healthcare 4.0, the digital transformation of the healthcare sector through Industry 4.0 technologies, promises to improve patient outcomes, enhance access to healthcare services, improve operational efficiency, empower patients, and even improve the health of nations. This paper contributes to the understanding of the economic and public value creation potential of Healthcare 4.0 technologies. A qualitative content analysis of 21 innovator interviews provides rich data on the value proposition of Healthcare 4.0 technologies for different stakeholders. The findings highlight previously under-researched stakeholder perspectives, the existence of new types of value creation, the relevance of technology in promoting foundational public values and the interconnectedness of the different value elements.

Subject classification codes

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1. Introduction

Healthcare expenditure remains one of the largest items on government expenditure lists, representing 8.1 % of GDP in Europe (Eurostat, 2023) and 18.3 % in the USA (CMS, 2023). This provides ample economic motivation for initiatives that can make healthcare more effective and efficient. Digital transformation in healthcare promises to do exactly that: improve patient outcomes, enhance access to healthcare services, administrative efficiency gains, service improvement and citizen engagement (Askedal et al., 2017). Healthcare 4.0 refers to the digital transformation of the healthcare sector via Industry 4.0 technologies like internet of things, cloud computing, big data, artificial intelligence, or additive manufacturing (Aceto et al., 2020; Gupta and Singh, 2023). New technologies are implemented to improve medical services, enhance operational processes and reduce expenses, to create effectiveness and efficiency all around the healthcare sector (Al-Jaroodi et al., 2020) with a potential to reform public healthcare systems (da Silveira et al., 2019) and contribute to healthier societies. A high level of uncertainty and challenges still exist regarding how and to whom Industry 4.0 technologies will create value in the healthcare sector (Schlecht et al., 2021), many are still sceptical (Spano et al., 2021). Our research aims to address this research gap.

Healthcare organizations function at the crossroads of three different value systems: they are at the intersection of the public, private, and non-profit sectors (Spano et al., 2021) where a multidimensional value system is created by the concurrent, competing and sometimes seemingly irreconcilable value propositions of economic efficiency, public value creation and citizen satisfaction (Wakefield, 2008; Murray and Evans, 2003; Porter, 2010). That is why the value proposition of Healthcare 4.0 innovations needs to be clear and attractive to a wide range of stakeholders, including users and decisionmakers in the private and public sector (Conaty, 2012; Buttigieg and Hoof, 2018). That is also why it is worth exploring the promise of Healthcare 4.0 from a stakeholder perspective, including the value captured by patients, health care service providers, pharmaceutical companies, insurance companies, supervisory authorities, innovators and research organizations.

This research aims to explore the question of how Industry 4.0 technologies can be used within the healthcare sector to create value among different stakeholders. These actors differ in terms of their institutional logics, innovation demands, and motivations, however, the body of scholarly literature currently in existence provides little assistance in comprehending value capture strategies among the different stakeholders (Alalääkkölä et al., 2023). Patients or even physicians have only a few experiences with Healthcare 4.0 technologies, limited in

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scope and scale, and the multidisciplinary of the advances makes it challenging for those involved in this profession to stay up to date with technology advancements (Aceto et al., 2018). At the same time, for healthtech innovators it is vital to be widely informed about the present and future state of the field and understand the viewpoint of different stakeholders, and they not only have the motivation but also the means to monitor stakeholders' value perceptions via market interactions. Also, innovators are the first links in the chain of technology development, thus understanding their perception of the landscape can be instrumental for innovation and healthcare policy. These are the reasons why our research approach of qualitative content analysis of 21 Healthcare 4.0 startup CEO interviews provides a valuable way to explore Healthcare 4.0 value creation potential in its full richness and complexity.

To establish the theoretic background, we first summarize the relevant concepts of Healthcare 4.0 and public value creation in the healthcare sector, building on the foundations of the Public Value literature (Meynhardt, 2009), and introducing the value model of Rose et al. (2015a). This is followed by a methodological overview of sampling, data collection design and content analysis methodology. The results and discussion are structured around the core value proposition categories. The results will not only contribute to the enrichment of the scarce empirical data on Healthcare 4.0 value creation, but also to the deeper understanding of the feasibility, scalability, and sustainability of Healthcare 4.0 innovations, helping to identify areas for improvement and optimization, understanding the stakeholders' motivations through their value perceptions.

2. Literature review

Industry 4.0 is usually described as a phenomenon conceptualizing drastic digital transformation in the manufacturing industry (Bai et al., 2020), that goes far beyond efficiency improvements: change is exponential concerning satisfaction of existing but unmet demands, ability to address negative externalities, emphasis on innovation, organisational change, and corporate competitiveness (Schwab, 2017). Commonly considered technological pillars of Industry 4.0 are artificial intelligence (AI), simulation, robotics, big data, internet of things (IoT), blockchain, cyber-physical systems, automatization, augmented reality, cloud computing, RFID, cybersecurity (Culot et al., 2020; Jáki and Halmosi, 2019).

As sector-specific implementation of Industry 4.0 technologies, the concept of Healthcare 4.0 refers to a new phase of digital revolution in the healthcare sector. Authors, (Li and Carayon, 2021; Gupta and Singh, 2023) identify Healthcare 4.0 as the fourth of the following stages of technology advances in healthcare:

1. Healthcare 1.0: traditional personal doctor-patient encounter for diagnosis and treatment, stand-alone administrative automation is introduced in the new medical-industrial complex.
2. Healthcare 2.0: new monitoring devices and medical equipment (like MRI, CT scan) used in hospitals and the goal of technology advancements is to increase efficiency and data exchange.
3. Healthcare 3.0: emphasizing proactive care electronic health records, health information technologies are introduced, remote care, computerized and digitalized services can replace personal meetings.
4. Healthcare 4.0: building on all these advancements promises to revolutionize service delivery by Industry 4.0 smart and connected technologies, affecting prevention, diagnostics, therapy, and aftercare, often in a personalized manner, with a paradigm shift towards predictive care.

Although there is no absolute consensus on the technological elements of Healthcare 4.0, most authors include cyber-physical system, internet of things, cloud computing, big data, artificial intelligence, blockchain, additive manufacturing, smart manufacturing, virtual and augmented reality, radio frequency identification (RFID), edge computing and cybersecurity (Innuwa et al., 2022; Popov et al., 2022).

While there are many promising future research directions concerning Healthcare 4.0 (Gupta and Singh, 2023), developing effective value propositions for Healthcare 4.0 innovations is one of those (Lepore et al., 2023). A clear value proposition which is attractive to a wide range of stakeholders is a necessary condition to motivate innovators and investors on this field (Tortorella et al., 2020). This is an especially complex challenge though, concerning the hybrid characteristics of healthcare organizations: as they operate in the intersection of public and private sectors, and as the number of dominant stakeholders (political, governmental, business and social stakeholders) is greater than in the case of non-hybrid business organizations (Conaty, 2012), they face serious challenges in defining their primary objectives. They typically stress divergent and partly irreconcilable value systems, and they are characterized by external pressures and multiple institutional logic (Grossi et al., 2020). This research aims to contribute to mapping and understanding the Healthcare 4.0 value creation potential in the context of the complex value system of healthcare.

As a result of the hybrid nature of the sector, instead of a clean value concept, healthcare system goals often include multiple dimensions: improving access to healthcare, improving the quality of care, reducing healthcare costs, reducing health disparities, improving the coordination of care, responsiveness, safety, timeliness and patient satisfaction (Wakefield, 2008; Murray and Evans, 2003; Porter, 2010; Schlichter et al., 2014; Puro et al., 2023). These dimensions of healthcare value aspirations are stable over time, they remain the same, as new waves of technological innovation attempt to meet them. One of the most influential healthcare goal conceptualizations is proposed by the Triple Aim framework (Berwick et al., 2008), which suggests that healthcare systems shall aim to improve population health, patient experience, and cost of care – later also extended by employee wellbeing by the Quadruple Aim model (Lapaine, 2021).

The Quadruple Aim extension, and also some other approaches to healthcare value creation (Schlichter et al., 2014) reflect a definite stakeholder approach. Stakeholder theory is especially relevant on this filed, as one of the focal questions of it is how value is created in a rapidly changing global business context (Parmar et al., 2010; Freeman, 1984). Hall and Martin (2005) argue that stakeholder analysis is essential for the development of any new radical technologies due to its potential to have extensive and often contentious impacts. The key stakeholder absorbing the value created by healthcare in the form of health outcomes is the patient (Porter, 2010) – this seems to be the key premise of the Value Based Healthcare (Gray, 2017; Kokshagina, 2021) approach as well. On the other hand, wider goal sets include the value perceived by other stakeholders, like employees or the patients' families (Gyllenhammar et al., 2023). The existing empirical literature (Tortorella et al., 2020; Laurisz et al., 2023) suggests that approaching healthcare value from a stakeholder perspective can be useful to map the diverse coexisting value concepts in the sector.

The stakeholder approach becomes even more complex as we consider the society as a whole as one of the key beneficiaries of healthcare advancements, with captured benefits like population health or health equity, or even in the case of cost of care. Kokko (2022) international overview suggests that most national healthcare systems currently adopt a wide public value perspective regarding healthcare value – that is also the theoretic basis our research builds on. 'Public value is value for the public' (Meynhardt, 2009, 212), it covers 'producing what is either valued by the public, is good for the public, or both' (Bryson et al., 2014, 448), public services created for the public, or even partly by the public in a value co-creation process (Meynhardt and Jasinenko, 2021).

There is a wide variety of political, moral, social, and cultural views behind public value creation, making it a very complex social phenomenon (Nabatchi, 2011; Nemeslaki, 2015). Still, many authors in the public value and public information technology literature use common or fundamentally similar value categories including cost reduction,

efficiency gains, service level or service quality increase, as well as societal values like transparency or safety (Bannister, 2002; Gichoya, 2005; Moga, 2012; Bannister and Connolly, 2014; Rose et al., 2015a; Rose et al., 2015; Benčina and Jukić, 2015; Scott et al., 2016; Twizeyimana and Andersson, 2019). These categorisations are rooted in mainstream public administration approaches: New Public Management (Alford and Hughes, 2008), emphasizing business-like efficiency in the public sphere and the Public Value approach (Moore, 2003; Bryson et al., 2014), highlighting also the importance of citizen participation and democratic values. The most compact, inclusive and most widely

Table 1
Systematic summary of Healthcare 4.0 value propositions explored by previous research
(the first rows and column provide conceptualisation for the elements of the two dimensions of our theoretic framework).

Stakeholders (beneficiaries of value creation, definitions by Petkovic et al. (2023, 3))	Public Value categories proposed by Rose et al. (2015a)			
	Efficiency	Service improvement	Patient engagement	Foundational values
	efficiency effectiveness economy productivity performance	public service citizen orientation service level service quality	responsiveness consultation collaboration participation	honesty, fairness, impartiality, equality before the law, legality, objectivity, professionalism, legitimacy, trustworthiness, openness, transparency, robustness, reliability, accountability, security
Patients ("those with lived experience with the condition of interest")		- protecting patients from illnesses (Ahsan and Siddique, 2022) - following patient demands, personalized treatment (Ahsan and Siddique, 2022) - monitoring of health status (Popov et al., 2022) - controlling physiological activities (Aceto et al., 2020) - better understanding of illnesses (Al-Jaroodi et al., 2020) - higher quality service (Abbate et al., 2022) - providing quality services (Al-Jaroodi et al., 2020)	- consultation (Popov et al., 2022) - interaction with medical workers (Popov et al., 2022) - connecting patients (Al-Jaroodi et al., 2020) - individual decision making (Aceto et al., 2020)	- improving availability of data (Abbate et al., 2022)
Health care service providers ("persons and their professional associations who provide health care in a professional capacity and allowed by regulatory bodies to provide a health care service")	- remote diagnosis (Abbate et al., 2022) - improving surgery planning (Adugna et al., 2021) - increasing efficiency of institutions (Abbate et al., 2022) - supporting planning, controll and decision making (Al-Jaroodi et al., 2020) - supporting the diagnosis (Popov et al., 2022) - improving management of procedures (Al-Jaroodi et al., 2020)	- complex view on patients health evolution (Abbate et al., 2022) - insight into correlation of illnesses (Al-Jaroodi et al., 2020) - improving of service quality (Popov et al., 2022) - introducing smart services (Ahsan and Siddique, 2022)	- sharing information among professionals (Paul et al., 2021) - consultation with colleagues (Popov et al., 2022) - enhancing cooperation with patients (Ahsan and Siddique, 2022)	- feedback on efficiency of therapies (Aceto et al., 2020) - evaluating operational procedures (Al-Jaroodi et al., 2020) - risk reduction (Popov et al., 2022)
Pharmaceutical companies (an entity that develops, manufactures, markets, distributes, imports, offers for sale or sells pharmaceutical products)		- improving of new therapies (Popov et al., 2022) - access to patient data (Popov et al., 2022)		
Supervisory/governmental authorities ("individuals, organizations and entities that craft public or private policy (on health) at any level of government")				- exchange of information (Popov et al., 2022)
Insurance providers ("organizations and entities that pay for health services")	- improving risk management (Popov et al., 2022)	- direct interaction with patients (Abbate et al., 2022)	- increasing collaborations (Al-Jaroodi et al., 2020)	
Universities, research institutions ("individuals, organizations, and associations that conduct or advocate health research")		- developing new models (Popov et al., 2022) - better understanding of interactions (Adugna et al., 2021) - designing intelligent services (Aceto et al., 2020)	- increasing communication, establishing networks (Abbate et al., 2022) - reaching global patient community (Abbate et al., 2022)	

cited models are the ones of Bannister and Connolly (2014) and Rose et al. (2015a), Rose et al. (2015). They can be particularly useful in Healthcare 4.0 research, as both focus especially on IT-based initiatives in the wider public domain, and they are not sector-specific. Also, they were developed specifically to capture diverse, complex, even rival value propositions of public IT initiatives. While both models use value categories of work efficiency, service level improvements and society-wide values, Rose et al. (2015a) divide the last category into two distinct groups: fundamental value (like fairness or transparency) and citizen engagement (see in the title row of Table 1). The distinction of this last category can be especially important if we think of the newly emerging research theme of value co-creation in healthcare (Lee, 2019; Rossi and Tuurnas, 2021). Also, Rose et al. (2015a) framework is one of the IT public value conceptualisations which has already been successfully applied in healthcare setting: Askedal et al. (2017) used the categories to systematically review the telehealth value literature.

Based on these characteristics, we believe that the model of Rose et al. (2015a) will be a useful basis of research exploring Healthcare 4.0 value creation. Also, this model can be easily combined with the stakeholder approach highlighted earlier (Laurisz et al., 2023; Freeman, 1984) – these two dimensions capturing most of the complexity of Healthcare 4.0 value creation in a simple matrix (see the dimensions of Table 1). Table 1 applies this matrix framework to summarize the scattered empirical findings of this relatively new field of research. The results of the few empirical studies published since 2020 (Abbate et al., 2022; Aceto et al., 2020; Ahsan and Siddique, 2022; Al-Jaroodi et al., 2020; Adugna et al., 2021; Paul et al., 2021; Popov et al., 2022) can be systematically summarized using the categories of Public Value and the stakeholder approach, although we can see that most of the research has focused on the service providers and the patients as key stakeholders, and most of the value potential explored has been related to the traditional economic categories of efficiency and service improvement. This leaves a significant research gap regarding other stakeholders and public value elements – and our aim is to systematically extend this state of the art with focused data collection and analysis.

3. Materials and methods

According to present evaluations, incorporating Healthcare 4.0 technologies is expected to enhance the efficiency of the healthcare system, foster the creation of patient-centric innovations, and drive changes in business models (for a systematic overview of past empirical findings see Table 1), although researchers (Tortorella et al., 2020; Li and Carayon, 2021; Popov et al., 2022; Lepore et al., 2023) suggest that there is a great demand for further exploring the value creation potential of up-and-coming digital innovations in medicine and healthcare. This is what we propose to do in this research, routed in the Public Value theory (Moore, 2003; Bryson et al., 2014), using the model of Rose et al. (2015a) as a guiding principle and following a timely and fitting (Schiavone et al., 2021; Tortorella et al., 2020; Laurisz et al., 2023) stakeholder-centric approach of stakeholder theory (Freeman, 1984):

RQ: How can Industry 4.0 technologies be used within the healthcare sector to create value among different stakeholders?

The proposed theoretic framework is introduced in details in the dimensions (the first rows and column) of Table 1, based on the conceptualization of public value by Rose et al. (2015a) and stakeholders by Petkovic et al. (2023). Due to the novelty of the focal topic and the exploratory nature of the research we chose a qualitative approach, which also fits our research aims and holistic viewpoint (Corbin and Strauss, 2014). We agree with Gummesson (2006, 170-171), that in this innovative digital context, how 'business decision-makers and practitioners operate has been accompanied by a transition to more complex research methodologies, which seems to favor recourse to qualitative methods of investigation'. In this section we introduce our qualitative approach by following the research planning steps suggested by Bengtsson (2016).

3.1. Sampling and data collection

We approach the realm of digital healthcare innovations from the innovators' perspective for several reasons. Firstly, key value beneficiaries, like patients and physicians often have only limited experience with novel Healthcare 4.0 technologies, both in scope and scale. Additionally, the multidisciplinary nature of Healthcare 4.0 makes it difficult for professionals in the field to keep up with technological advancements (Aceto et al., 2018; Chipman, 2018; Sony et al., 2022). Digital innovations are limited to certain sectors, departments, treatments, or processes (Tortorella et al., 2020), the details of novel healthcare technologies, tools and methods are only known by few specialized doctors, so related knowledge is very dispersed among medical professionals, hindering systematic data collection from these stakeholders.

Fortunately, innovators are less affected by these information barriers, as it is key for their business survival to stay well-informed about the present and future of the technology landscape and to understand and build on the perspectives of various stakeholders (Fleming and Sorenson, 2003). Innovators not only develop, but also validate new technologies in real-world settings, with several affiliated institutions and many experts involved in trials – so the full complexity and data of these experiments is only seen by innovators. The innovators' perspective is not only wider, but through market interactions (Sprong et al., 2021) it can also inform and guide other stakeholders in understanding the potential return on investment and the broader impact on the healthcare ecosystem and serve as advocates for the adoption of new technologies.

As our analysis is future centric, we are looking at technologies that patients may not yet have practical experience of, and their technological and medical complexity is high, making patients an unreliable source of information regarding the expected value creation and a representative study difficult to implement. That is why the innovators' wider horizon and more extensive knowledge and market experience can shed light on the feasibility, scalability, and sustainability of Healthcare 4.0 innovations, and help identify areas for value creation and optimization.

Lastly, innovators are at the forefront of developing and implementing new technologies – so exploring innovators' opinions can inform policy and decisionmakers on how they, as the first links in the chain of technology development perceive value creation opportunities, and use this to create supportive regulatory frameworks that facilitate innovation and motivate future value co-creation (Laurisz et al., 2023).

These are the reasons why is why we chose to target innovators and collect data through innovative startups recently having received funding and offering IT-based solutions in healthcare sector. A successful funding round is also an objective criterion to filter out unviable technology initiatives and reduce data bias (Spano et al., 2021). Central Europe is underrepresented in the Healthcare 4.0 research, although Hungary serves as a perfect research field with the healthcare technology sector having seen a century of widely acknowledged innovations (Fabrègue, 2022). As there is no comprehensive database of all Hungary-based digital healthcare startups, we collected our initial company list going through public venture capital portfolio information. We were able to widen the list via professional recommendations, and it has been filtered according to how relevant the focus of each startup was to Healthcare 4.0. From the 26 companies we eventually approached, 21 agreed to anonymously participate in the research. Table 2 summarizes key sample characteristics in terms of products/services offered and the embedded, applied relevant technologies.

The data sources used in the analysis were qualitative in their nature, based on structured interviews carried out between November 2022 and March 2023. The standardized interview's predetermined questions were carefully designed to cover two core themes: the company's own business model and value proposition, and the respondent's views on the overall developments of the global Healthcare 4.0 industry. All 21 interviewees were the founders and/or CEOs of the companies, providing

Table 2
Sample composition, product and technological profile of the selected startups
(1: we use it in our operation, but it does not appear in the product/service; 2: it appears in the product/service, but is not a central element; 3: the central element of the product/service).

Start-up ID	Product/service	Cyber-Physical System (CPS)	Internet of Things (IoT)	Cloud Computing	Artificial Intelligence (AI)	Blockchain Technology	Additive Manufacturing	Smart Manufacturing	Virtual and Augmented Reality	Cyber Security	Simulation and Modelling	Big data	RFID	Edge Computing
SU1	Surgical navigation system for soft tissues.			1	3			3		3	3	2		**3**
SU2	Software based on an artificial intelligence algorithm supporting medical image diagnostics.			2	3									
SU3	Device supporting sample identification in diagnostic labs.	3	3	1	1	1	2	2		1	3	1		
SU4	Baby monitoring hardware and software.		3	3	2		2			2		3		2
SU5	Clinical trial support device and software system.		1	3	1	3				1		3		1
SU6	A software used in the preclinical and clinical tests, that can predict the effect of lead molecules proposed by the drug development company.			2	2					1	3	2		
SU7	Online patient journey management software.			3								1		
SU8	A clearing and accounting platform for healthcare services.		3	3										1
SU9	A laboratory software that processes and transmits patient data and test results.		1	3		2				3		2		
SU10	Medical device and software to assist doctors in intervention operating rooms.				1					2	3			
SU11	Prostate cancer diagnostic method.				2							1	1	
SU12	Insulin resistance nutrition-support software.		1	2								1		
SU13	Fall detection application for elderly care.		1	1	3						3	2		**3**
SU 14	Preclinical animal testing device and technology.		2	2	2	1					1	2		1
SU15	Navigation system for traumatology and orthopaedics.		3	3			3				3	1		
SU16	Sotware and hardware aiming to support personalized surgical education.		1	2	2	1	3	2	2		3	3		
SU17	A device processing and analyzing the electrophysiological activity of cultured neurons in large quantities.		1	1	2			1				3		

(*continued on next page*)

Table 2 (*continued*)

Start-up ID	Product/service	Cyber-Physical System (CPS)	Internet of Things (IoT)	Cloud Computing	Artificial Intelligence (AI)	Blockchain Technology	Additive Manufacturing	Smart Manufacturing	Virtual and Augmented Reality	Cyber Security	Simulation and Modelling	Big data	RFID	Edge Computing
SU18	Automated artificial intelligence-based diabetes management application.		2	2	2						2	2		
SU19	Portable device for the therapy of skin diseases.		3	3	3		3		1	3	1	3		1
SU20	Design engine that enables design and creation of orthoses and prostheses.	1	1	3	2		3	1	2		3	1		
SU21	Comprehensive health application for personalized disease prediction and prevention.		2	2	2	1			1	2	1	3		
	How many firms state, that the given technology is the core element of their product/service (where the value = 3)?	**1**	**5**	**8**	**4**	**1**	**4**	**1**	**0**	**3**	**8**	**6**	**0**	**2**
	How many firms state, that the given technology is part of their business model (where the value is 1, 2 or 3)?	**2**	**15**	**19**	**16**	**6**	**6**	**5**	**4**	**9**	**12**	**18**	**1**	**7**

an excellent opportunity to collect data from a person with the most comprehensive knowledge regarding value proposition and also concerning the strategic developments of the industry in a wider sense. The interviewees were informed about the research goals, the privacy policy, and gave their written consent. The 1:1 interviews lasted from 40 to 90 min, were conducted online (via Microsoft Teams) and were recorded (with consent). Our interview scheme contained some questions where respondents had to choose their answers from a list or evaluate a statement on a 1–7 Likert scale (not for quantitative analysis, but mostly to provoke further discourse or validate other questions). Most of the interview time was however used to explore open-ended questions – the answers to these were recorded in full transcripts. Interview questions and early results were tested and validated by healthcare professionals and industry experts, including a hospital director and a state secretary. These external experts also confirmed the relevance of exploring the innovators' perceptions, who represent a strong market perspective and have a wider overview of the innovations than individual medical professionals.

3.2. Content analysis methodology

To explore the data, we used content analysis methodology, which is a systematic method of analyzing text to extract significant information (Krippendorff, 2013). Qualitative content analysis is a useful method for exploratory research because it allows researchers to gain insights into participants' experiences and perspectives and based on that, to identify and understand the themes, patterns, and underlying meanings in textual data. Elo et al. (2014) note that while as an alternative, grounded theory places a greater emphasis on theory development, content analysis is more focused on identifying patterns and themes. Content analysis works with smaller data collection as well, while it can also incorporate a more deductive conceptualization approach (Charmaz, 2006). Stemler (2015) argues that there are three main approaches to content analysis of textual data: empirically driven automated content analysis, theoretically driven content analysis, and somewhere between these two: emergent coding. Our approach is mostly theory-driven: as shown in section 2 we believe that the categories of Rose et al. (2015a) are applicable and useful to explore Healthcare 4.0 value creation. In line with this we used a priori coding (Stemler, 2000), the initial code structure has been established prior to the analysis based upon Rose et al. (2015a) categories. Also, the researchers were allowed to add to these categories if deemed necessary – this more inductive additional approach (similar to emergent coding) enables discovery of further meaningful underlying patterns (Ramsdal and Bjørkquist, 2020). The resulting codes were discussed by the researchers to reach consensus and were explicitly defined in the coding protocol. The final Public Value code list is shown in Table 3, while further explanation of the codes is provided in section 5 to facilitate discussion.

Regarding the stakeholder dimension of our coding, our approach was also theory-driven, using the high abstraction level stakeholder categories of Sultana Nipa et al. (2021) and Tampio et al. (2023) we could identify the following stakeholder groups with distinct characteristics in the coding phase: patients, healthcare service providers, pharmaceutical companies, insurance companies, supervisory/governmental authorities, universities and other research institutions (see definitions in the first column of Table 1, based on Petkovic et al., 2023).

While innovators might be one of the stakeholder groups with a more optimistic view of the healthtech value creation potential, they also recognize the barriers of innovation diffusion. As this is out of the scope of this current research and other studies have already explored the key barriers of Healthcare 4.0 implementations (Al-Jaroodi et al., 2020; Ahsan and Siddique, 2022; Popov et al., 2022), so we will only briefly refer to these concerns in the discussion.

All the interview transcripts were imported and organized into an NVivo (Lumivero, 2023) project. A practice coding was carried out to refine the coding protocol (Lacy et al., 2015), followed by the coding of

Table 3
Final code list and inter-rater reliability.

Public Value categories	Codes	Kappa	Kappa - weighted with text length**
Efficiency	Reduction of administrative burden*	0,861	0,873
Efficiency	Effectiveness 1	0,811	0,771
Efficiency	Effectiveness 2*	0,678	0,698
Efficiency	Economy	0,556	0,548
Efficiency	Productivity	0,545	0,510
Efficiency	Efficiency	0,457	0,456
Service improvement	Citizen orientation	0,805	0,812
Service improvement	Service level	0,496	0,518
Service improvement	New service*	0,514	0,383
Service improvement	Service quality	0,374	0,378
Patient engagement	Responsiveness	1000	1000
Patient engagement	Participation	0,971	0,997
Patient engagement	Consultation	0,941	0,936
Patient engagement	Collaboration	0,927	0,932
Foundational values	Openness	1000	1000
Foundational values	Impartiality	1000	1000
Foundational values	Equality before the law	1000	1000
Foundational values	Legitimacy	0,971	0,936
Foundational values	Objectivity	0,971	0,936
Foundational values	Honesty	0,971	0,936
Foundational values	Fairness	0,971	0,927
Foundational values	Professionalism	0,882	0,916
Foundational values	Transparency	0,941	0,893
Foundational values	Accountability	0,882	0,891
Foundational values	Robustness	0,886	0,884
Foundational values	Trustworthiness	0,874	0,843
Foundational values	Legality	0,912	0,814
Foundational values	Reliability	0,808	0,778
Foundational values	Security	0,740	0,697

* emergent codes added during the coding process, while all the other codes are based on the model of Rose et al. (2015a).
** all values above >0.21 (Xie, 2013) indicate a fair level of inter-rater agreement.

all materials by two researchers in parallel to assure inter-rater reliability (Stemler, 2000), while the relatively short and dense coding period (two weeks) helped to increase intra-rater reliability. Our process corresponded to the suggested characteristics by Lacy et al. (2015). We used Cohen's kappa coefficient weighted by length of texts to evaluate inter-rater reliability, the degree of coding agreement between the two coders. The kappa coefficients (see Table 3) show that we achieved at least fair level of agreement (>0.21; 2 of the 29 categories with a value of 0.38), and in most cases, reliability can be qualified as very good (>0.81; 19 of the 29 categories) (Xie, 2013). Although our approach is latent analysis, 'extended to an interpretive level in which the researcher seeks to find the underlying meaning of the text' (Bengtsson, 2016, 10), we provide relevant quotes for each identified category to stay very close to our textual data to ensure trustworthiness (Burnard, 1991).

4. Results

To ensure that the technology profile of the companies in our sample is indeed Healthcare 4.0 focused, the core technologies of the innovations were first analysed. The most frequent core technologies (where the given technology plays an elemental role in the product/service) in our sample are simulation and modelling, and cloud computing (8–8 startup), while big data and IoT are also often mentioned as central technologies (6 and 5 cases respectively, see last line of Table 2). Cloud computing, big data, AI and IoT are mentioned most frequently as used in some capacity in the business models. This is mostly in line with other recent review studies about Industry 4.0 technologies with the most potential in the healthcare industry (Ahsan and Siddique, 2022; Popov et al., 2022), suggesting that our sample represents Healthcare 4.0 innovations well from a technological perspective. A slight difference to the literature could be the less than prominent role of AR/VR applications, which seem to have much promise in the industry, although innovative startups in the region only use it in a supporting role. We also see that cyber-security and RFID are rarely mentioned and never in a central role: our interviews also confirm that respondents see them as necessary but not focal technology (cybersecurity) or a non-innovative element (RFID).

Second, focusing on our main research question, we explored and categorized the potential value creation opportunities offered by Healthcare 4.0 innovations for different stakeholders in the healthcare sector. The results of our systematic mapping of value potential by Public Value categories and beneficiary stakeholders are shown in Table 4. This systematic analysis provides significant addition to the existing empirical data (in Table 4 these novel extensions are highlighted in bold), while confirming some value elements already described by Ahsan and Siddique (2022), Popov et al. (2022) and others (non-bold items of Table 4).

Our results also highlight, that Healthcare 4.0 value is captured by many different actors: industry players, patients and national authorities profit from the new technologies – some are enjoying these benefits as externalities. Our research directly considers benefits captured by stakeholders like insurance companies and supervisory authorities as well, which were mostly ignored by previous studies. We see that though the efficiency and service improvement aspects of the innovative products and services seem to be the most manifold and frequent (see Table 5), especially for the healthcare service providers as direct beneficiaries, there is value creation potential beyond these effects as well, especially for the patients. Lastly, reflecting the hybrid nature of the healthcare sector, aiming to create private and public value as well, we could also capture some of the public aspect, foundational value creation potential in the data.

Some of the most important novel value potentials rarely mentioned in the Healthcare 4.0 are (1) the administrative burden reduction, which is novel extension of the efficiency public value category, (2) the opportunities for new added services and cross-selling enabled by technology advancements (novel extension of the service improvement category), (3) the new opportunities for patient engagement through collaborations via data sharing and (4) the identification of many foundational values promoted by Healthcare 4.0 on a societal level. In the next section we will discuss these and other findings in more details.

5. Discussion

To shed light on the perceived and intended value dimension of the healthcare 4.0 innovations in more details in the next segments we will discuss the related findings following the main categories of Rose et al. (2015a): efficiency, service improvement, patient engagement and foundational values. In this section, following the methodological

Table 4
Systematic summary results: Value potential of Healthcare 4.0 by Public Value categories and beneficiary stakeholders.

Stakeholders (beneficiaries)	Public Value categories			
	Efficiency	Service improvement	Patient engagement	Foundational values
Patients	**- efficiencies via cloud-based platforms** **- shorter waiting times**	- shortening waiting lists - better patient outlook - higher patient satisfaction **- new services empowering patients** - personalized therapy	**- online communities to support each other**	**- safety and security during the treatment** **- data security** **- professionalism,** transparency and **accountability** **- trustworthiness**
Health care service providers	- administrative burden reductions: **> automate previously manual labour** > efficiencies via cloud-based platforms **> decrease in errors** - effectiveness via: > data monitoring > new diagnostics > better tools - efficiency by precision and lower resource needs at the same time - economy via **> higher future revenue** > cheaper availability of data > cheaper treatment options > shorter hospitalisation > human resource productivity	- increased service levels due to > increased productivity > **avoidance of unnecessary procedures** > **new or increased demand** > **new opportunities for cross-selling** - better quality services due to better data (in diagnosis, treatment, and aftercare phases) or geographic flexibility - new services - personalized therapy	- patient participation via > feedback **> data sharing**	- safety and security during the treatment - **data security for compliance and legality** **- reliability and robustness regarding data** - professionalism, transparency and accountability
Supervisory/ governmental authorities	**- healthcare costs can be decreased by better prevention and earlier diagnostics**			**- safety and security during the treatment** **- data security, legality** **- professionalism,** transparency, and accountability
Pharmaceutical companies	**- efficiency by precision and lower resource needs at the same time** **- economy via shorter test phase**	- better drugs due to better data **- new value added services** - personalized therapy	**- patient participation via data sharing**	**- safety and security during the treatment**
Insurance companies	**- efficiencies via cloud-based platforms** **- economy of less false positive diagnoses and more specific treatment, cheaper aftercare**	**- new value-added services** - personalized services	- patient collaboration for individualized offers **- patient participation via data sharing**	
Universities, research institutions	**- administrative burden reductions:** **> automate previously human labour** **> decrease in errors**	- better quality services due to **geographic flexibility** **- new research opportunities**	- patient participation via data sharing	**- reliability and robustness regarding data**

With bold: novel elements, where this study complements existing literature.

suggestions (Elo et al., 2014) and the best practices of qualitative research (e.g. Spano et al., 2021) on the field we will provide relevant quotes from the interviews as clear evidence of the data and the analysis process to ensure trustworthiness. The quotes are identified by the interviewees' start-up ID number (SU1-SU21, see Table 2) and the reference numbers of the coded texts. (We also refer to findings-related evidence in the discussion by the interviewees' ID number.)

5.1. Efficiency

Although many authors do not define the different efficiency/effectiveness concepts clearly, we worked with the following explicit distinctions between the categories, based on Hogya (2023): The first level of effectiveness means that the realised outcome reaches the expected outcome, while the second level means that the original outcome goals were 'good'. Productivity refers to the ratio of outputs and inputs, while economy refers to the ratio of outputs and inputs measured financially. Efficiency means the co-existence of economy and effectiveness. During the test coding, an additional efficiency category emerged: the reduction of administrative burden is a novel sub-category suggested by our results.

Starting with the **administrative burden reductions** we see three distinctively different types of value sources. First, digitalisation can provide solutions to automate previously manual labour – like SU3 in lab diagnostics. This might not only enhance administrative productivity, but in extreme situations this might even ensure the survival of labs:

'In places where tens of thousands of tubes are titled every week, people were on the verge of quitting. After the introduction of the robot, the mood became completely relaxed.' (SU3, reduction of administrative burden, Reference1).

Secondly, cloud-based platforms are created to take care of parts of the administrative processes (SU8), which will increase the speed of transactions and eventually benefit all stakeholders, including those not paying for the service. For example, in the case of an automated healthcare services clearing platform, although the service providers are paying the platform fees, patients also benefit from the fact that they do not have to pre-finance the services. Thirdly, the digitalisation and automation of administrative processes will also decrease the number of errors (SU7).

Using technology solutions for **effectiveness** gains is the key underlying promise of Healthcare 4.0 (Ahsan and Siddique, 2022). The potential for increased medical effectiveness can be easily demonstrated along the lines of the patient care process:

- Prevention can be supported by continuous data monitoring (SU4,13,21).
- Diagnostic procedures can be supported by new, faster, and/or more accurate diagnostic tools (SU2,3,11,17) – and this will also influence the quality, quantity, and cost of care.

Table 5
Frequency of coded references related to each value categories.

	Value categories	The startups' own Healthcare 4.0 product/service		The potential of Healthcare 4.0 in general	
		Startups	**Coded references**	**Respondents**	**Coded references**
Efficiency	Reduction of administrative burden	6	21	4	5
	Effectiveness 2	7	13	5	7
	Effectiveness 1	15	28	11	18
	Efficiency	23	58	17	51
	Economy	16	29	12	21
	Productivity	20	60	11	27
Service improvement	Service level improvement	14	36	8	10
	Service quality improvement	20	67	17	50
	New service	17	34	4	7
	Patient orientation	10	20	13	25
Patient engagement	Responsiveness	0	0	1	1
	Consultation	2	2	0	0
	Participation	1	1	1	1
	Collaboration	3	5	2	3
	Transparency	2	2	6	8
Foundational values	Security	9	21	8	14
	Accountability	3	4	3	3
	Legitimacy	1	1	1	1
	Legality	3	3	1	1
	Robustness	5	10	3	4
	Reliability	8	21	4	5
	Trustworthiness	5	8	3	3
	Fairness	1	1	0	0
	Objectivity	1	1	1	2
	Honesty	1	1	0	0
	Professionalism	3	9	5	9

- Therapy itself can be supported by decision making support (SU19), surgical aid (SU1,10,15) or better physical tools, like protheses (SU20).
- Aftercare can also be directly supported by remote monitoring, or indirectly by better quality or less invasive treatment options.

The effectiveness gains have manyfold and interconnected effects on the economy of medical work:

'They [the doctors] themselves can diagnose faster. Less medical litigation because we're helping them make a decision, which will make it more secure. Actual money savings through these processes: faster work – more patients – more revenue, less error – less legal expenses.' (SU2, effectiveness, Reference1).

The last quote already touches on the **efficiency** of the healing process as well, when effectiveness is reached at the same time as economy. In case of pharmaceutical technologies (SU6,14) and medical education (SU16), effectiveness of the work process and lower resource needs also typically go together.

We should also highlight one of our novel findings: the benefits of the innovations are not only reaped by the medical service provider who pays for them, but by other stakeholders as well, as an externality. Patients will enjoy the improved customer experience of a shorter waiting time for diagnosis (SU2,9), faster time-to market of effective drugs (SU6). Insurance providers also benefit from less false positive diagnoses and more specific treatment options (SU6,11), less risk exposure (e.g., radiation, SU10) or cheaper aftercare (SU13). On the long-term national level healthcare costs can be decreased by better prevention and earlier diagnostics (SU1). As one interviewee summarized the multifaceted benefits of their technology:

'Reduction of intervention time, shortening of healing time, lengthening of prosthesis survival time, and relief of the care system.' (SU15, efficiency, Reference5).

Also, the seemingly external effects of better-quality care for patients can be internalized by doctors in the form of patient retention and higher future revenue (SU12). On the other hand, the externalities are not only captured by the patients: externalities of technology usage by patients can also benefit the doctors or service providers:

'The patient uses [the IoT tool and that] provides faster, clear-cut indicators, easier decision making, decision reinforcement, cost reduction [for the service provider].' (SU18, efficiency, Reference1).

We already mentioned several effects that increase the **economy** of healthcare at the same time as effectiveness, let us focus on effects that are purely decreasing resource requirements. This can be the result of cheaper therapy methods with less complex technology (SU1) or portable solutions (SU19). The source of cost reduction can also be a positive effect on one small element of the value chain, like a shortened test phase in pharmaceutical development (SU6,14,17), waste reduction (SU20) or shorter hospitalisation time (SU10,20).

'As doctors perform the operation faster, financial gains are generated. Each minute spent in the operating room costs 100 USD, according to one estimate: lighting, utilities, amortization, wages, etc. Any solution that reduces the time spent in the O.R. by 20 minutes is a theoretical saving of 2000 USD'. (SU1, productivity, Reference3).

A specific form of more economical operation is increased **productivity**, which manifests itself mainly in the form of human resource productivity. Healthcare 4.0 technology can increase human resource productivity for doctors in the diagnostic phase through AI applications (SU2), before and during operations (SU15), for nurses in aftercare via automated monitoring (SU13), for insurance administrative personnel via process automation (SU8) and increasing student-professor ratios with medical education software (SU16).

All in all, our results enrich the empirical findings about the potential effectiveness and efficiency gains of Healthcare 4.0 suggested by earlier research (Abbate et al., 2022; Adugna et al., 2021; Al-Jaroodi et al., 2020; Popov et al., 2022; see Tables 1 and 4), but also highlight the inseparable nature of different types of benefits for different stakeholders.

5.2. Service improvement

Some elements of service improvement are direct consequences of the above described more efficient work methods – this is especially true for **service level improvements**. As the time or human resource needed to carry out a diagnostic test (SU2,17), surgical intervention (SU1,15) or monitoring (SU14) decrease, the maximum capacity of the facilities increases, which means a potential service level expansion. Some

technologies enhance the scalability of prothesis production (SU20) or healthcare administration (SU8), others contribute to faster training to alleviate medical skill shortages (SU20) and thus, support the creation of new medical care capacities. In other cases, the capacity-increasing effect is more indirect, via the avoidance of unnecessary procedures:

'If we give you a more accurate diagnosis, a lot of patients won't need to be biopsied unnecessarily.' (SU11, service level, Reference2–3).

All these lead to shortening waiting lists (SU9, 15) and better patient outlook and satisfaction. On the other hand, innovative healthcare technologies also affect service levels on the demand side: less invasive diagnostics (SU11), tests for special need target groups (SU10), service differentiation potential (SU2) or data-driven opportunities for cross-selling (SU17) might drive more patients towards the service providers.

Although service level improvements are rarely mentioned in the Healthcare 4.0 literature, service quality gains are often highlighted (Abbate et al.; Al-Jaroodi et al., 2020; see also Table 1). **Service quality improvement** by Healthcare 4.0 technologies has two important sources in our sample: data and geographic flexibility. Digital technology makes more types, more detailed, and more accurate data available, which can result in better services throughout the patient journey in the form of:

- better diagnosis (SU2,11,19);
- better therapeutic decisions (SU6, 12);
- better drugs (SU5, 6, 17) and medical devices (SU10,20);
- better surgery outcomes (SU1,10,15);
- better monitoring of the effects of therapy (SU4,18,19);
- better after-care services (SU13).

Respondents are confident that these service improvements can lead to revenue growth for service providers – but can also have widespread positive spillover effects on other stakeholders:

'The child will have fewer health problems, and we will be able to intervene more quickly for a better prognosis, even lifesaving. Via improving sleep quality, it will also create value for parents, because they can be more relaxed about the child's condition.' (SU4, service quality, Reference2–3).

In addition to data availability, the other key source of technology-enabled quality improvements is geographical flexibility. This can mean enabling telemedicine (SU4), distance learning (SU16) or portability of devices (SU19), thus eliminating the barrier of physical distances from some medical value chains.

These functional improvements might also lead to **new services**. Healthcare 4.0 developments will lead to diverse medical novelties from gamified medical education (SU16) to new research opportunities (SU14,17), but in our sample two distinct directions for new service development can be identified. The first direction is the opportunity to add digital services to accompany existing products like drugs (SU12,18,19), medical devices (SU2) or insurance services (SU13). This can help providers to differentiate themselves on the market or achieve higher patient retention rates. Another class of technology-enabled new services focuses on empowering patients (SU12,18,21) or their caretakers (SU14) to make informed decisions about their health with the help of IoT-based mobile apps, partly eliminating other medical service providers from the value chain. These two development directions have opposite effects on demand, thus suggesting a fierce fight for patients in the future.

A special class of new medical services will fuel **patient-oriented value creation** through personalized therapy, in the form of individualized treatment (SU12, 19, 20, 21) or personalized drugs (SU6). The other key source of citizen-oriented service improvements will be captured as increased patient experience (SU23,4,7,8,13), which can include a general increase in patient satisfaction, or specific positive effects like the preservation of individual dignity during patient management (SU7) or elderly care (SU13), or empowering patients through increasing their sense of competence (SU2). To illustrate the value chain of service improvements one of our respondents states:

'Those who apply the data, on the client side, get more quality and reliable data. And the user receives a higher level of service, user experience, or quality of service, this is an indirect benefit.' (SU5, service quality, Reference4).

Our results highlight the previously rarely discussed opportunities for new value-added services and cross selling opportunities. This again illustrated the inseparable nature of the different stakeholder perspectives: while the Healthcare 4.0 innovations' positive effects on capacities and portfolio diversification are in the focus of healthcare providers' attention, this will create value from the patients' perspective as well.

5.3. Patient engagement

Participation encompasses a broad spectrum of involvement, ranging from passive presence to active contribution, without necessarily implying a collaborative process – while collaboration emphasizes the cooperative and coordinated effort, working together towards a shared goal. The European Commission (2019) highlights the importance of participation as a societal value, and in some countries, patient and public involvement has even become a policy requirement. Still, consultative participatory approaches seem to be more common than partnership-based collaborations and have even led to some consultation fatigue (Renedo et al., 2014).

Only a few startups in our sample have a value proposition concerning patient engagement, partly because only a handful of the companies work with a business-to-customer business model. The few startups targeting patients directly usually offer some **participation** opportunities: by sharing their feedback (SU7) or participating in an online community supporting others (SU12). These examples reflect the collective coproduction opportunities created by technology (Jo and Natachi, 2019). Collective coproduction, as a form of public participation happens when one or more state actors collaborate with a lay actor community, like in the case of the user community of insulin resistance patients (SU12).

The interactions between stakeholders can also be more **collaborative**, working towards a common goal, like in the case of drug-related patient compliance (SU12), or like in the following opportunity to enable lower insurance fees by sharing more detailed patient health data:

'[Insurance company might import the patient] data into a software, and then shows, for example, that sleep quality is improved, stress is reduced, which the insurer can consider in the form of a lower insurance fee.' (SU12, collaboration, Reference2).

This already highlights the most valuable participatory action of patients rarely discussed in this regard in Healthcare 4.0 value literature: sharing their data. Passively shared patient data is an important input of big data and AI applications, while collaboratively shared patient data (see also Sun et al., 2022) can be the source of value co-creation:

'The users shall participate […] by continuously using the [digital] devices and making the data available.' (SU17, sharing patient data, Reference2–3).

Some of these engagement opportunities also strengthen the patients' trust in medical service providers – but this is also connected to the fourth category of public value: foundational values.

5.4. Foundational values

The foundational value that came up in the most interviews is **safety and security** in healthcare. Extending Rubbio and Bruccoleri (2023) argument, human safety can be enhanced via tech solutions throughout the patient journey by:

- preventing false diagnoses, mismanagement or malpractice (SU2,6,12);
- avoiding the need to practice on people via simulations (SU16);
- less invasive treatments decreasing additional risks (SU10,11);
- increasing drug safety (SU6,17);

- ensuring continuous monitoring of vital signs of patients (SU4,13).

On the other hand, another important security concern is data security – that is also an aspect that is often considered by the Healthcare 4.0 innovators (SU1,2,3,5,9,13,14,18,19), including its implications for legal compliance (SU13). Especially the anonymity of patient data used in big data and AI models is an issue, which is identified as one of the key bottlenecks of future Healthcare 4.0 developments in the region:

'The problem here is that health data is highly sensitive (…) and the handling of these is a high risk according to the Data Protection Act. This is a limitation, but there is enormous potential in this. If this data can be acceptably anonymized in some way, (…) then an algorithm can be run on them, which would greatly facilitate diagnosis and avoid unnecessary medication and doctor-patient encounters.' (SU5, legal barriers, Reference1).

Another foundational value that is often considered by the interviewees is **reliability**. Reliability as a value is most often mentioned in relation to data: new data sources from diagnostic and other innovations (SU5,7,11,18), data availability (SU7) and data transfer (SU9) via new healthcare management software. Reliability is also enhanced by the elimination of human error via technology (SU2,5,8). Increased reliability of data also contributes to another value: **robustness** of the systems (SU3,20). Technology also helps eliminate opportunities of data manipulation (SU5), thus contributing to the values of **objectivity** and **honesty**, and ultimately: **legality**.

'So, when the protocol only allows patients with a bodyweight above 45 kg, then the system does not allow to register someone with 46 instead of the actual 44 (…) – it filters out these fraud-like little manipulations.' (SU5, honesty, Reference1).

At the same time, the availability of numerous and high-quality new data points also enables objective performance measurement (Aceto et al., 2020; Al-Jaroodi et al., 2020) and performance control (SU2,16), promoting the values of transparency (SU2,5) and **accountability** in the industry.

The availability of big data can contribute to another foundational value: **professionalism**, in the form of data-driven decision making (SU2,6,7,12 – see also 4.2). At the same time, professionalism can also be furthered by implementing IT directly in some supporting function: patient management (SU7) or inventory management (SU15).

All these technology-driven advancement in security, reliability, transparency, honesty, and professionalism can lead to an advanced level of **trustworthiness** (S5,16). The benefit of increased patient trust is confirmed by 19 of the 21 interviewees (when directly asked in a control question), making trust the second most common foundational value potentially promoted by Healthcare 4.0 innovations.

Considering the fact that the Public Value literature and policymakers also stress healthcare's allocative value, it is interesting to see that none of the startups identify the direct effects of their innovations on **fairness, impartiality, equity** and **accessibility** of the healthcare system. Although some (SU9,15) mentioned the fact that the capacity-enhancing effects will lead to an ability to serve a wider patient community and the shortening of waiting lists, or that monitoring technology will help the value-based reallocation of nursing staff (SU13), none of the interviewed innovators argued for the benefits of Healthcare 4.0 technology on a more moral or ethical basis.

Our research makes a significant contribution to the existing Healthcare 4.0 literature by extending the scope of value creation with society-level value categories. We were able to identify potential for promoting public values like security, transparency, reliability, trustworthiness, robustness and professionalism, and we believe that future studies may be better suited to exploring Healthcare 4.0's effects on equity or accessibility.

5.5. An interconnected web of values for all stakeholders

An important conclusion enabled by our qualitative research design is that the value categories – efficiency, service improvement, patient engagement and foundational values – are not independent of each other: the value elements form an interconnected web of effects (illustrated in Fig. 1). For example, trustworthiness can contribute to the patients' willingness to share their data, which can lead to new and/or better services, higher healthcare effectiveness and in the end, efficiency. Another example could be that better data regarding the effectiveness of treatment can lead to increased professionalism through accountability and at the same time influence future treatment decisions making healthcare more effective.

This kind of relationship-focused analysis is also useful to explore and understand the interdependence of the value capture of different stakeholders. For instance, enhanced robustness and reliability captured by the research and pharmaceutical companies can lead to superior or novel services, ultimately creating customer value for patients as well. Similarly, the health service providers' increased productivity can lead to higher service levels for patients, alleviating the problem of long waiting lists. If policy and decisionmakers – and researchers – disregard this interconnectedness of values might they miss several opportunities for value creation.

Also, it is important to mention that while this study focuses on potential benefits and value creation of Healthcare 4.0 innovations, some barriers of technology innovation diffusion have also been highlighted by the respondents. These include many prominent economic barriers (lack of funding, lack of market incentives), technological challenges (including cybersecurity or user friendliness), regulatory issues (regarding data sharing for example) or obstacles related to user adoption (conservative attitude of doctors or security concern of patients) – signalling that there is a long way to go before Healthcare 4.0 innovations are widely adopted. Still, we believe that our detailed analysis of value potential will draw attention to the potential benefits of implementation of novel technologies in healthcare and provide incentives for decisionmakers to overcome these mentioned barriers.

6. Conclusions

6.1. Theoretical contributions

Industry 4.0 technologies such as advanced data analytics, IoT and AI are set to revolutionize the healthcare sector, promising to increase efficiency, accuracy, and accessibility (e.g. Popov et al., 2022). While a wide range of academic studies aim to explore how to develop and implement Healthcare 4.0 innovations (Gupta and Singh, 2023), the aim of this paper is to understand the question of why to implement them: to systematically explore the value creation potential of novel Healthcare 4.0 technologies. As Alalääkkölä et al. (2023) suggest: the exploration of the perceived value of different stakeholders participating in healthtech innovations is an intriguing and underrepresented research goal. Due to the hybrid nature of the healthcare sector the number and diversity of beneficiary stakeholders is high, and instead of clear value concepts healthcare system goals frequently encompass numerous dimensions, including society-wide public values. Therefore, similarly to the telehealth study of Askedal et al. (2017), we applied the Public Value categories of Rose et al. (2015a) as the basis for our exploratory qualitative study of Healthcare 4.0 value potential, while we chose a novel holistic approach to complement it with stakeholder theory. While the stakeholder approach is widespread in Healthcare 4.0 research (Laurisz et al., 2023), studies mostly focus on one stakeholder group (e.g. Miozza et al., 2024), often patients or doctors – we chose a more comprehensive approach. At the same time the Public Value concept is present in the healthcare literature (Jones, 2022), but not in connection with Healthcare 4.0 innovations.

This novel approach to systematically and holistically mapping of Healthcare 4.0 value potential resulted in many relevant extensions to previous empirical findings in this area. Some of these extensions included new relevant and significant value categories, such as: reduction of administrative burden, opportunities for new value-added

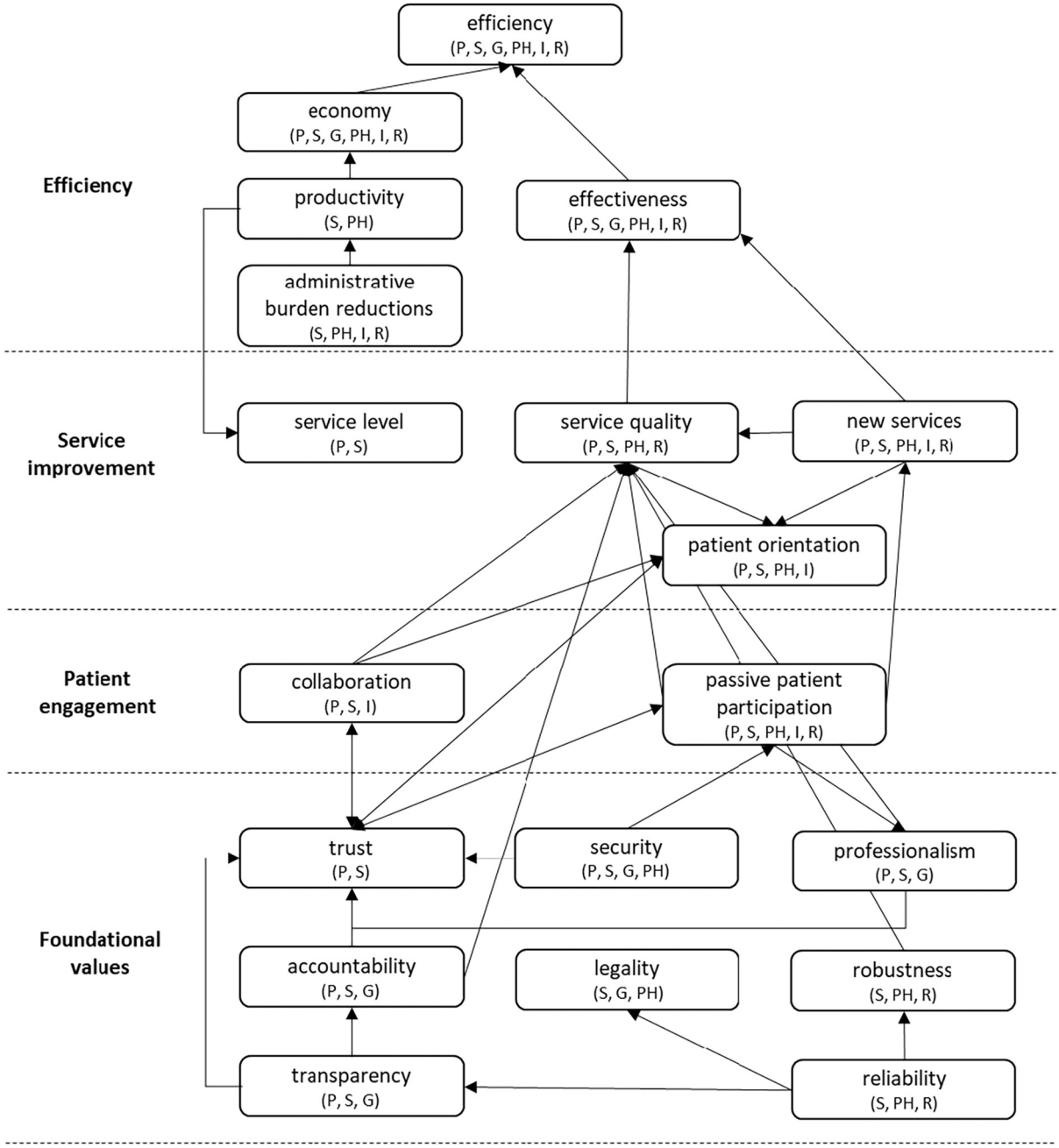

Fig. 1. Interconnectedness of the different value categories
(in brackets: the stakeholder groups benefitting from the different value elements
P – patients; S – health care service providers; G – supervisory/governmental authorities; PH – pharmaceutical companies; I – insurance companies; R – universities, research institutions).

services, and new opportunities for patient engagement through collaborative data. Other extensions focused on the perspectives of under-researched stakeholder groups, such as government bodies or insurance providers – although we agree with Sony et al. (2022) that the research on the perspectives of different and diverse stakeholder groups needs to continue. Last, but not least a novel contribution of our analysis was the inclusion of the societal level foundational public value categories, among which security, transparency, reliability, trustworthiness, robustness and professionalism appear to be promoted by Healthcare 4.0 innovations. These additions to the research body and the systematic thinking about value creation become more and more important in convincing stakeholders, because the cost of technology is high (Sony et al., 2023).

Extending prior empirical evidence, we identified numerous divergent and potentially conflicting values as part of the Healthcare 4.0 value propositions. On the other hand, we also see the convergence and interdependence of the different aspects of value: for example, efficiency gains contribute to increased service levels, or patient participation increases service quality, which in turn influences professionalism and ultimately contributes to the trustworthiness of the system. We conclude that the conceptualisation of healthcare value as an interconnected system of economic and public values (as illustrated in Fig. 1) may be a more accurate and constructive way of representation for future research and practice. Thus, healthcare – and specifically Healthcare 4.0 – research might benefit from borrowing the concepts of Public Value Chains (Moore, 2003) or Public Value Process Mapping (Alford and

Yates, 2014) to promote a complex understanding of value creation.

6.2. Managerial implications

Concerning managerial and policy implications we need to consider the various challenges that hinder the realization of the full potential of Healthcare 4.0 technologies, also highlighted by our respondents: barriers of big data availability, significant funding requirements, or the lack of organisational capabilities for complex IT implementation (Ahsan and Siddique, 2022; Talwar et al., 2023). One step towards surmounting these obstacles is to understand the full value creation potential of the new technologies, so that legislators, financiers and other decision makers can see the interconnected web of business and public value elements supported by Healthcare 4.0. Our framework and the list of potential value effects – based on the literature overview in Table 1 and extended by our numerous original findings in Table 4 – provide structure and content for related arguments. Our results highlight for example that IoT and telehealth technologies enabling remote health service provision (Popov et al., 2022) might provide the best value for money for service provider in the Central Eastern European region, offering solutions where it is most needed: solving human resource shortage, migration of doctors abroad, overstretched capacities and long waiting lists. Another fertile ground for healthtech innovations might be based on data-driven, AI-supported decision making – although this is where many regulatory, institutional and cultural barriers hinder development and implementation on the short run.

We agree with Gyllenhammar et al. (2023): healthcare value propositions must consider all stakeholders, all levels of the loci of value creation: patients, their families, service providers, and the general public as well. As innovators and policy makers work to advance the cause of Healthcare 4.0, they will need to balance financial goals with social and non-financial objectives, as the stakeholder community they seek to impress consists of public, private, and non-profit organizations and individuals alike. Our findings emphasize the importance for healthcare service providers and decision-makers to explicitly articulate their values and priorities and using them as decision criteria, as advances in Healthcare 4.0 might have varying impacts on different groups of stakeholders. An explicit focus on efficiency gains, revenue growth or patient engagement can result in investments in very different type of Healthcare 4.0 solutions.

Also, our in-depth qualitative analysis provides insights into the logic and process behind value creation, which is crucial for effectively managing Healthcare 4.0 implementation projects in the future. For instance, understanding how better data and geographic flexibility might have a positive influence on service level, service quality, and eventually on revenue growth, can help setting the priorities for the implementation project of related technology innovations.

In addition, our unique research strategy of collecting data from the innovators, who have a broad and deep understanding of the perspectives of other stakeholders, gives us the opportunity to better understand the innovators' perspectives. The systematic assessment of the motivations and value perceptions of Healthcare 4.0 innovators can inform future policy decisions on innovation incentives and supportive regulatory changes. For example, we found that patient participation or increasing accessibility are not at the forefront of the innovators' mind – even though these aspects are highly prevalent in the scientific and healthcare policy literature. This suggests that if governments want healthtech innovations to prioritize these democratic societal values they can not rely on market forces alone, policies should explicitly support or prefer innovation with these features.

6.3. Limitations and directions for future research

The research design is not without limitations. The most important limitation concerns the geographic concentration of the sampling: although the target market of the examined Healthcare 4.0 startups is mostly global, but the founders' Central Eastern European origin might cause some cultural distortions. Also, while we believe that collecting data through the innovators has significant advantages in terms of the scale and scope of the experience and innovation available for analysis, the indirect nature of the stakeholder perspective can be compensated in the future by research directly approaching other stakeholder groups, like health service providers or patients. The subjectivity of the qualitative study (although controlled by research design) can affect the robustness of the results, but we believe that it does not influence our conclusions regarding the types and interconnectedness of the value elements.

These limitations can also inform the future research agenda: further international data collection is needed to corroborate early results, and our understanding of the interconnectedness of the value structure in healthcare needs to be deepened, also by explanatory studies. Although value mapping – similar to our conceptualisation of the interconnected network of values – is not without example in the healthcare literature, earlier studies mostly focused on the patients' perspective (Li and Lin, 2011; Kumar et al., 2020), so this approach might be a promising direction for future research.

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CRediT authorship contribution statement

Marta Aranyossy: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Peter Halmosi:** Writing – review & editing, Validation, Investigation, Formal analysis.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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