Hospital Investments Decisions in Healthcare 4.0 Technologies: Challenges, Trends, and Research Directions

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Abstract

Background: The literature has increasingly discussed alternative approaches to analyze and evaluate healthcare investments in state-of-the-art technologies, especially with the advent of Healthcare 4.0 technologies or e-health. Such investments generally involve computer hardware and software that deals with the storage, retrieval, sharing, and use of healthcare information, data, and knowledge for communication and decision-making. Besides, the utility of these technologies significantly increases when addressed in bundles. However, a structured and holistic approach for analyzing investments in Healthcare 4.0 technologies is not available in the literature.

Objective: This study aims to analyze previous research related to the evaluation of Healthcare 4.0 technologies in hospitals and characterize the most common investment approaches used. We propose a framework that organizes the research associated with Hospitals 4.0 investment decisions and suggest five main research directions on the topic.

Method: To achieve our goal, we carried out the standard procedure for scoping reviews. We performed a search in the Crossref, PubMed, Scopus, and Web of Science databases with the keywords "investment," "health," "industry 4.0," "investment," "health technology assessment," "healthcare 4.0," and "smart" in the title, abstract, and keywords of research papers. We retrieved 5701 publications from all databases. After removing papers prior to 2011, duplicates, and performing further screening, we arrived at 244 articles from which 33 were selected after in-depth analysis to compose the final publications' portfolio.

Results: Our findings show the multidisciplinary nature of the research related to evaluating hospital investments in H4.0. We detect that the most common investment approaches focused on cost analysis, single technology, and single decision-maker involvement, which dominates over bundle analysis, H4.0 value considerations, and multiple decision-maker involvement. We propose a framework for clasifying H4.0 investment methodologies and suggest five main research directions for this topic.

Conclusions: Some of our findings were unexpected given the interrelated nature of H4.0 and its multidimensional impact. Given the absence of a more holistic approach for H4.0 investment decisions, we identified five promising research directions on the topic: (*i*) development of economic valuation methodologies tailored for healthcare 4.0 technologies, (*ii*) account for technology interrelations in the form of bundles, (*iii*) account for uncertainties in the process of evaluating such technologies, (*iv*) integration of administrative, medical and patient perspectives into the evaluation process, and (*v*) balancing and handling of complexity in the decision-making process.

Keywords: H4.0, Investments, Real Options, Health Technology Assessment, Technological Bundles, Decision-Makers.

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Introduction

How do health organizations manage and determine their investment decisions in Industry 4.0 technologies (known as Healthcare 4.0 or H4.0)? Having the right answer to this question is essential since the healthcare value chain is increasingly applying H4.0 technologies [1]. Also, the rising demand for more efficient, qualified, and less expensive health services has motivated novel technological solutions [2]. Healthcare organizations have incorporated innovative technologies around the internet to facilitate and support more efficient and flexible processes, services, and products [3,4]. Such technologies started playing a pivotal role as enhancers of efficiency and quality in healthcare systems in the 1990s, culminating in what is currently known as "e-health" [5]. Healthcare institutions extend the emerging principles and technologies belonging to the Industry 4.0 realm to healthcare as a continuous and disruptive process of innovation and transformation of the entire healthcare value chain [6].

The magnitude of the technological shift, the scope of activities affected, and their interrelationships expose healthcare decision-makers to large and complex investment decision problems [7,8]. The scope of activities encompasses procedures, equipment, and processes used to deliver medical care [9]. The range of such investments usually involves computer hardware and software that deals with the storage, retrieval, sharing, and use of healthcare information, data, and knowledge for communication and decision-making [10]. Even though it is possible to identify stand-alone technologies under the H4.0 umbrella, they tend to be highly interrelated, generating the need to assess them in bundles. Also, there is significant uncertainty on which technology will be the industry standard, adding an extra level of complexity to financial evaluations.

Since the level of investment required to stay competitive with these new technologies is massive, health institutions and countries' financial budgets are constantly stressed. For instance, data from BRICS nations (i.e., Brazil, Russia, India, China, and South Africa) indicates that their average health expenditure grew from 5.41% of their GDP in 1995 to 6.94% in 2013, and is forecasted to reach an average of 7.86% by 2025 [11]. Hence, there will be an increasing need for massive and interconnected investments that will impose non-trivial challenges in determining their value, optimum level, and implementation sequence.

Several different theoretical lenses help to enlighten managers in their technological investments. The Health Technology Assessment International Policy Forum recently concluded that the assessment paradigms need to be more agile, helping healthcare systems understand the potential of innovations and ensure that their potential value is realized [12]. However, while the literature has suffered from balkanization since multiple alternative approaches have significantly grown during the last years, hospitals rarely have or use a systematic decision process for H4.0 investments, accounting for all organizational objectives and utilizing objective data [13,14].

This paper aims to address the current gap between the literature and practice by examining trends, challenges, and research opportunities in hospital investment valuations of H4.0 technologies. To achieve that goal, we opted to carry out a scoping review of the literature, which is appropriate for identifying and mapping critical concepts that underpin a specific research topic, especially in the absence of previous comprehensive studies [15,16]. More important, the scoping review approach is also suggested as an alternative to a systematic review when literature is vast, sparse, and complex [17,18], which is the case of investments in H4.0 [19].

The research has been structured in the following manner. First, we proceed to motivate the study, present the protocol for the scoping review (i.e., the research method section) and summarize the manuscript selection process. Second, we define the research questions and identify the relevant studies, selecting the final list. Third, we present the main findings in a section devoted to the analysis of results, addressing the first two research questions. Fourth, we develop a framework that synthesizes the analysis and identifies promising research directions regarding the most crucial characteristics for evaluating investments in H4.0, addressing the third research question.

Hospital investments, the fourth industrial revolution, and alternative evaluation approaches

The advent of I4.0 technologies has significantly affected the global healthcare value chain. The recent integration of disruptive technologies derived from Industry 4.0 into healthcare systems aims at achieving virtualization to provide care in real-time [20]. Healthcare institutions have incorporated cyber-physical systems, cloud computing, the internet of things, and big data, among others, into healthcare processes, services, equipment, material, and people. H4.0 allowed establishing a smart system to monitor, track, and store patient records for ongoing care and analysis [21,22]. The combination of new technologies has expanded the scope of hospital activities. Economically, H4.0 technologies come with a value proposition of simultaneously incrementing efficiency and quality of care while reducing operating costs [23].

However, healthcare institutions need to carry out substantial investments to achieve the economic gains associated with H4.0. In 2014, US healthcare expenditure was $3.0 trillion and is forecasted to rise to $5.1 trillion in 2023, outpacing the expected GDP growth rate in the corresponding period [24,25]. These expenditures imply multiple

investments that are not free of uncertainties since evaluating the impact on patient care is extremely difficult [26].

The unique characteristics of H4.0 add a layer of evaluation complexity in an industry where assessing economic value was already challenging. For instance, studies on Health Technology Assessment (HTA) have primarily recognized that not every technological development results in net health gains [27]. The history of medicine and health counts many examples of technologies that did not produce the expected benefits or even proved harmful. On the other side, proving the effectiveness of technologies creates a continuous challenge for health systems since their application may require additional resources or the need to select between competing alternatives within the health system.

The literature has examined how healthcare organizations struggle to benefit from investments in H4.0 technologies [28,29]. Therefore, the dramatic increase in firms' technology investments in the last years has not necessarily resulted in significant increase in productivity [30]. The complexity of understanding the economic impact of H4.0 resulted in non-trivial challenges to determine the policy and practice implications associated with them [31].

Organizations contribute significant financial resources to developing and implementing H4.0, and the potential for a negative return on investments or total implementation failure is a worrisome possibility [32]. Assessing technological investments is of great interest to hospital managers to raise capital to expand services [33]. With the rapid growth of e-health in developing countries, there is an urgent need for substantial evidence of its impact on justifying and guiding the investment of resources in such systems [26].

Studies evaluating H4.0 investments have taken different approaches. A wide array of manuscripts focuses on cost reduction evaluation. For instance, [34] report that healthcare

decision-makers base their adoption decisions on cost-effectiveness and cost-minimization analysis. The approach's main limitation is the focus on just one side of the decision (cost), underemphasizing value considerations.

The real options approach to decision-making has been useful in capturing and valuing uncertainty in many operating decisions that decision-makers face [35]. Its utility emerges from the fact that real-options are contingent on future discretionary investment. The magnitude, timing, and schedule of investment outlay affect the value of firms' growth opportunities. Although correcting limitations from the cost perspectives, the real options approach increases the analytical effort organizations need to carry out economic evaluations.

Besides, H4.0 requests multilateral stakeholder dialogue and collaboration that addresses health needs and product conceptualization [12]. The nature of H4.0 imposes challenges on how to assess the various aspects of technological value into the decision-making processes, so it simultaneously accounts for the input of physicians, patients, and society [36].

Not surprisingly, despite the expected benefits of H4.0 technologies and the interest from hospitals and policymakers in implementing them, the uptake and adoption of these technologies have not always been consistent within the health care practice, and adoption of these technologies has lagged [37]. There is a need to synthesize research activities and evidence to clarify the evaluation process of H4.0 investment in hospitals. Our scoping review explored such knowledge gap by mapping the extent and nature of the available literature. For that, our study focused on literature evidence that approached the integration of H4.0 technologies investments into hospitals.

Research method

The scoping review design represents a methodology that allows assessing emerging evidence; therefore, it is a the first step in research development [16]. It is a relatively new approach to evidence synthesis and differs from systematic reviews in its purpose and aims. The purpose of a scoping review is to provide an overview of the available research evidence without producing a summary answer to a discrete research question [38]. The methodology can help answer broad questions and gather and assess information before conducting a systematic review. It is suitable for achieving several objectives such as identifying types of existing evidence in a given field, clarifying key concepts or definitions in the literature, surveying how research is conducted on a specific topic, identifying key characteristics related to a particular topic, and identifying knowledge gaps. Compared with systematic literature reviews and meta-analyses, a scoping review provides more flexibility and allows for diverse, relevant literature and studies using different methodologies [17,39,40]. Our research domain is adequate for taking a scoping review since the literature regarding H4.0 is multidisciplinary and relatively new.

To achieve our goal, we followed a standard scoping study procedure comprised of five steps: (i) identify the research questions, (ii) identify relevant studies, (iii) select studies, (iv) chart the data, and (v) collate, summarize, and report results. Immediately below, we detail each stage and the outcomes of our work.

Identify the research questions

As with most systematic literature reviews, scoping reviews start with a primary research question to focus the inquiry [15,16], guiding how to build the search strategies [17]. Our broad initial research question was "How have healthcare institutions assessed their H4.0 investments?". However, given the multidisciplinary nature of the subject and the

comprehensive sources of reports, we narrowed the main research question into three more specific research questions:

RQ1. What methodologies healthcare institutions use for evaluating investments in H4.0?

RQ2. Which are the main challenges that healthcare institutions face when evaluating investments in H4.0?

RQ3. Which are the most important characteristics that methodologies for evaluating investments in H4.0 must have?

To answer these questions, we develop a rigorously structured and sufficiently documented method to provide robust evidence and arguments.

Identify relevant studies

A scoping study requires identifying all relevant literature, regardless of methodological design [16]. This step aims to find all available published and unpublished work that addresses the research questions, operationalized through the search terms. Since familiarity with the research topic is likely to increase as the review advances, we searched for relevant studies in two stages. In the first stage of identification, in order to include as many relevant studies as possible, we defined the set of keywords that best represents the scope of the study. In the second inclusion stage, we randomly selected a group of papers from each database and analyzed their keywords to determine the need to add more keywords to our inquiry. This two-stage process allows us to address the search string's potential problem of being overly specific or entailing (partially) misleading buzzwords.

In the first stage, we defined the three research dimensions or keywords that best reflect our research questions: investment, health, and Industry 4.0. We then proceed to combine an initial set of keywords using AND and OR boolean search operators ("investment"

AND "health," "health" AND "industry 4.0", "investment" AND "industry 4.0", "health technology assessment" AND "industry 4.0") to retrieve publications that used them in the title, abstract and/or keywords. The use of the AND operator in the search process significantly reduced misleading results, especially in the case of the "4.0" string. We searched for scientific articles in the following databases: Crossref, PubMed, Scopus, and Web of Science (that comprises biomedical literature from MEDLINE, life science journals, and online books).

Since H4.0 derives from principles and technologies from I4.0, whose concept was formally acknowledged in 2011 [41], we only considered publications after that year. Further, in the widely referenced literature review study due to [3], the authors indicated that, even though the announcement of the I4.0 concept traces back to April 2011, it began to attract attention only after it became one of the ten official projects within the 'High-Tech Strategy 2020' action plan, in March of 2012. In fact, no study was identified before that date, supporting the choice of cut-off year of 2011 for our scoping review.

We applied the query string to the indicated databases and retrieved a total of 5701 publications from all databases.

In the second stage, we randomly selected five articles from each database to compare their keywords with the ones from the research dimensions used in the first stage [42]. The objective was to take into account that different taxonomies may be associated with a given subject, potentially compromising the search. From the comparisons, we identified the need to add the keywords "smart" to our inquiry. A new search , including those keywords, generated 74 additional papers, totaling 5,775 publications scattered among the databases as informed in Figure 1. We conducted both search stages between July and August 2020. Figure 1 reports the process of identification of relevant studies and the final selection included in the review.

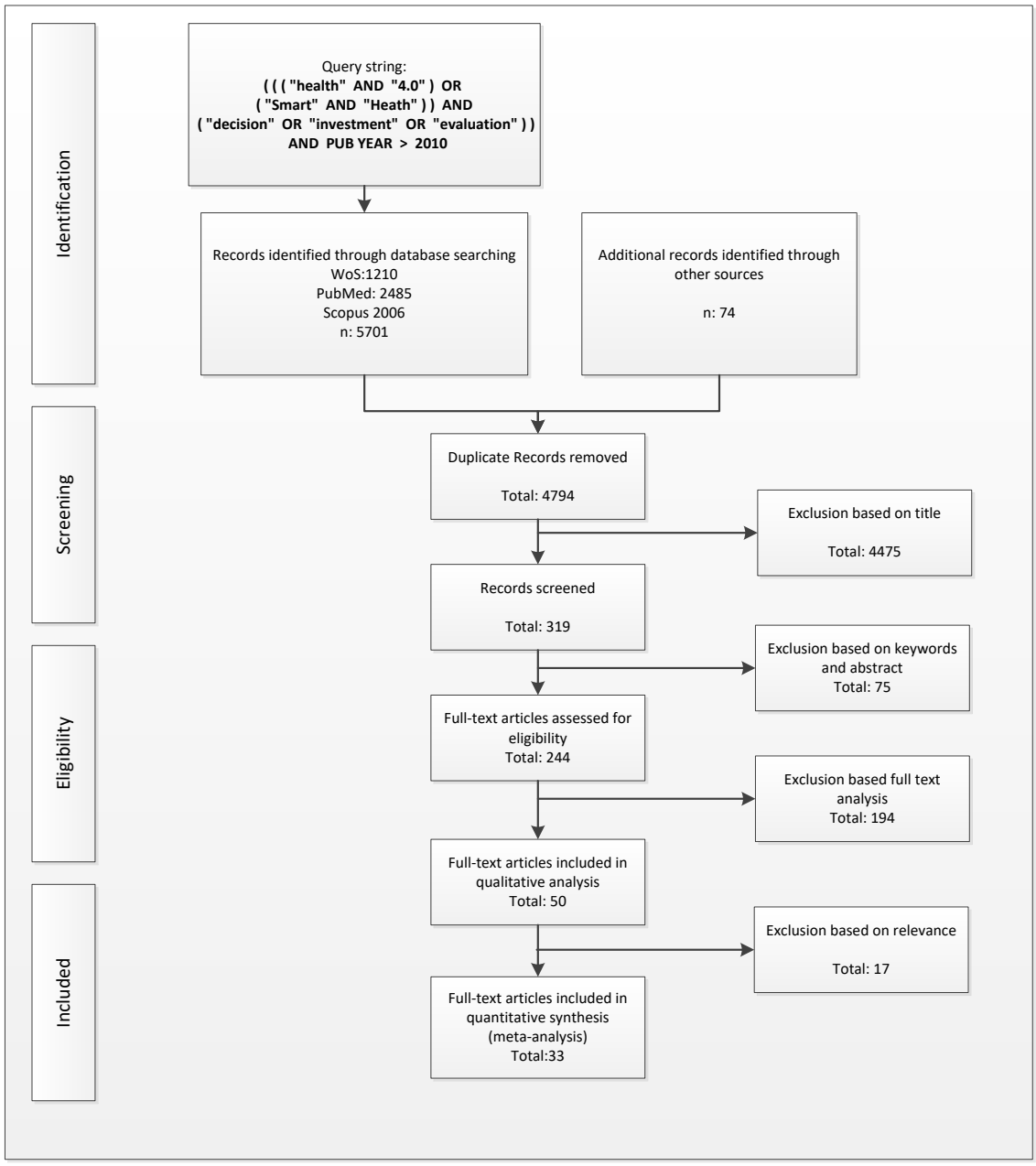

Figure 1. Selection of studies for the review.

Selected studies

The definition of different inclusion/exclusion criteria was post hoc, as the researchers' familiarity with the literature increased. In the first exclusion process (screening), we considered only articles in English published in peer-reviewed journals. We removed duplicate publications from the portfolio, which reduced from the initial 5,775 to 4,794 articles. In the next exclusion step, paper titles were individually verified, determining

their alignment with the research topic. That resulted in 4,475 paper titles deemed not relevant to the research. The remaining 319 articles that passed the title screening were then checked for alignment of keywords and abstracts with the research topic. 75 articles were excluded, resulting in 244 to be considered in the eligibility step.

The next step is to determine the eligibility of the papers. Best practice guidelines for conducting scoping reviews recommend that two separate reviewers should carry out the literature search and sifting process. They must both agree for the work to be included. Therefore, we took special care to assure inter-rater reliability, with at least two separate reviewers involved in the process.

We carried out the two separate review processes and performed a full-text analysis of 244 articles to determine their eligibility. Fifty articles were identified as fully aligned with our research interests by both reviewers. We then proceed to evaluate the papers regarding the criteria of relevance and methodological rigor. In this process, we added a third reviewer, and a majority vote determined the inclusion of a paper. By the end of this stage, 30 articles were considered appropriate for inclusion in the review. We also analyzed those articles' references to identify relevant studies not yet included in the portfolio, but none was found. However, based on experts' recommendations (qualitative analysis), three articles were added to the portfolio, leading to a final number of 33 studies in the publications' portfolio, as displayed in Figure 1.

Chart the data

We will now chart and interpret critical data from the publication portfolio to establish the grounds for the subsequent analytical step [39]. We followed a descriptive-analytical method [17,43], providing a broader and meaningful view of all papers and collecting standard information from each study. Driven by our investigation's research questions,

we organized the articles in a spreadsheet including the following information: authors, year of publication, journal, aims, type of technology, application focus (e.g., hospital processes or health treatments), valuation methods, decision-maker, users, challenges and opportunities.

Figure 2 reports the histogram with the basic descriptive numerical summary of the publication count per year. Three main characteristics are noteworthy. First, as expected, studies on H4.0 financial evaluation are recent. Second, there is a slight increase in the number of publications in recent years (2018-2020). Finally, the number of publications is relatively small (33), which may be due to the novelty of H4.0, the multidisciplinary nature of the investment evaluation requirements, and its complexity. These findings reinforce the convenience of taking a scoping review approach.

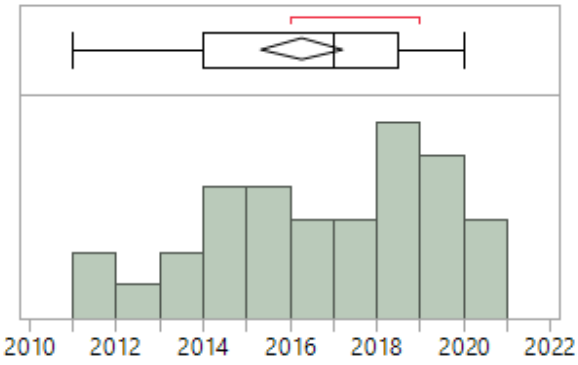

Figure 2: Evolution of the number of publications

Collate, summarize and report results

In this step, results are collated, summarized, and reported based on a thematic framework, such that a narrative account of the publication portfolio becomes available. Following [39], we carried out three complementary analyses to increase this step's consistency. First, we performed a descriptive thematic analysis to collate and summarize results. Second, based on reported results, we develop a detailed analysis of

characteristics, contributions, and challenges on H4.0 evaluation tools. We report this analysis in section 4. In section 5, we describe an emerging framework that synthesizes the analyzed papers' empirical patterns. Finally, we discuss our findings' implications in a broader context, ensuring the scoping study methodology's legitimacy for both theory and practice [39]. In that discussion, we also listed research gaps and proposed research alternatives for future studies.

We now expand on the first step, providing detailed information on key publications' characteristics. For that, we conducted a word cloud analysis using the title, keywords, and abstracts of papers in the portfolio. Figures 3 to 5 and Table 1 include the results, which provide initial evidence to answer the research questions. "Health" was the most frequent word, followed by "cost," "cost-effectiveness," "study," "evaluation," "care," "patients," and "data."

Figure 3: Cloud analysis using titles as input.

Figure 4: Cloud analysis using keywords as input.

Figure 5: Cloud analysis using abstracts as input.

The word cloud analysis anticipates the interdisciplinary nature of the manuscripts in the portfolio, allowing us to identify cost-effectiveness evaluation as the most recurrent. Besides, the incidence of the words "management," "clinical," and "patient" anticipates the need for healthcare institutions to incorporate a broad set of players in the investment decision process. We emphasize the absence of words such as quality, value, and bundle, which anticipate challenges and opportunities in current research on H4.0 investment analysis.

Title		Keyword	
Word	Count	Word	Count
health	12	health	31
evaluation	10	results	26
cost	8	methods	24
cost_effectiveness	7	study	23
effectiveness	7	analysis	20
study	7	based	19
based	5	care	19
decision	5	data	17
economic	5	background	16
management	5	cost	16

Table 1: Most frequent words in Titles and Abstracts

Figure 6 reports the top 15 most frequent authors in the portfolio and the number of documents they authored, showing some of those that authored just one paper and the entire list of those that authored two or more. From the list of 146 authors, one participated in three studies, two participated in two studies, and the remaining 143 appeared in only one article. A large number of authors with small authoring prominence is typical of research topics about which knowledge is still incipient, such as H4.0 investment evaluation, reinforcing the convenience of adopting a scoping review as the methodological approach. We also observe a large average number of authors per publication (mean value of 4.33), which is typical of publications in the medical field.

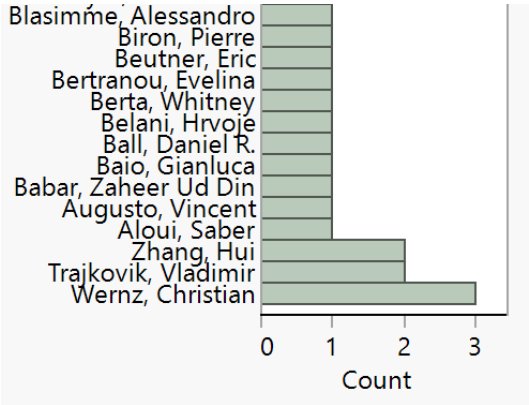

Figure 6: Top 15 authors and frequency of appearance in publications.

The journals' analysis also reinforces the topic's multidisciplinary nature. Figure 7 reports the number of papers by category and Figure 8 by journal. The Web of Science category "Health Care Sciences & Services" has the highest frequency of 15, followed by "Medical Informatics" (10), and "Pharmacology & Pharmacy" (2). Remaining seven categories display a frequency of 1 (70% of the sample). Two journals published four manuscripts each: Journal of Medical Internet Research and JMIR MHealth and UHealth.

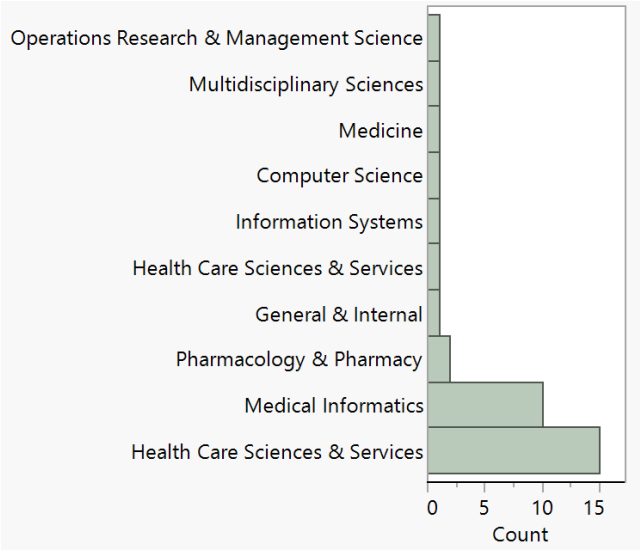

Figure 7: Frequency of manuscripts stratified according to Web of Science category.

Figure 8: Frequency of manuscripts by journal.

Analysis of Results

Table 2 summarizes the papers listed in the rows by year of publication and their different content characteristics. We start reporting the type of technology analyzed, grouping them according to their role within the healthcare organization. Aceto et al. [5] proposed four interrelated subsets: (i) communication, (ii) sensing, (iii) processing, and (iv) actuation. Communication involves different interactions and disseminating health-related information, supporting patient-professional relationships, and collaborative care. Related H4.0 technologies provide support to increase accessibility, exchange, and sharing of information. Sensing refers to acquiring information about a patient, equipment, material, or process without necessarily making physical contact with them. Processing refers to technologies that may change or process the acquired data producing actual information in any manner detectable by an observer. Finally, actuation refers to technologies responsible for moving and controlling a system, mechanism (electronic or mechanical), or software based on the information and signals received.

There may be overlaps between the technology subsets. Following the classification in [44], we further grouped H4.0 technologies into two bundles according to their role within the hospital: sensing-communication (reported under the column labeled "sensing") and processing-actuation (reported under the column labeled "actuation"). Consistent with previous studies' reports on the incidence of technological applications (e.g., [1]), the number of articles evaluating sensing-communication is significantly greater than those analyzing processing-actuation. Besides, and somehow paradoxically given the nature of H4.0, most studies focus on just one technology, with only six manuscripts addressing bundles of technologies.

Regarding the thematic analysis (data not included in the table due to space limitations), we observe two groups of studies on H4.0 evaluation in healthcare organizations: those related to (i) health treatments and to (ii) hospital's supporting/administrative processes. Articles in group (i) are relatively more frequent than those in group (ii).

The evaluation of different technologies contributes to health improvement in various manners. H4.0 technologies contribute to disease reductions such as cancer [45,46] and allow for better connectedness that manages individual and community health holistically by leveraging various technologies [47]. Connectedness can also incorporate telehealth and integrated care services, covering the whole spectrum of health-related services addressing healthy subjects and chronic patients [47]. Besides, neural networks improve decision-making, improving care delivery at a reduced cost [48].

The analysis above allowed us to describe types of technology and the health improvement aimed by their use. We now address the first research question. For that, we survey what methodologies healthcare institutions reportedly use for evaluating investments in H4.0.

Regarding the different methodologies for evaluating investments in H4.0, only 14 (42.4%) of the 33 papers analyzed presented valuation methods, 7 of which (21.2%) focused on cost valuation methods, and 7 (21.2%) on value methods. Regarding forms of considering uncertainty in the analysis, 2 (6%) used deterministic techniques which disregard uncertainties, 5 (15.2%) accounted for uncertainty but did not use real options, and 7 (21.2%) accounted for uncertainty using a real-options approach.

As we can observe, studies that consider the cost implications of investing in H4.0 focus on economic analysis, adopting a cost-effectiveness and cost-minimization perspective. These studies were complemented by the application of Bayes sequential economic evaluation model for health technologies in which an investigator has flexibility over the

timing of a decision to stop carrying out research and conclude that one technology is preferred over another on cost-effectiveness grounds [49]. Five manuscripts took a real-options perspective that incorporates value considerations but refers to past work, mainly published at the beginning of the time window of analysis.

The portfolio of 33 works lists three types of decision-makers, which may be consulted individually or in groups: doctors, administrative, and patients. Doctors appear in 27 of the 33 documents, complemented by 13 papers that incorporate the administrative perspective and 7 containing the patient perspective. Although there is a dominance of expert opinion based on medical advice, the variety of decision-makers is a positive result that further claims for a multidisciplinary analysis that incorporates the different types of users affected when evaluating investments in H4.0. Users of the information derived from the evaluations are also doctors, administrative, and patients; however, administrative users are predominant since they are direct users of the economic information.

A relevant aspect of the works analyzed in the portfolio is that 16 articles present results of scoping or systematic literature reviews and meta-analysis (in one of them). However, they focused on the medical convenience of H4.0 investments, not exploring specific economic evaluation tools, and mainly assessing a particular technology (e.g., physicians' adoption of e-health technology or smart device applications for older adults).

We were able to consolidate several relevant propositions for the economic evaluation of H4.0 technologies. A fundamental contribution of our review is identifying the main antecedents of hospital investment decisions in technology, such as the healthcare system, the socio-economic and cultural context, and its mission [13,14]. Regarding the healthcare system, findings emphasize the role of health insurance coverage, financing method, reimbursement method for hospitals, payment method to physicians, and hospital

ownership as antecedents of H4.0 investments. The existence of these various antecedents anticipates the challenges of investment evaluations.

			Healthcare 4.0		Technologies		Valuation Methods						Decision Maker			User		
							Deterministic		Uncertainty No Option		Uncertainty Option Analysis							
Year	Papers	Non Healthcare 4.0	Sensing & Comunication	Processing & Actuation	Stand Alone	Bundle/Portfolio	Cost	Value	Cost	Value	Cost	Value	Medical	Administrative	Patient	Medical	Administrative	Patient
2011	Dreyfuss & Roberts [45]			X	X							X		X			X	
	Grutters et al. [73]			X	X							X		X			X	
2012	Marsh et al. [74]	X			X							X	X	X		X	X	
2013	Favato et al. [75]				X							X	X			X		
	Drummond et al. [50]	X			X		X						X			X		
	Pertile et al. [49]	X							X					X			X	
2014	Boydell et al. [51]		X		X								X		X			X
	Kvedar et al. [52]		X	X	X	X							X		X			X
	Wernz et al. [14]		X	X	X							X	X	X			X	
2015	Atwood et al. [53]		X	X	X							X	X	X			X	
	Wernz et al. [13]		X	X	X							X		X			X	
	Gobbi & Hsuan [55]		X		X				X					X			X	
	Merlo et al. [56]								X				X	X	X	X	X	
2016	Sharma et al. [57]		X	X		X							X			X		
	Matthew-Maich et al. [58]		X	X	X								X	X		X		
	de Grood et al. [37]		X		X								X	X		X	X	
2017	Lavallée et al. [59]		X			X							X			X		
	Kim & Lee [60]		X	X	X								X		X			X
	Rejeb et al. [46]	X				X			X				X			X		
	Greenhalgh et al. [61]		X	X	X		X								X			X
2018	Long et al. [62]		X			X							X			X		
	Adjekum et al. [63]		X		X								X			X		
	Winters et al. [64]		X		X								X		X	X		X
	Baines et al. [65]		X	X	X								X		X	X		X
2019	Taj et al. [66]		X	X	X								X			X		
	Dogba et al. [67]		X		X								X		X	X		X
	Loncar-Turukalo et al. [68]		X	X	X	X							X			X		
	Shahid et al. [48]		X	X	X								X			X		
	Wüller et al. [69]		X	X	X								X			X		
	Chouvarda et al. [47]		X		X				X				X			X		
2020	Hasselgren et al. [70]		X										X	X		X	X	
	Peng et al. [71]		X	X	X								X			X		X
	Isamil et al. [72]		X	X									X	X		X	X	

Table 2: Classification of contents in the portfolio of papers.

[14,37,45–75]

The appropriate deployment of medical technology should help contribute to the quality of healthcare delivered, improve access to information, and contain costs [53]. Among the most promising evaluation alternatives is the framework in [61] to assist implementation teams in identifying, understanding, and addressing the interacting challenges to achieving sustained adoption, local scale-up, distant spread, and long-term sustainability of their technology investments in hospitals. Complementing this analysis is the call for applying a simple, multiattribute rate technique in the valuation process – SMART, as proposed in [13].

We identified four main challenges that healthcare institutions face while evaluating investments in H4.0. First, H4.0 should be analyzed as a bundle of technologies rather than individual solutions. As [5] proposes, there are four overlapped groups of technologies based on their roles and applicability within the hospital. In our portfolio, only 6 (18.1%) of the papers analyze H4.0 as a bundle. Second, as mentioned earlier, there is a research gap on valuation methodologies for H4.0 technologies, especially in the realm of real-options analysis. Third, regarding who makes the decision to acquire the technology (medical, administrative, or patient), 27 studies (81.8% of the sample) focus on the medical personnel as the main decision-makers. In contrast, only 8 (24.2%) focus on patients, and a single paper integrates the three actors in the process [56]. Fourth, regarding the user of the technologies, 22 studies (66.6%) focus on the medical personnel, while 8 papers (24.2%) indicate that the main user is the patient.

Real-options strategies offer a transparent method for weighing the costs and benefits of adopting and further researching new and expensive technologies [45,73]. Such valuation methodologies incorporate the value of future new information in current analyses. Articles in the portfolio report real-options applications in proton therapies' adoption analysis [45,73], and helping to formulate better human papillomavirus vaccination

strategies [75]. Surprisingly, none of the articles using real-options analysis incorporate uncertainty correlations among technological bundles. That is a critical shortcoming given antecedents that reports the importance of taking broader portfolio considerations when evaluating related and uncertain investments in areas such as biotechnology R&D [76].

Healthcare managers often make purchasing decisions without adequately assessing the resource demands, up-front costs (including integration costs), workflow impact, reimbursement potential, and other factors needed to fully understand the value added by new medical technology [53]. Consequently, healthcare authorities may risk failing at conducting thorough due diligence before purchasing medical technology. Under these circumstances, organizations might add unnecessary costs to their budget without adding significant clinical or operational value.

Selecting new medical technology for a healthcare organization can be a daunting task. It is crucial to implement a systematic approach for evaluating the latest medical technology, starting with a clearly articulated need for the technology. If organization authorities are unwilling to assess and redesign processes to utilize the new medical technology fully, investment withholding may be the most suitable course of action. Moreover, there is the risk of bias in purchasing the latest technology simply because it is available [53]. Overall, healthcare organizations rarely assess a systematic decision process that considers all organizational objectives and analyzes and integrates comprehensive data [53].

Providing universal access to innovative, high-cost technologies leads to tensions in today's healthcare systems. The stress becomes particularly evident in the context of scarce resources, where the risk of taking contentious coverage decisions increases rapidly. If healthcare institutions intend to maintain sustainable access to H4.0 in the

future, they will need new approaches to reconcile these different perspectives [50]. Overall, while policymakers request a rapid and at-scale technology implementation, the reality is that when dealing with the multiple complexities of health and care, it is challenging to go beyond small-scale demonstration projects [53]. To address the need for new approaches, we propose in the next section a framework for the evaluation of H4.0 technologies in hospitals.

Classification Framework

Scientific research presents frameworks since managers use them to support their analysis and provide validity to the decision-making process [77]. We develop an emerging framework from the study we carried out about the research on hospital evaluations of H4.0.

Developing frameworks has multiple advantages. They decrease the number of uncertainties when addressing a new phenomenon, as is the case of H4.0. Frameworks can support the selection of investment strategies. Besides, frameworks can depict features of various phenomena [78], compare and guide numerous organizational practices [79], support the execution of tasks [80], and refute or confirm a particular management approach [81].

When developing the framework, it is fundamental to determine the rationale that provides validity to the theoretical process. Given the scoping review's multidisciplinary, integrative nature, we have taken a process of abstraction. That is, we obtain higher-order themes from lower-order elements [82]. We follow, therefore, the most common abstraction process, in which lower-order themes are a function of the findings of individual studies, and higher-order structures link and organize the lower-order themes [82]. Such a method should result in the advancement of knowledge rather than a simple

overview or description of a research area [83]. That is, it should not be descriptive or historical but should preferably generate a new conceptual framework. In addition, check the reliability of higher-order themes using a focus group of experts. It is worth noting that the higher-order themes respond to taxonomy and not from a typological process [83,84].

Figure 9 presents the proposed classification framework. It focuses on the most fundamental tensions that organizations face when analyzing H4.0 investments and reflects the most prominent features of our manuscripts' portfolio. We categorized the type of technology analyzed based on its focus, sensing-communication or processing-actuation, following the classification in [1]. In this process, we classify lower-order themes into higher-order classification. We describe the number of technologies evaluated, depending on whether the analysis refers to stand-alone technologies or bundles. We also report the evaluation method, saying whether it is just based on cost or also taking into account value considerations. We considered whether the analysis does not incorporate flexibility in the valuation process or explicitly incorporate it using a real-options approach. We also examine the portfolio of manuscripts regarding the variety of decision-makers included and the type of technology users. For all of these cases, we propose higher-order themes for the portfolio of manuscripts.

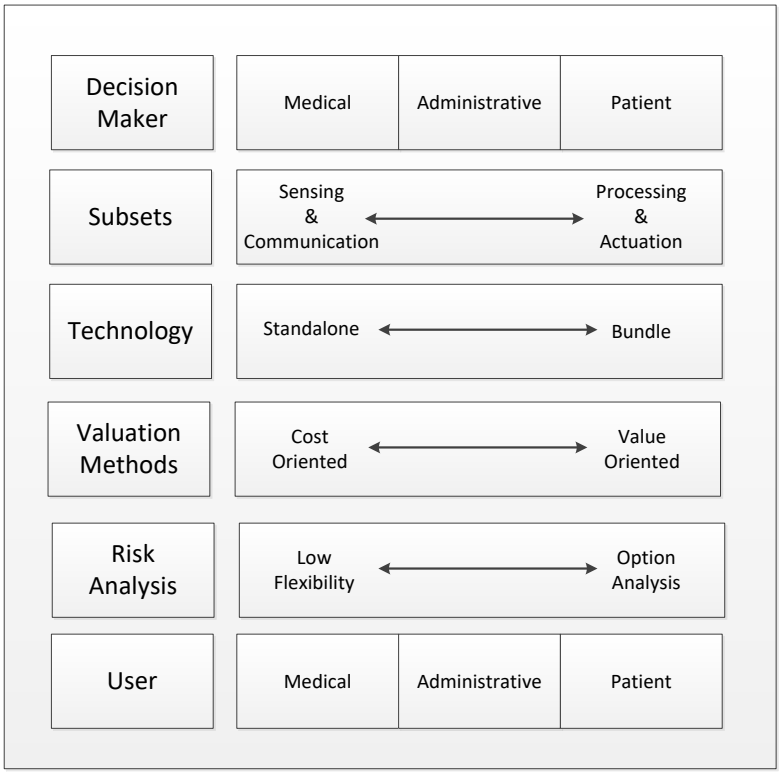

Figure 9: Classification framework.

The framework not only helps to classify a particular research paper but also has utility for practice. It may allow hospital authorities to understand what type of organizational process they have in place to analyze investment decisions in H4.0. Also, it helps to anticipate the complexity of the task. When reflecting on the most critical tensions hospitals face, the structure would allow authorities to detect the underlying leadership and change management challenges.

When categorizing the portfolio of manuscripts using the proposed framework, we identified a significant concentration of studies on the left side. It seems reasonable to observe such unbalanced distribution, given the developing nature of H4.0. However, it also signals an essential shortcoming of the current literature, directing further research propositions. There is a risk that hospitals might have been making decisions following an isomorphic behavior [85] which is not necessarily the best rational approach. Research concentration might reflect a herding behavior in which hospitals imitate one another instead of following a robust, innovative path.

We further analyze the framework and develop a research opportunity map, displayed in Figure 9, focusing on two dimensions of the framework: the complexity of the analysis and the number of technologies considered.

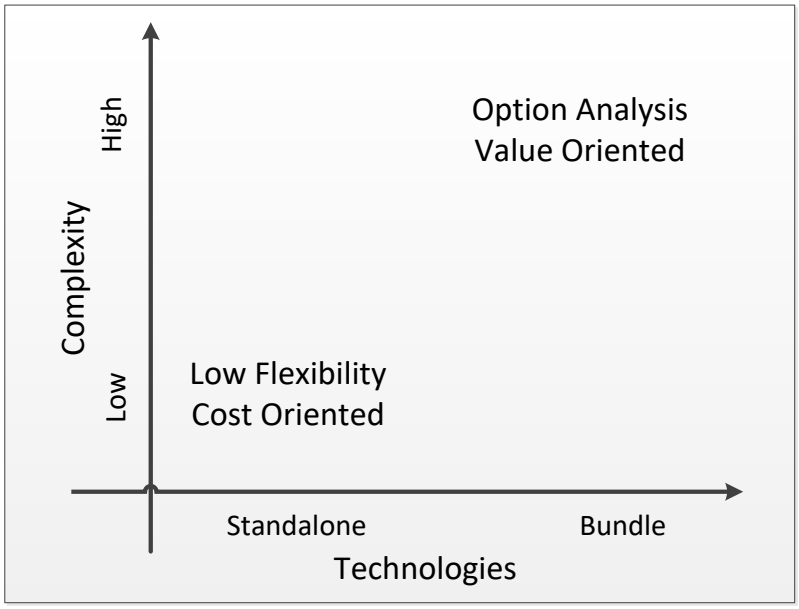

Figure 10: Research opportunity map

From the research map it is possible to indicate that there is a research opportunity related to analyzing bundles of technologies with complex relationships which incorporates uncertainty correlations. It is important to emphasize that complex relationships do not necessarily imply more complex analyses. The challenge is to integrate a higher level of complexity with straightforward analytical tools. We will return to this point at the end of the following section.

Research directions

This section addresses the third research question; that is, we identify the crucial characteristics that methodologies for evaluating investments in H4.0 should have. These characteristics also represent research gaps that future research needs to address.

Overall, we anticipate that the evaluation of H4.0 presents similar challenges and opportunities compared to general technology investments, although more complex due to the nature of H4.0 technologies. We also observe that the existing research does not entirely succeed in helping hospitals in the investment decision-making process, leading to promising research opportunities.

Insufficient economic valuation of H4.0 investments

Decades of research on health technology assessment (HTA) resulted in a framework that includes economic evaluation as a fundamental pillar. However, the list of manuscripts that integrates this economic perspective rigorously is still scarce. Advancements focus more on cost-effectiveness than economic value, at a public policy level rather than at the hospital level. Besides, studies confirmed that health care institutions rarely apply a systematic analysis that considers all organizational objectives and integrates comprehensive data [13]. For instance, among the shortcomings of economic analysis is the relatively low commercial externalities valuation.

Although some older studies on real options include cost and value considerations, more recent propositions tend to overfocus on cost analysis, imposing a challenging bias on investment decisions. Among propositions that incorporate value, the net present value analysis is the most frequently used, often resulting in a sub-optimal decision, as it does not consider the value of future options and managerial flexibility [13]. Usually, simple cost-benefit analysis and subjective assessment replace sophisticated analytical methods and objective data, at the risk of not investing in more expensive technologies with higher health impacts due to their investment requirements. The development of real-options approaches that include value considerations targeted at evaluating investments in H4.0

technologies is a promising research opportunity that should resonate positively among practitioners.

Explicit assessment of technological interrelationships

The literature provides evidence that for maximizing the return on H4.0 investments, hospitals should consider them in bundles. Studies proposed distinct bundles (or groupings) of H4.0 technologies. Sharma et al. [57] categorized technologies into three bundles according to their extent of patient-centered integration and caregiver interaction. [5] conceptually proposed four overlapped groups of technologies based on their roles and applicability within the hospital. Gastaldi and Corso [86] proposed another categorization of H4.0 technologies dividing them into four macro-areas, further subdivided into fourteen solutions provided by each technology. Finally, [87] suggested a taxonomy to classify wearable technologies in healthcare systems according to three major dimensions: application, form, and functionality.

Even though the literature still lacks consensus on the correct taxonomy of bundles of H4.0 technologies and how to combine them to act synergistically, it is clear that valuation should incorporate the bundling of technologies. For that, researchers and institutions need to assess portfolio effects explicitly [76]. The literature in real options includes several studies that explicitly address portfolio considerations [76,88–90], providing a potential area of extension to H4.0 technological investments. In analyzing hospital investments, research incorporating portfolio considerations is scarce (e.g., [13]) and does not include real-options valuations. It is fundamental to understand if investing in technologies' bundles creates super and subadditivity [76], altering the net economic contribution of different alternatives and, eventually, changing the suggested priorities.

We detected recent efforts to provide an accessible and usable framework that would enable multiple objectives, mainly developed by authors seeking to design, develop, implement, scale-up, spread, and sustain technology-supported health or social care programs to identify and help address the critical challenges in different domains and the interactions between them [52,61,68]. However, developments only start to address the shortcomings identified in our scoping review, opening opportunities for future research.

Incorporate fundamental uncertainties

Healthcare 4.0 technologies enhance efficiency and quality in healthcare systems. However, fundamental uncertainties exist on the definition of the industry standards on many of those technologies, creating uncertainty when evaluating investments. Factors that add additional complexities to technological advancements relate to uncertainty on patient demands and competition [13].

To reduce the risk of investing in a technology that ends being crowded out and not adopted as the standard, hospitals have several alternatives; further research is needed to explore their viability. Surprisingly, the discussion about standards is scarce in the economic evaluation of H4.0 technologies, with the main focus still being on their efficacy.

Integrating administrative, medical, and patient perspectives in the evaluation process

The fourth research opportunity relates to integrating medical, patient, and administrative considerations in the valuation process. We already stressed that interrelationships among technology bundles incorporate non-trivial challenges. On top of that, institutions should consider the risk of investing in technologies that fail to establish the industry standard. The final layer is to balance medical benefits with economic costs adequately. It is still unclear how to achieve such reconciliation [50]. The central problem is how to merge

different logics. On one side, doctors favor technologies with the most promising medical effects, regardless of uncertainty and varying requirements of investments and costs. On the other side, the administrative staff needs to ensure the hospital's economic viability. Under high levels of uncertainty, the amount of investment and the operating costs (i.e., the economic logic) might contradict the medical logic. Research is needed to explore the most suitable ways that hospitals have to coordinate both perspectives.

In integrating into the valuation process the different perspectives, hospitals need to include that of the patient for at least three reasons [50]. First, a comprehensive assessment should consider patients' views about satisfaction and acceptability of health technologies. Second, with chronic forms of disease and disability, patients and their families play a more active part in healthcare decisions. Patients' lifestyles and behaviors may dramatically influence long-term prognoses of chronic conditions. Third, involving patients increases transparency and openness in public policy [50]. We acknowledge that incorporating the patient's view in the investment decision analysis will add a layer of complexity in a process that is already difficult to manage. However, any valuation analysis that considers costs and value without including the patient perspective will be incomplete.

The integration of different perspectives provides an opportunity to cross-fertilize research on H4.0 investments with adaptive leadership tools [91]. Alternatively, the incorporation of H4.0 technologies equals establishing a dynamic organization capability that demands from employees the ability to leverage interpersonal relationships conducive to productive dialogue [92].

Remain manageable in the decision-making process

Antecedents describe hospitals' investment decisions as ad-hoc, informal, political, without enough data analysis, and not aligned with the institutions' mission and strategy [13]. We argue in favor of assessments that explicitly consider technological interrelationships, incorporate fundamental uncertainties, and integrate administrative and medical insights. However, our claim comes with an essential restriction: analytical methods should avoid introducing complex evaluation tools that hamper the hospital's decision-making process.

At first, such a requirement seems challenging. We claimed to incorporate bundles of technologies, map multiple uncertainties, consider value implications and not exclusively cost aspects, and include different stakeholders' perspectives. A priori, these requirements go against the simplification of the decision-making process. However, it might be possible to solve this tension by articulating the valuation process in different stages. We envision a lean financial valuation that combines those competing demands without drastically complicating the decision process.

Lean financial valuation of H4.0 investments involves simplifying, streamlining, and harmonizing essential valuation processes to create a leaner, more efficient valuation operation. The current research opportunity relates to developing lean organizations that incorporate valuation tools that simultaneously address challenges such as complex uncertainty relationships and bundle effects into organizational structures that adjust to lean principles.

Limitations and final remarks

This research examined how hospitals approach investment decisions in H4.0 by using a scoping review of the existing literature. For that, we searched for journal articles in four databases and screened relevant contributions to consolidate a publications' portfolio on

the topic, following predefined criteria. Results of the scoping review were explored through:

1. A descriptive numerical summary and thematic analysis;
2. Identification of trends and challenges in H4.0 investment evaluation;
3. Proposition of a classification framework for H4.0 investment evaluation; and
4. Identification of research opportunities and proposition of future research directions from a hospital investment management point of view.

Despite the subject's recency, we observed that research in H4.0 expands interdisciplinarily with a diversified set of applications and functionalities. In terms of the economic evaluation, manuscripts on H4.0 tend to overfocus on cost considerations and underemphasize cost-value relationships. Studies that consider both sides of the economic valuation (i.e., value and cost) use real-options analysis and tend to be older in the sample of manuscripts analyzed. Although impacts of H4.0 adoption substantially increases when hospitals adopt technologies in bundles, research mainly focuses on the analysis of single technologies. Finally, recent manuscripts call for an integration of different actors in the decision process by developing a comprehensive, consistent, and data-driven framework for evaluating hospitals' investment decisions. We propose a framework that serves as a starting point.

Some limitations in our study are noteworthy, mostly related to its nature and methodological choices. Since I4.0 has been formally acknowledged in 2011 and H4.0 is a concept derived from it, our scoping study only encompassed publications after that year. However, it is worth mentioning the existence of initiatives aimed at valuing I4.0 technologies in heathcare systems not characterized as such,dating earlier than 2011, which is a limitation in our research. Nevertheless, as studies before 2011 were scarce

and scattered, and the number of publications on the topic has significantly increased in the past few years, we believe that our choice of search period returned all relevant works on H4.0.

A second limitation is that we focused our literature analysis and discussion on H4.0 evaluation within hospitals. However, the concept of healthcare has expanded and gone beyond the limits of healthcare organizations (i.e., hospitals and clinics). In fact, with the advent of 'smart cities', complementary aspects of healthcare have been integrated due to the increased level of interconnectivity and data acquisition, allowing to demand healthcare services remotely. Our study did not analyze those aspects and exclusively considered hospitals as units of analysis.

Third, it is worth emphasizing that we combine insights from two perspectives for developing the proposed framework: the state-of-the-practice at hospitals and the state-of-the-art in the literature. However, our main focus has been on research, and we did not include a specific survey of empirical studies mapping hospital tools. That is simultaneously a limitation of our investigation and a research opportunity.

Finally, identifying trends, challenges, and theoretical gaps through this scoping review allows us to develop a framework. However, we acknowledge that this is a first step towards the proposition of an in-depth framework. Future studies could use the theoretical consolidation of the literature in our study as a conceptual subside for developing such a detailed H4.0 evaluation framework. We hope that our classification framework will act as a solid starting point for future developments in evaluating H4.0 technological investments.

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