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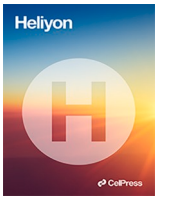

Literature review of digital twin in healthcare

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ABSTRACT

This article aims to make a bibliometric literature review using systematic scientific mapping and content analysis of digital twins in healthcare to know the evolution, domain, keywords, content type, and kind and purpose of digital twin's implementation in healthcare, so a consolidation and future improvement of existing knowledge can be made and gaps for new studies can be identified.

The increase in publications of digital twins in healthcare is quite recent and it is still concentrated in the domain of technology sources. The subject is majorly concentrated in patient's digital twin group and in precision medicine and aspects, issues and/or policies subgroups, although the publications keywords mirror it only at the group side. Digital twins in healthcare are probably stepping out of the infancy phase. On the other hand, digital twins in hospital group and the device and facilities management subgroups are more mature with all knowledge gathered from the manufacturing sector. There is an absence of some publication's types in general, device and care subgroup and no whole body or hospital digital twin was reported. Based on the presented arguments, guidelines for future research were presented: advance in the creation of general frameworks, in subgroups not as much explored, and in groups and subgroups already explored, but that need more advancement to achieve the main goals of a whole human or hospital digital twin with the main issues resolved.

1. Introduction

"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [1]. Healthcare is the provision of medical care services to achieve this definition and is a resource that helps people lead with their everyday lives. It is a complex system and new improvement's methods besides old ones, like lean, are vital to increase its efficiency, productivity, and quality [2,3]. Therefore, Digital Twin (DT), that is the pinnacle of the fourth industrial revolution or the so-called industry 4.0, is being used to optimize this complex system. DT is a digital representation of a physical entity that combine different technologies like Internet of Things (IoT), big data, Cyber-Physical System (CPS), Artificial Intelligence (AI), and Machine Learning (ML), to provide automation, quality, efficiency, productivity etc. [4,5]. It became so significant, that the consulting firm Gartner named it as one of the top ten strategic technology trends that organizations need to explore for three consecutive years (2017–2019) [6–8]. Since it combines many technologies, several companies, such as Microsoft [9], Siemens [10], and GE [11] recently launched solutions to facilitate the development of digital twins for devices, processes, systems, and persons.

As there is a certain literary and practical relevance of digital twins in healthcare, the idea was to assess how the phrase "digital

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twin" is being used in the healthcare sector in databases publications. Thus, the constructs of this research are digital twins and healthcare.

Concerning previous discoveries in the literature, the main authors of the healthcare area thought about literature reviews of DT to give an overview in precision medicine [5], in hematology [12], and in facilities management [13]; to analyze characteristics and tools [4,14], issues [15–18], risks [19], possible applications [20–25], gaps in modeling supply chain for vaccines [26], and state of the art in general [27], in medical imaging [28] and in Intensive Care Unit (ICU) medicine [29]; and to investigate goals [30], open research problems [31], and the progress made for precision medicine [32–34].

However, there is the limitation of a literature review to know the evolution, domain, keywords, literature content type, and kind and purpose of DT in healthcare, so a consolidation and future improvement of existing knowledge can be made and gaps for new studies can be identified as the theoretical contribution of this project. Therefore, the main objective of this article is aligned with this limitation in the literature and the research question related to this objective is: How is the evolution, domain and keywords of the subject? How is the literature content type and concentration themes of digital twins in healthcare?

This article adopts the method of a bibliometric literature review from a miner's perspective using systematic scientific mapping and content analysis. This method was chosen in accordance with this article's goal of mapping existing knowledge and of establishing, criticizing, or connecting previously existing sets of knowledge to identify researchers and influential research groups in a field, its evolution curve, and trends to improve understanding of the topic and feed future studies.

The structure of this article comprises the sections: materials and methods (section 2), results (section 3), discussion (section 4), and conclusion (section 5).

2. Materials and methods

In this article, the method of bibliometric literature review with a miner perspective using systematic scientific mapping and content analysis adapted from Ref. [35] was chosen in accordance with this article's goal. In addition, this method was chosen to increase the rigor and quality of the research, with aims to "strict precision, accuracy" [36,37].

The bibliometric literature review approach augments the traditional literature review by analyzing the whole research activity to discover patterns and provide fresh insights [38]. This method has an intrinsically mining perspective, as it identifies gaps, organizes, and categorizes the literature, problematizes it, and identifies and exposes contradictions [39]. Scientific mapping has the potential of introducing a transparent and replicable process, and it is increasingly being used to map, represent, and visualize the structure and development of scientific fields and disciplines [40]. Content analysis is a technique for reading and interpreting the content of publications. It explores knowledge of aspects and phenomena that is otherwise inaccessible [41], and it is carried out by reading abstracts of publications.

2.1. Search strategy

To set a golden list of publications to the search string formation, one previous search was conducted at Google Scholar, ordered by relevance with this article's constructs (("digital twin*") OR ("process twin*") OR ("data twin*")) AND (("healthcare") OR ("health care")). From these research's results, the first 20 publications specifically to healthcare were added to the golden list (e.g., not specifically: "Digital twin technologies and smart cities" and "Industry 4.0: digital twin and its industrial applications").

Then search strings were tested on their respective databases until the whole golden list was covered. Finally, the research for this article was done with the validated search string in the IEEE, Scopus, and Web of Science databases made in titles, abstracts, and keywords of publications up to the date 6th July 2022, and the number of results is listed in Table 1. These databases were chosen because IEEE is the leading academic database in the field of engineering and computer science, and Scopus and Web of Science are two of the biggest commercial, bibliographic databases covering almost any discipline [42,43].

2.2. Selection criteria

From the publications found, duplicates were removed, and then exclusion/eligibility criteria with due justification were used (Table 2) to select only publications that fit the subject and purpose of this article. Then the remaining publications abstracts were read and publications not specific to the healthcare sector and not related to digital twins were eliminated. No quality assessment was made after the selection criteria since this is not required for mapping studies [35].

The database search identified in the literature search for digital twins in healthcare totaled 409 publications. After duplicates' removal, a total of 293 publications remained. Afterward the exclusion criterias (according to Table 2 and abstract read) were used and a total of 121 publications were included in the review for the bibliometric and content analysis (Fig. 1).

Table 1
Search string in databases and results.

Search string	Database	Number of Results
(("digital twin*") OR ("process twin*") OR ("data twin*")) AND (("healthcare") OR ("health care"))	IEEE	61
	Scopus	153
	Web of Science	195

Table 2
Exclusion/eligibility criteria and justification.

Criteria	Justification
Publication type: not article, paper, book, and book chapter.	Elimination of ineligible publication type.
Keyword: no "digital twin", "process twin", "data twin", "healthcare" and/or "health care" words found in abstract, keywords, or title.	Search revalidation and eligibility.

2.3. Bibliometric analysis strategy

At first analysis of the selected publications, Excel and VOS viewer (visualization of similarities) software were used to graphically analyze the results [44] from the following methods, which are immediately available after publication and do not take time to accumulate like citations [40]: (a) Publication year, to assess the importance of the subject for the academic field over time; (b) Publication sources with more than one publication, to identify the domain in which the publications are being published; (c) Co-occurrence of all keywords with more than five occurrences, to identify the current keywords on the subject's research and to use as criteria in the content analysis strategy of publications' objective theme and subtheme (Chapter 2.4). Afterward, a content analysis was used since it is a systematic analysis of textual elements.

2.4. Content analysis strategy

The content analysis of the selected publications was carried out mainly through the reading of abstracts. There it was possible to group the publications in families according to Table 3 of: (a) Literature content type; (b) Publications' objective theme (one publication can be classified in more than one group), that refers to the kind of digital twin used; (c) Publications' objective subtheme, that is the digital twin's main purpose in the publication. Then the grouping results of theme and subtheme divided by literature content type were printed as bar chart.

3. Results

3.1. Bibliometric analysis results

With application of bibliometric methods to publication year (Fig. 2), it is possible to observe that the interest in the topic is growing exponentially, with an increase of more than 100% from 2020 to 2021 and that the years 2021 and 2022 concentrates 65% of all publications considered.

Regarding the sources in the final selection of publications with more than one publication (Fig. 3), it is possible to note that the subject is being published majorly at technological sources with 62%. The rest of the sources are from the medical and biological domain.

In the co-occurrence of all keywords with more than five occurrences (Fig. 4), the three different colors are the clusters of related items, the size of circles and label are relative to the number of publications, and the distance and line thickness reflect the strength of the relation between the items. The red cluster is related to publications of hospital's, device's, and data's digital twin with its issues; the green one is of human's digital twins for precision medicine; and the blue cluster is related to knowledge management. Here it is

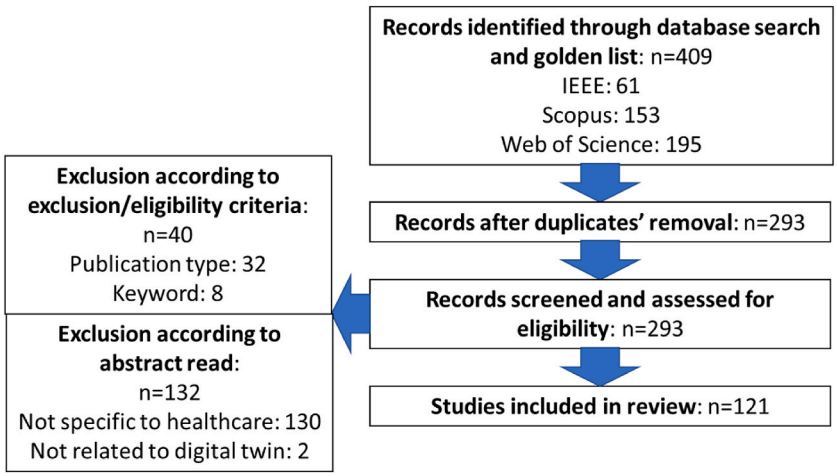

Fig. 1. Flowchart of the literature review.

Table 3
Group properties and criteria.

Property	Group criteria
Literature content type [45,46]	•Application: detailed descriptions of the application in specific fields, with technical details and detailed case studies. •Framework: general descriptions of the application in respective fields, with in-depth analysis, implementation framework, and a rather detailed case study. •Discussion: research summary or discussion on selected literature concerning a particular topic. •Review: structured research summary on existing literature concerning a particular topic.
Publications' objective theme group	•Concern: related to digital twins in general, not focused on places and/or humans. •Hospital: digital twins with the purpose of places. •Patient: digital twin with the purpose of humans.
Publications' objective subtheme group	•Aspects, issues and/or policies: regard to aspects, issues, problems, risks, requirements and/or policies of digital twin, like security, privacy, or knowledge management. •Care: digital twin of services or supplies related to the health of a patient, like crisis/emergency alarms, notifications, and management. •Device: about a device or an equipment digital twin, like dual energy x-ray absorptiometry or electrocardiogram. •Facilities management: digital twin that integrate multiple disciplines to ensure the organization has the necessary resources to function on a day-to-day operation [47]. •Precision medicine: digital twin customized individualized patient's care and treatment based on genetic, environmental and lifestyle factors [48]. •General: related to digital twins in general, not focused on a specific subtheme.

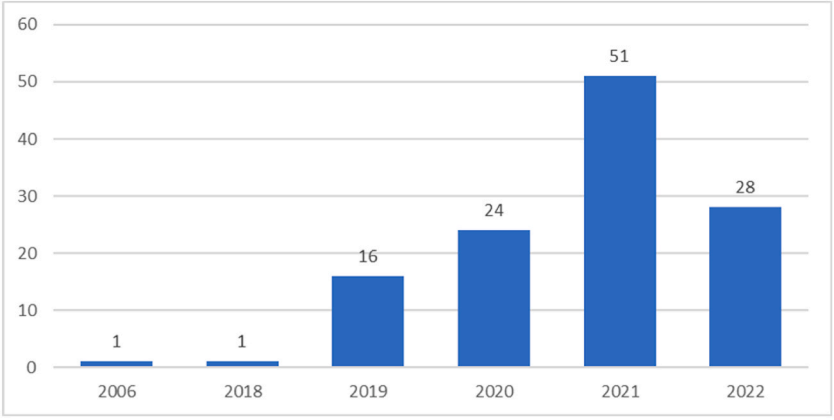

Fig. 2. Chart of publication years.

also possible to identify that after digital twin (81 occurrences and 2071 link strength) or digital twins (19 occurrences and 360 link strength) and health care (52 occurrences and 1387 link strength) or healthcare (22 occurrences and 484 link strength), the most important keywords were related to patient (human – 27 occurrences and 853 link strength; humans – 21 occurrences and 745 link strength) and to the main technologies of the digital twin (artificial intelligence – 27 occurrences and 799 link strength; internet of things – 21 occurrences and 666 link strength; machine learning – 18 occurrences and 682 link strength) and medical services (20 occurrences and 608 link strength).

3.2. Content analysis results

Regarding the analysis of literature content type (Fig. 5), it is found that framework highlights with 31% of all publications (37 of 121 publications) and other types have almost the same number of publications. In addition, the number of applications, that was the lowest until 2021, in 2022 trespass other types.

The analysis of objective theme groups (Fig. 6) shows that the subject is majorly focused on publications related to patient's digital twins (63 of 136 publications or 52%) and that the two top theme groups (patient and hospital) have 89% of all publications (108 of 136 publications). Additionally, discussions, frameworks and reviews are majorly concentrated in patient group (respectively 13 of 32 or 41%, 22 of 40 or 55% and 17 of 36 or 47%) and application are in hospital group (14 of 28 publications or 50%).

As for the analysis of objective theme subgroups (Fig. 7), it is possible to identify that precision medicine concentrates 29% of all publications (35 of 121 publications) and aspects, issues and/or policies comes in second place with 25% (30 of 121 publications). Moreover, applications are concentrated in device and facilities management subgroup (15 of 28 publications or 54%), discussions in precision medicine subgroup (9 of 37 publications or 34%), frameworks in aspects, issues and/or policies subgroup (14 of 37 publications or 38%) and review in general and precision medicine subgroups (20 of 29 or 69%); Another point is the absence of applications and frameworks in general subgroup, of discussion and review in device subgroup and of review in care subgroup.

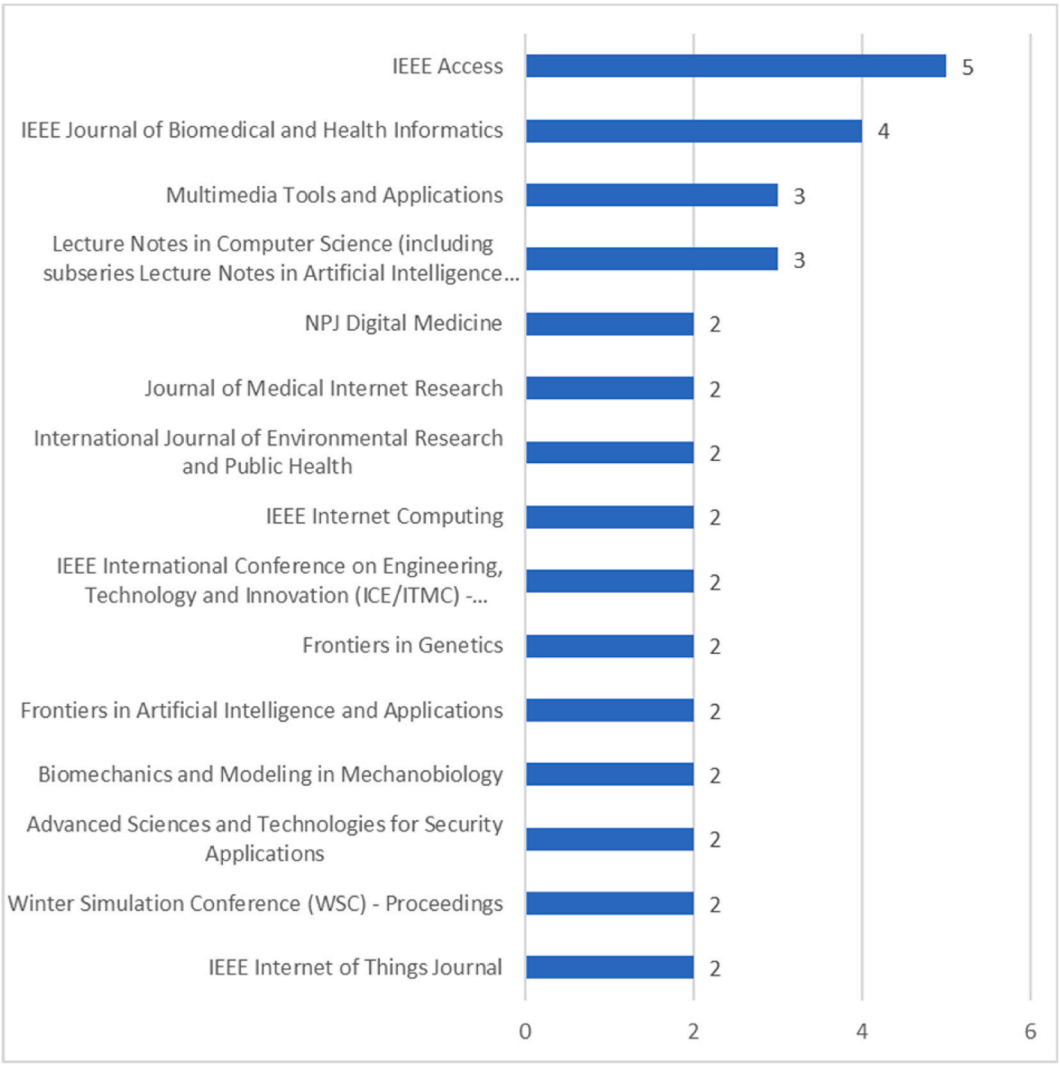

Fig. 3. Publications' sources with more than one publication.

The complete table of publications with literature content type, theme groups, and theme subgroups are in Table A1, Appendix A.

4. Discussion

The main objective of this review was to synthesize evidence on the evolution, domain, keywords, content type, kind and purpose of digital twin applied to healthcare, highlighting potential areas for future studies, and using a bibliometric literature review from a miner's perspective through systematic scientific mapping and content analysis.

The bibliometric analysis results shows that the increase in publications of digital twins in healthcare is quite recent (Fig. 2), i.e., 2019, three years later than the general number of publications reported by Ref. [49] and that it is still concentrated in the domain of technology sources (Fig. 3).

The keywords importance results of Fig. 4 (co-occurrence of all keywords with more than five occurrences) agreed with the objective theme group (Fig. 6), where the patient group is the most important and the most challenging demand in the future of healthcare [21,22,50,51]. However, this result did not agree with the objective theme subgroup analysis (Fig. 7), since precision medicine and aspects, issues and/or policies are not so crucial in the keywords results, but precision medicine is one of the main subject for the effective future of healthcare [52] that will only work if aspects, issues and/or policies are resolved [4,53].

The development of digital twins in healthcare indicates that if the number of applications in 2022 remains greater than other publications types (Fig. 5), according to Ref. [45], it could suggests that digital twin in healthcare is stepping out of its infancy phase, where it was not mature enough to have only a few frameworks to be followed, that the number of publications regarding the subgroup of aspects, issues and/or policies is still the second highest and there is an absence of frameworks in general subgroup (Fig. 7). Another

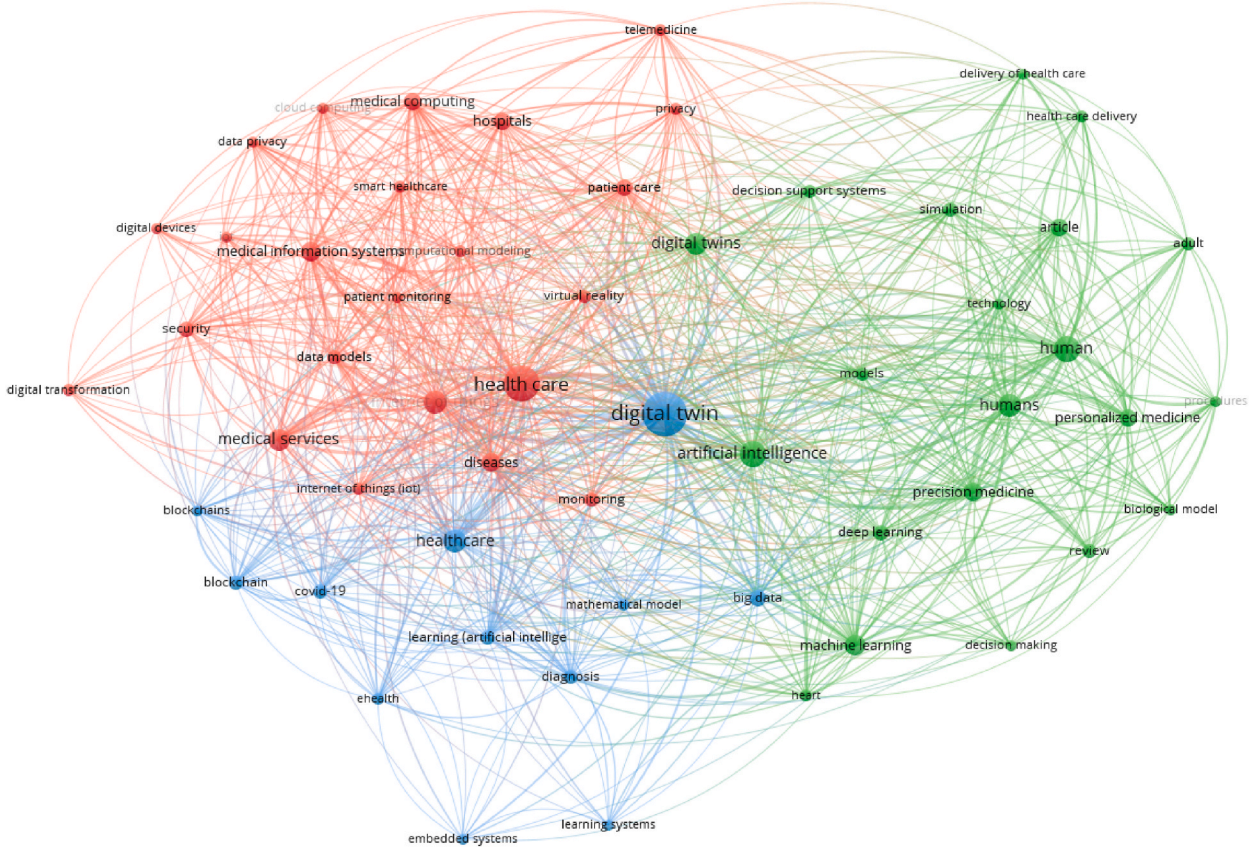

Fig. 4. Co-occurrence of all keywords with more than five occurrences.

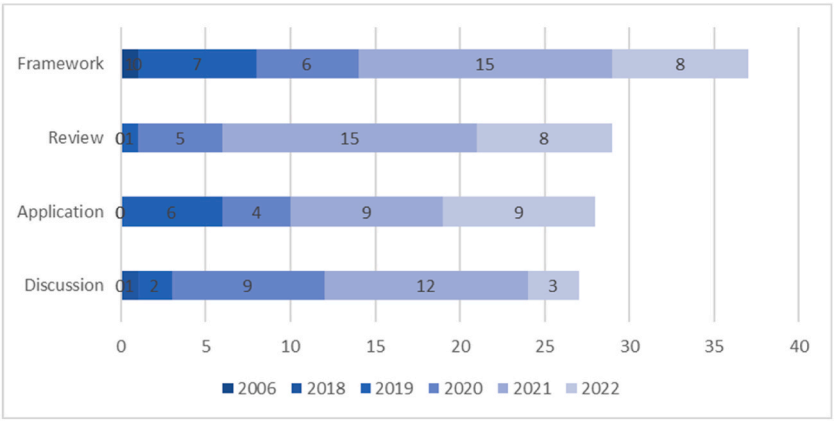

Fig. 5. Literature content type.

point of attention regarding theme groups (Fig. 6) and subgroups, is that the hospital group and the device and facilities management subgroups have more applications and are more mature than patient group and other subgroups, since many ideas could be learned and utilized from the digital twin of the manufacturing sector (i.e., [29]) that is in a rapid development stage, where researchers explore more real practices.

As for gaps in literature, as already mentioned, the absence of applications and frameworks in general subgroup is due to the maturity level of the healthcare sector, however there are some interest frameworks in other subgroups that could be explored, like [54–58]. As for the device and care subgroups, reviews and discussions could already be made, since there are relevant and significant publications, like different standardized and generalized frameworks for care [54,55] or devices digital twin applications for

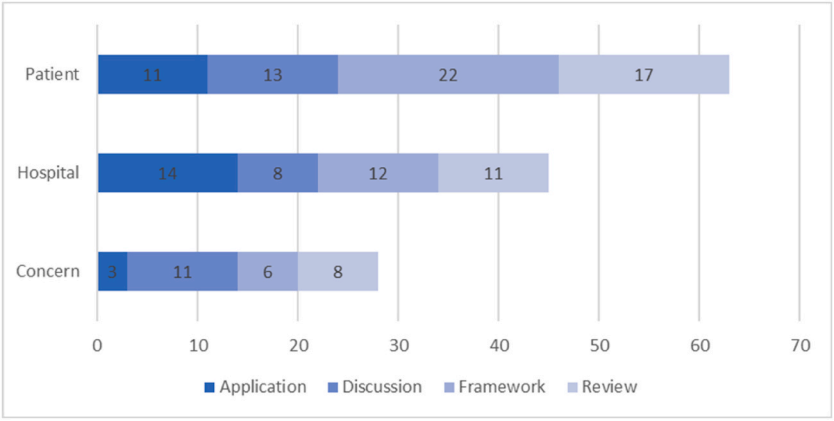

Fig. 6. Publications' objective theme group.

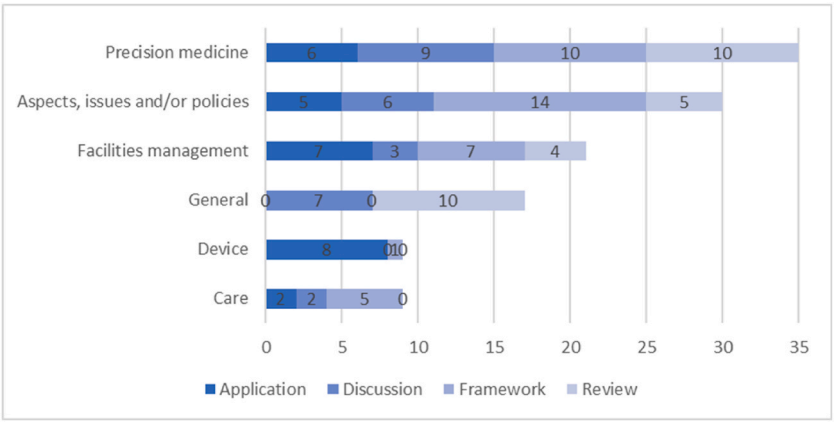

Fig. 7. Publications' objective theme subgroup chart.

cardiovascular system [59,60]. Another point is that it was not reported any whole body or hospital digital twin, something that many publications envision and it could be explored.

5. Conclusions

The finding of this review has implications for the theoretical and practical side of digital twins in healthcare. It achieved the theoretical contribution of understanding the evolution, domain, keywords, content type, nature and purpose on the subject, identifying gaps for future studies; since that, it gave new fresh insights and perspective to the actual view: (1) The increase in publications of digital twins in healthcare is quite recent, three years later than the general number of publications and it is still concentrated in the domain of technology sources; (2) The subject is majorly concentrated in patient's digital twin group and in precision medicine and aspects, issues and/or policies subgroups, although the publications keywords mirror it only at the group side; (3) Digital twins in healthcare is probably stepping out of the infancy phase, with more applications in 2022 than other publications types. On the other hand, digital twins in hospital group and the device and facilities management subgroups are more mature with all knowledge gathered from the manufacturing sector; (4) There is an absence of applications and frameworks in general subgroup, of discussions and reviews in device subgroup and of reviews in care subgroup; and no whole body or hospital digital twin was reported.

The main limitation to that achievement is that the publications do not represent the universality of the subject but only those that were captured by the adopted keywords search and the adopted databases. Based on the aforementioned foundations, three directions are proposed for future research: (1) Advance in the creation of general frameworks that can serve as basis for researches to resolve any gap group presented, for example, through questions, critiques, reviews, and discussions of analogies about frameworks and real-life applications already published; (2) Advance of the subject in subgroups not as much explored, such as digital twin in the improvement of services or supplies related to the health of a patient in remote areas in Brazil or digital twin of a magnetic resonance imaging (MRI) to a future facility management improvement; (3) Advance of the subject in groups and subgroups already explored, but that need more advancement to achieve the main goals of a whole human or hospital digital twin with the main issues resolved. In addition to this proposal, it is suggested that this publication should be repeated in the future to understand how the subject of digital twins in

healthcare progressed.

Author contribution statement

Tatiana Mallet Machado: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Fernando Tobal Berssaneti: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

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

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Appendix A. Publications' list by group, subgroup, and content type

The complete table of publications by group, subgroup, and content type is in Table A1.

Table A.1
Publications' list by group, subgroup, and content type.

Group	Subgroup	Content type			
		Application	Discussion	Framework	Review
Concern	Aspects, issues and/or policies (19)	[61–63]	[64–68]	[56,69–73]	[15–19]
Hospital	Aspects, issues and/or policies (4)	[74]	[75]	[76,77]	
Patient	Aspects, issues and/or policies (10)	[78]	[75]	[76,77,79–84]	
Concern	Care (1)		[85]		
Hospital	Care (4)	[86]	[87]	[88,89]	
Patient	Care (6)	[90]	[87]	[54,55,89,91]	
Concern	Device (0)				
Hospital	Device (6)	[59,60,92–94]		[95]	
Patient	Device (3)	[96–98]			
Concern	Facilities management (0)				
Hospital	Facilities management (21)	[99–105]	[106–108]	[57,109–114]	[13,25,26,29]
Patient	Facilities management (0)				
Concern	General (8)		[50,115–118]		[4,22,28]
Hospital	General (8)		[119,120]		[12,20,21,23,24,27]
Patient	General (9)		[119,120]		[12,14,20,21,23,24,27]
Concern	Precision medicine (0)				
Hospital	Precision medicine (2)		[121]		[30]
Patient	Precision medicine (35)	[122–127]	[121,128–135]	[58,136–144]	[5,30–34,145–148]

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