Healthcare Information Technology: A Systematic Mapping Study

Enrique Maldonado Belmonte, Salvador Otón Tortosa, Luis de-Marcos Ortega, José-María Gutiérrez-Martínez
Department of Computer Science, University of Alcalá, Madrid, Spain

Objectives: This paper presents a systematic mapping of studies related to information systems and technology in the field of healthcare, enabling a visual mapping of the different lines of knowledge that can provide an overview of the scientific literature in this field. This map can help to clarify critical aspects of healthcare informatics, such as the main types of information systems, the ways in which they integrate with each other, and the technological trends in this field. **Methods:** Systematic mapping refers to a process of classifying information in a given area of knowledge. It provides an overview of the state of the art in a particular discipline or area of knowledge, establishing a map that describes how knowledge is structured in that particular area. In this study, we proposed and carried out a specific implementation of the methodology for mapping. In total, 1,619 studies that combine knowledge related to information systems, computer science, and healthcare were selected and compiled from prestigious publications. **Results:** The results established a distribution of the available literature and identified papers related to certain research questions, thereby providing a map of knowledge that structures the different trends and main areas of research, making it possible to address the research questions and serving as a guide to deepen specific aspects of the field of study. **Conclusions:** We project and propose future research for the trends that stand out because of their interest and the possibility of exploring these topics in greater depth.

Keywords: Health Information Technologies, Information System, Biomedical Technology, Medical Informatics, Hospital Information System

I. Introduction

Healthcare and its improvement have historically been one of the highest priorities both individually and for society [1]. Several factors improve both the length and quality of life, among which one of the most important is the quality of healthcare and clinical care [2]. In this context, information technology has emerged as a tool that helps healthcare both quantitatively and qualitatively [3]. The primary purpose of information technology in healthcare is to automate and facilitate tasks previously carried out manually, with examples including the digitization of health records, job listings, clinical records, and paper requests for clinical tests [4].

The management of clinical information systems became a profession with the emergence of real enterprise resource planning solutions or global business management systems

(hospital information systems), and also with the treatment of clinical data (clinical information systems) [5]. Simultaneously, technology has been increasingly used in clinical practice to perform new tasks or obtain information that would have been otherwise unworkable or directly impossible. Clinical analysis tools and support systems for surgical interventions are good examples of this [6]. Ongoing technological progress and new developments constitute a considerable source of innovation that can result in substantial improvements for healthcare systems. Relatively recent concepts such as big data [7], telemedicine [8], and the Internet of Things (IoT) [9] are already part of everyday life in healthcare settings.

Globalization is, in our opinion, one of the most significant challenges that information technology faces in the field of healthcare. Interoperability between systems and the need for the homogenization of processes and information among different agents demand robust criteria to make decisions [10]. Standards are the result of the work of organizations focused on structuring clinical information and the means for communicating and interpreting it. A common standardized language is a fundamental prerequisite for the implementation of new technologies encompassing organizations globally [11].

In order to address the application of technology in the healthcare field, it is essential to be familiar with the knowledge provided by previous research to avoid redundant work and to avoid making mistakes that are already known. For this reason, systematic research on previous publications allows us to obtain a global vision of this field of knowledge.

This paper presents a systematic mapping of the state-of-the-art of information systems in the field of healthcare to characterize the different trends of information technologies in the healthcare field, raised as research questions (RQs). The next section describes the methodology used.

II. Methods

Systematic mapping is a process of classifying information in a particular area of knowledge. It yields an overview of the state of the art in a particular discipline or area of knowledge, establishing a visual map that describes how knowledge in that particular area is structured, as stated by Barbosa and Alves [12]. Systematic mapping is a technique related to systematic literature reviews, although systematic mapping does not provide information on the depth of the published literature at the same level that a systematic literature review enables. However, systematic mapping may be a better choice as an initial approach to determine the level of

progress in particular fields or areas, which can then be followed by a systematic review of the literature if needed.

In our particular case, when facing a field as broad as information systems in healthcare, the first approach should be conducted using systematic mapping.

Although we did not use a specific protocol to conduct the systematic mapping, we followed the methodology of systematic mapping presented by Petersen et al. [13], applying several criteria for classification and mapping as suggested by Engstrom and Runeson [14], and adapting the methodology to the specific aspects of the field of study. The steps of systematic mapping are as follows: (1) reviewing the scope, (2) conducting the search, (3) gathering all papers, (4) screening the papers, (5) assessing the impact of primary keywords, (6) developing a classification scheme, (7) assessing the impact of secondary keywords, and (8) conducting data extraction and the mapping process.

The volume of records processed was described according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard [15], as shown in Figure 1.

Systematic mappings usually tend to cover narrower areas of knowledge. The generality of the area studied allows for a complete overview of the scope of the area, but also presents as a constraint the impossibility of dealing in depth with specific aspects, which should be left for later studies.

1. Definition of Research Questions

This study set out to address the following RQs dealing with information systems within the field of healthcare:

RQ1: What technological solutions are used as clinical information systems and for healthcare management?

RQ2: How are those information systems integrated?

RQ3: What are the technological trends in the healthcare field?

2. Review Scope

The data sources were repositories whose areas of knowledge included technology. The results of the systematic mapping should identify which sources are more specialized in information systems as related to healthcare.

The selected sources were ACM Digital Library (ACM), IEEEXplore (IEEEX), Google Scholar (GS), ISI Web of Knowledge (WoK), CiteSeerX (CSX), Science Direct (SD), Springer (SL), The Collection of Computer Science Bibliographies (CSB), Scopus (SCO), ResearchGate (RG), PLOS One (PO), PubMed (PM).

The search period had no initial date, and it included studies until December 2017.
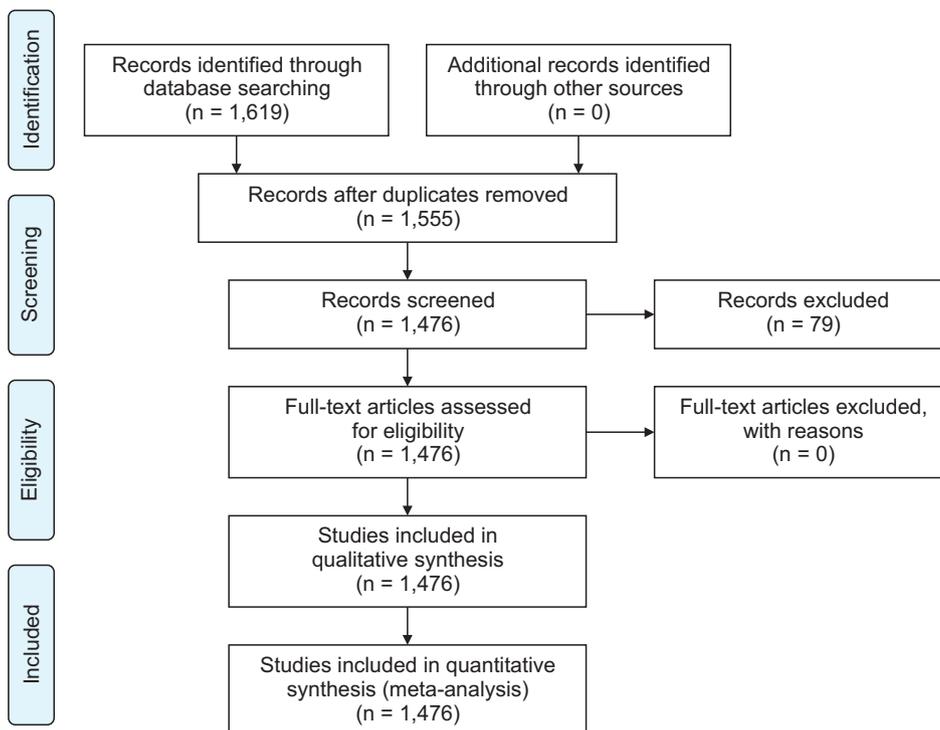
Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist.

3. Conduct Search

Search terms were selected according to the following premises:

(1) Papers should be technical, and related to technology and information systems.

(2) The area in which each paper is framed should be healthcare.

(3) Papers should deal with at least one of the leading areas of knowledge from which a taxonomy can be established: architecture, integration, and standards.

(4) Synonyms or similar terms should be considered.

(5) The quality of the paper was not quantified or assessed. The contribution, significance, or other scientific merits were not used to discard papers. The objective was to map the current situation of literature in the given area. It was not to select high-quality papers.

Based on these criteria, we selected three sets of search terms: (1) terms relating to health, (2) terms relating to information technology, and (3) terms relating to architecture, integration, and standards.

The selected terms, called "primary keywords," are shown in Figure 2.

Broader terms were not taken into account to avoid redundancies (e.g., "Electronic Device" when "Electronic" is already taken into account). The following search query was used: ("Clinic" OR "Health" OR "Hospital" OR "Medic*" OR "Patient") AND ("Analysis" OR "Digital" OR "Electronic" OR "Hardware" OR "Software" OR "Information System" OR "Process" OR "Informatic" OR "Technology" OR "Tech-
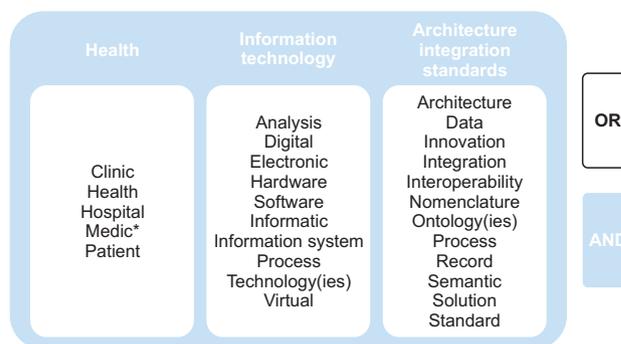
Figure 2. Primary keywords.

nologies" OR "Virtual") AND ("Architecture" OR "Data" OR "Innovation" OR "Integration" OR "Interoperability" OR "Nomenclature" OR "Ontology" OR "Ontologies" OR "Record" OR "Semantic" OR "Solution" OR "Standard").

4. Gathering All Papers

The heterogeneity of the data sources makes it necessary to make adjustments in the search string and filtering criteria (mainly by the paper title) to locate candidate studies that are relevant.

The number of papers obtained for each source was as follows: ACM (59), IEEEX (31), GS (86), WoK (284), CSX (239), SD (29), SL (165), CSB (532), SCO (75), RG (48), PO (16), and PM (55). In total, 1,619 papers were obtained.

5. Screening of Papers

The obtained studies were reviewed, removing duplicates and papers whose topic or content was unrelated to the subject of the investigation.

After removing the studies that were duplicates (64) or irrelevant (79), the number of studies considered for the elaboration of the map was 1,476.

6. Impact of Primary Keywords

An analysis of the 1,476 resulting studies was carried out, quantifying the occurrence of the different keywords in each of them. For this purpose, the information on the 1,476 studies was registered in a database, and a customized computer application was designed and implemented to process the information about the studies.

We then quantified the occurrence of each keyword. To indicate the relevance of each word, we used the Fibonacci series, where growth was represented through an exponential ratio in order to maintain the proportions that keep the readability of the results, as indicated by Basak [16]. More specifically, we applied the formula $F_{(n)} = F_{(n-2)} + F_{(n-1)}$ and assigned a value ranging from 1 to 10 that represented the relevance of each keyword based on the minimum number of occurrences according to the Fibonacci series, starting with the eighth value of 21. Therefore, a keyword was considered to be of relevance 1 if its number of occurrences was less than or equal to 21 ($F_{(8)}$), of relevance 2 if it was between 21 and 34 ($F_{(9)}$), of relevance 3 if it was between 34 and 55 ($F_{(10)}$), and so forth, up to a relevance of 8 it had between 377 ($F_{(15)}$) and 610 ($F_{(16)}$) occurrences. We then obtained the distribution of relevance for the different keywords analyzed, as shown in Table 1.

We also carried out an analysis between each pair of keywords to determine the frequency of their co-occurrence in the selected articles, as presented in Figure 3. In this way, we analyze the correlation of each keyword with the rest, in order to assess the relative relevance of each term.

7. Classification Scheme

After taking into consideration the relevance of the different keywords, their relationships with each other in the papers, and a selection of technological terms applied to health contexts, we selected secondary keywords from the highest-impact papers. Secondary keywords facilitate assessing the volume of publications of different subtopics. The list of secondary keywords is presented in Figure 4.

Table 1. Relevance of primary keywords

Keywords	Impacts	Relevance
Clinic(al)	133	4
Health(care)	736	8
Hospital	135	4
Medic(cine/al)	172	5
Patient	286	6
Analysis	213	5
Digital	32	1
Electronic	580	7
Hardware	2	1
Software	32	1
Informatic	80	3
Information system	11	1
Process	37	2
Technology(ies)	111	4
Virtual	39	2
Architecture	48	2
Data	302	6
Innovation	58	3
Integration	99	4
Interoperability	36	2
Nomenclature	3	1
Ontology(ies)	41	2
Process	72	3
Record	613	8
Semantic	60	3
Solution	30	2
Standard	81	3

8. Impact of Secondary Keywords

We analyzed secondary keywords in the same way that we did with the primary keywords. We used the impact analysis application and the list of publications to compute the occurrence of secondary keywords in the 1,476 articles selected after removing duplicate and irrelevant articles. The occurrence of each keyword was quantified, and a value ranging from 1 to 10 was assigned to the relevance of each keyword based on the minimum number of occurrences, following the Fibonacci series, as was done with the primary keywords.

The results obtained are presented in Figure 4, showing the correspondence of the impact level for each of the secondary keywords. We also analyzed the co-occurrence of keywords (Figures 5, 6). The value "0" indicates no matches. The figures presenting co-occurrence are separated into two parts

	Keywords	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	Clinic(al)	-	67	7	22	37	22	2	67	0	2	7	2	5	9	6	4	42	5	11	4	0	4	11	77	6	0	7
2	Health(care)	-	-	27	55	107	119	22	452	2	11	43	1	17	81	21	31	172	46	68	29	1	17	37	477	30	19	51
3	Hospital	-	-	-	28	24	38	6	36	0	0	32	6	5	10	4	6	51	7	27	1	0	1	16	35	2	5	11
4	Medic(cine/al)	-	-	-	-	39	20	5	78	0	11	11	2	7	11	7	4	44	1	5	3	0	11	6	83	8	6	11
5	Patient	-	-	-	-	-	43	3	176	0	3	10	4	10	11	11	10	84	5	10	2	0	7	12	186	6	7	17
6	Analysis	-	-	-	-	-	-	1	79	0	0	4	2	0	8	2	3	52	5	19	4	0	6	10	95	5	7	24
7	Digital	-	-	-	-	-	-	-	8	0	1	1	1	0	2	0	0	3	5	6	1	0	2	2	12	3	2	2
8	Electronic	-	-	-	-	-	-	-	-	0	5	12	3	13	22	10	18	148	4	19	17	0	6	27	547	21	5	22
9	Hardware	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0
10	Software	-	-	-	-	-	-	-	-	-	-	1	1	1	0	1	0	3	3	0	1	0	2	1	5	1	0	2
11	Informatic	-	-	-	-	-	-	-	-	-	-	-	1	4	1	0	6	19	3	23	3	1	2	7	17	1	5	5
12	Information system	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	0	7	0	1	0	0	0	11	3	1	0	0
13	Process	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	5	7	1	1	0	0	1	3	16	1	2	0
14	Technology(ies)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	9	24	20	2	0	2	3	31	2	5	12
15	Virtual	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	6	5	3	1	0	2	3	22	0	0	1
16	Architecture	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	3	0	1	0	1	21	0	0	2
17	Data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	18	10	0	12	17	148	10	3	18
18	Innovation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	6	5	0	3	1
19	Integration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0	3	12	16	2	2	3
20	Interoperability	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	5	1	16	14	2	5
21	Nomenclature	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0
22	Ontology(ies)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7	8	1	4
23	Process	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	3	2	2
24	Record	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	4	25
25	Semantic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5
26	Solution	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
27	Standard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 3. Analysis of the co-occurrence of primary keywords.

	Keywords	Impact	Relevance		Keywords	Impact	Relevance
1	IT governance	0	0	25	Machine learning	4	6
2	Management	8	38	26	SNOMED CT	1	1
3	Development	8	48	27	ICD	2	2
4	Project	4	7	28	CPT	0	0
5	Software asset	0	0	29	LOINC	0	0
6	SOA	2	2	30	DICOM	2	2
7	HIS	7	22	31	Clinical decision support	6	15
8	CIS	8	39	32	Optogenetics	0	0
9	Modeling	6	18	33	Hybrid operating room	0	0
10	RIS/PACS	9	70	34	Clinical trial chip	0	0
11	Mirth	0	0	35	Clinical research	4	5
12	Ensemble	0	0	36	Nanobots	0	0
13	Rhapsody	0	0	37	Robotic surgery	0	0
14	Semantic	9	60	38	Holographic images	0	0
15	HL7	3	4	39	Computational health informatics	0	0
16	Integration engine	0	0	40	Wearable	2	2
17	Big data	6	13	41	Internet of things	4	7
18	Hadoop	0	1	42	3D printing	1	1
19	Business intelligence	0	0	43	Telepresence	0	0
20	Data mining	6	13	44	EN13606	1	1
21	Data warehouse	4	5	45	OpenEHR	4	7
22	Distributed database	0	0	46	Real-time analysis	0	0
23	Machine intelligence	0	0	47	Complex-event processing	0	0
24	Data science	0	0	48	Telemedicine	2	2

Figure 4. Comparison of relevant results for secondary keywords. IT: information technology, SOA: service-oriented architecture, HIS: health information system, CIS: clinical information system, RIS: radiology information system, PACS: picture archiving and communication system, ICD: International Classification of Diseases, EHR: Electronic Health Record, CPT: Current Procedural Terminology, LOINC: Logical Observation Identifiers Names and Codes, DICOM: Digital Imaging and Communications in Medicine, HL7: Health Level 7.

(block I and block II) to increase readability. The indices in the first row and first column refer to the numbered terms in Figure 4.

A longitudinal analysis of the keywords was carried out to show the tendencies in the frequency of keywords over time. To do this, we analyzed the number of occurrences of each keyword in the datasets of the selected studies annually, as shown in Figure 7.

9. Data Extraction and Mapping Process

The mapping of the selected relevant studies was conducted by quantifying the occurrences of keywords and their relationships, establishing a classification of all papers in one or more of the defined categories. In this way, based on the incidence of specific terms or concepts that identify an area of knowledge within the scope of the investigation, we could quantify the actual volume of studies related to each of these

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	IT governance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Management	-	38	1	0	0	0	0	2	1	2	0	0	0	2	1	0	0	0	0	0	0	0	0	0
3	Development	-	-	48	0	0	0	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Project	-	-	-	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Software asset	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	SOA	-	-	-	-	-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	HIS	-	-	-	-	-	-	22	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	CIS	-	-	-	-	-	-	-	39	2	2	0	0	0	0	0	0	2	0	0	0	1	0	0	0
9	Modeling	-	-	-	-	-	-	-	-	18	1	0	0	0	2	0	0	0	0	0	0	1	0	0	0
10	RIS/PACS	-	-	-	-	-	-	-	-	-	70	0	0	0	1	0	0	0	0	0	2	0	0	0	0
11	Mirth	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Ensemble	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Rhapsody	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
14	Semantic	-	-	-	-	-	-	-	-	-	-	-	-	-	60	0	0	0	0	0	0	0	0	0	0
15	HL7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	0	1	0	0	0	0	0	0	0
16	Integration engine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0
17	Big data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	1	0	1	0	0	0	0
18	Hadoop	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	0	0	0	0
19	Business intelligence	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0
20	Data mining	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	0	0	0	0
21	Data warehouse	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0	0	0
22	Distributed database	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
23	Machine intelligence	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
24	Data science	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

Figure 5. Analysis of the co-occurrence of secondary keywords (block I). IT: information technology, SOA: service-oriented architecture, HIS: health information system, CIS: clinical information system, RIS: radiology information system, PACS: picture archiving and communication system, HL7: Health Level 7.

areas. The results are presented graphically in Figure 8.

III. Results

After processing all the information using the systematic mapping methodology with all the extracted data, sufficient information was available to group and visualize the structure of the information. For this purpose, the secondary keywords were grouped by topics, and considering the relevance of the terms and their co-occurrence patterns, the map of technologies and information systems is presented in Figure 9.

Obtaining the map of technologies and information systems will make it possible to address the RQs. Specifically, of the 1,476 papers, 238 dealt with solution-related topics, 120 with integration, and 77 with technology trends.

Carrying out systematic mapping made it possible to classify and analyze the situation of healthcare information systems and technologies from a neutral point of view. In light of the systematic mapping and the studies analyzed, we now address the research questions.

-RQ1: What technological solutions are used as clinical information systems and healthcare management?

In the map of technologies and information systems, we can see a clear differentiation between the methodology and management category and the architecture solutions, which cover the operational needs of clinical registries. Clinical information systems aim to handle clinical information, which can be divided into clinical data and clinical operative management data. In complex healthcare environments, such as large clinical centers, it is necessary to combine different specialized solutions to meet the needs of information management. Not surprisingly, the largest and most complex solutions have been the most frequently studied and analyzed. These solutions emphasize hospital information management systems [17], clinical information systems [18], radiological information management systems with storage and communication capabilities [19], and laboratory information systems [20]. These tools have been analyzed from different perspectives including, the functional point of view, the technical structure, the software architecture, and the success of their deployment. In practice, there are multiple solutions, both open source and proprietary, and even custom solutions. Additionally, many clinical information systems with specific purposes are available to support very particular needs, such as care for patients in a particular clinical specialty. These systems cover the organization's operational workflow, and they can produce reports and statistics from specific data. These systems usually rely on the large solutions previously mentioned [21].

-RQ2: How are these information systems integrated?

As indicated in RQ1, we found several central information systems (hospital information management systems, clinical information systems, radiological information management systems with storage and communication capabilities, and

		25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	IT governance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Management	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	Development	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1
4	Project	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Software asset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	SOA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	HIS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	CIS	1	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
9	Modeling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	RIS/PACS	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Mirth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Ensemble	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Rhapsody	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Semantic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
15	HL7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Integration engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Big data	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Hadoop	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Business intelligence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Data mining	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Data warehouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Distributed database	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	Machine intelligence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	Data science	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	Machine learning	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	SNOMED CT	-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	ICD	-	-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	CPT	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	LOINC	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	DICOM	-	-	-	-	-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Clinical decision support	-	-	-	-	-	-	15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
32	Optogenetics	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Hybrid operating room	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Clinical trial chip	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Clinical research	-	-	-	-	-	-	-	-	-	-	5	0	0	0	0	0	0	0	0	0	0	0	0	0
36	Nanobots	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Robotic surgery	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
38	Holographic images	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
39	Computational health informatics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0
40	Wearable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0	0	0	0	0	0	0	0
41	Internet of things	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	0	0	0	0	0	0	0
42	3D printing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0	0	0
43	Telepresence	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0
44	EN13606	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0
45	OpenEHR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	0	0	0
46	Real-time analysis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
47	Complex-event processing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
48	Telemedicine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

Figure 6. Analysis of the co-occurrence of secondary keywords (block II). IT: information technology, SOA: service-oriented architecture, HIS: health information system, CIS: clinical information system, RIS: radiology information system, PACS: picture archiving and communication system, HL7: Health Level 7, ICD: International Classification of Diseases, CPT: Current Procedural Terminology, LOINC: Logical Observation Identifiers Names and Codes, DICOM: Digital Imaging and Communications in Medicine, EHR: Electronic Health Record.

laboratory information systems, as well as other dependent secondary information systems). In practice, all systems share the same core data. The patient is at the center of the information, mainly in the form of electronic health records [22-24]. In a critical operating environment, such as a clinical care organization, it is essential to maintain principles such as data coherence and efficiency in information management. For this reason, interoperability between systems is probably the most critical factor in the implementation and management of an information system [25], both regarding communication [26] and the semantic interpretation of information [27].

We can see in the map how, in addition to covering traditional interoperability aspects, semantic standardization and nomenclature aspects are increasingly covered.

As solutions for integration, simpler mechanisms such as web services or sharing database tables exist. However, in minimally complex environments, the solution most com-
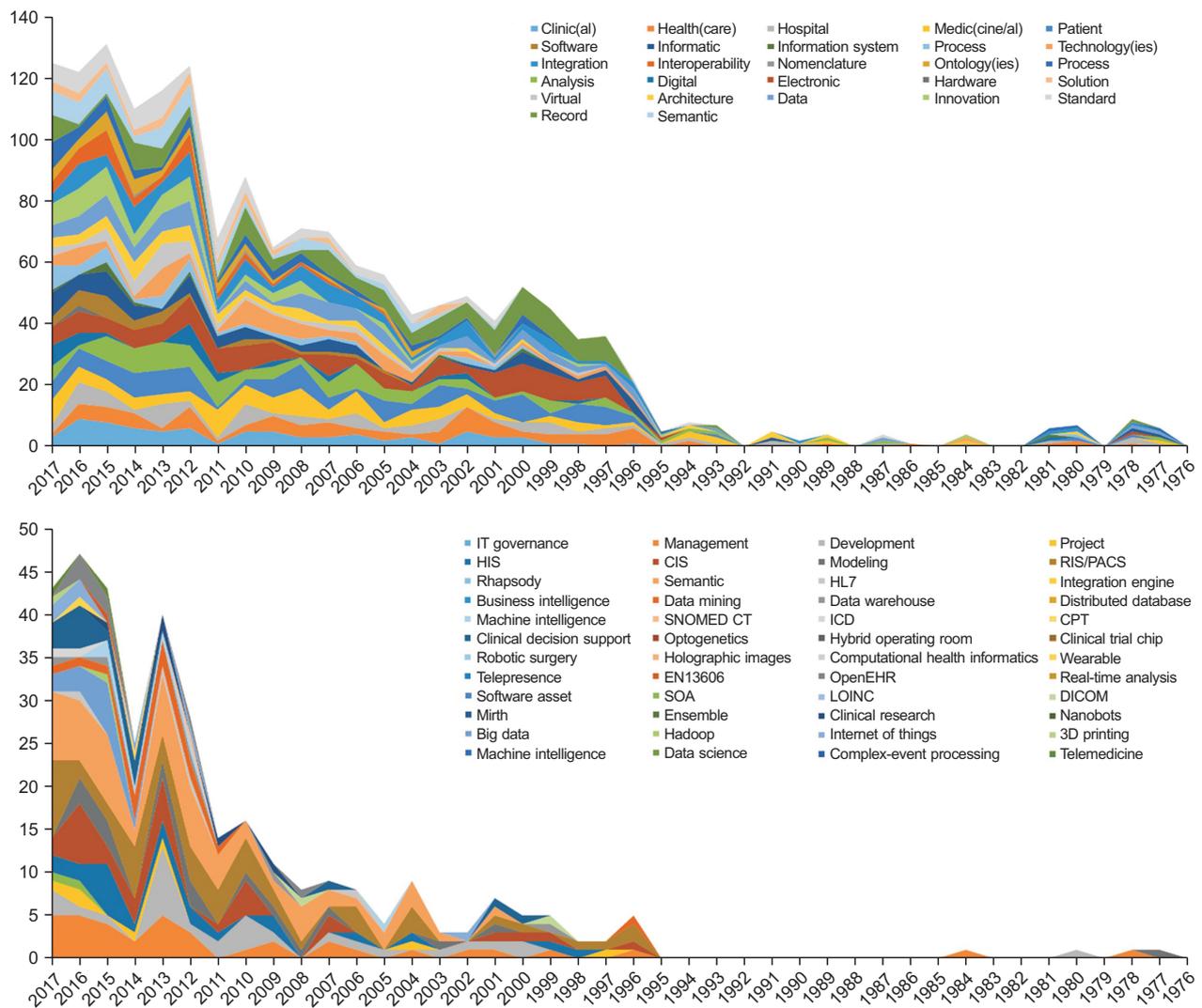
Figure 7. Historical trends in the keywords. IT: information technology, HIS: health information system, CIS: clinical information system, SOA: service-oriented architecture, HL7: Health Level 7, ICD: International Classification of Diseases, EHR: Electronic Health Record, LOINC: Logical Observation Identifiers Names and Codes, RIS: radiology information system, PACS: picture archiving and communication system, CPT: Current Procedural Terminology, DICOM: Digital Imaging and Communications in Medicine.

monly adopted is the use of integration engines. Integration engines are an efficient, structured, adaptive and multi-platform mechanism for information exchange that enables multiple messages to be sent sequentially among multiple points [28]. The adoption of standards also facilitates interoperability among heterogeneous information systems [29]. HL7 [30] is the primary protocol for information exchange, while naming standards like SNOMED-CT [31], ICD [32] and DICOM [33] are used for information encoding.

-RQ3: What are the technological trends in the healthcare field?

Continuing technological advances in the clinical field provide compelling possibilities for improving solutions to existing problems, as well as new ways to face challenges that were not even considered problems. With regard to new technologies, the map shows great heterogeneity, although several of the possible trends may end up being of marginal relevance. The rise of technologies that maximize the use of big data does seem clear. The historical evolution of the secondary keywords shows that support for clinical decision-making is an example of this and that it is now one of the leading fields of study. Support for clinical decision-making facilitates processing vast amounts of information using heuristics to obtain results unachievable exclusively through human intervention [34]. Other trends are the use of wearable devices [35] and the IoT [36], advances in clinical research and 3D printing, and the surgical use of robots or hybrid operating rooms.
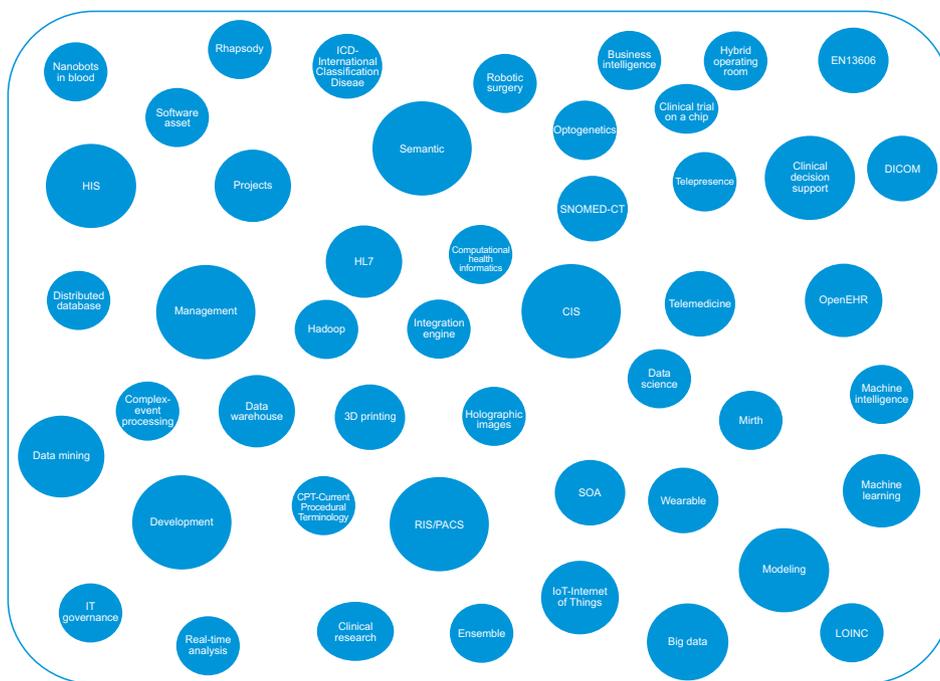
Figure 8. Set of secondary keywords according to their relevance. SOA: service-oriented architecture, HIS: health information system, CIS: clinical information system, RIS: radiology information system, PACS: picture archiving and communication system, ICD: International Classification of Diseases, EHR: Electronic Health Record, LOINC: Logical Observation Identifiers Names and Codes, DICOM: Digital Imaging and Communications in Medicine, HL7: Health Level 7.
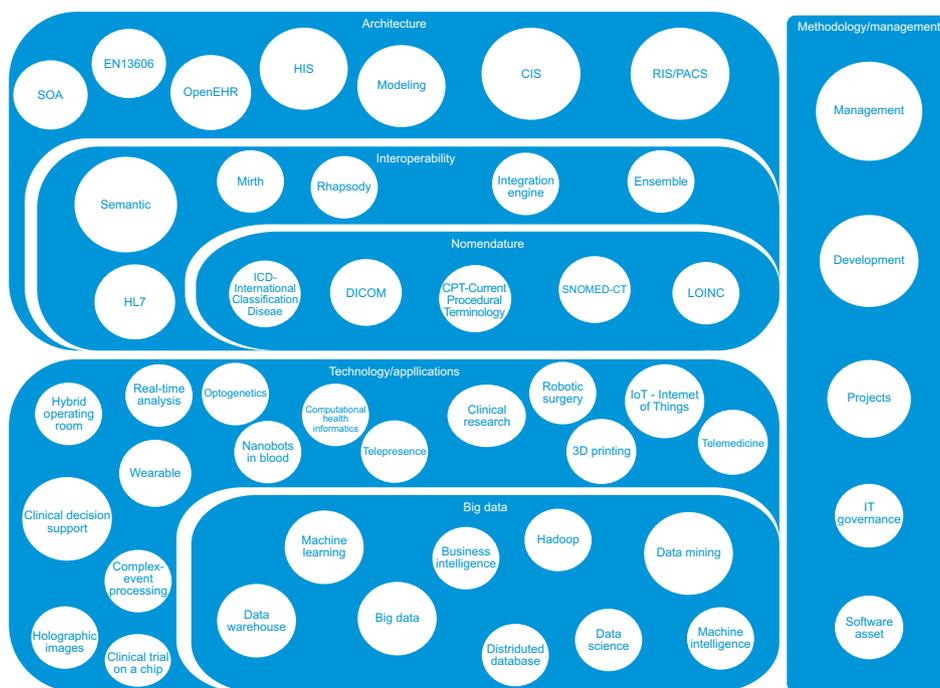

Figure 9. Map of technologies and information systems. SOA: service-oriented architecture, HIS: health information system, CIS: clinical information system, RIS: radiology information system, PACS: picture archiving and communication system, EHR: Electronic Health Record, LOINC: Logical Observation Identifiers Names and Codes, DICOM: Digital Imaging and Communications in Medicine, HL7: Health Level 7.

However, big data is the area where the most research efforts are currently being invested. The continuing increases in processing power, storage capacity, the use of information standards, and agreements between different data providers are factors that contribute to the growth of big data in healthcare environments. Thus, there is the possibility of accessing heterogeneous and distributed clinical information to obtain patterns that make it possible to address existing problems, as well as anticipating and preventing their origin [37].

IV. Discussion

It is necessary to consider the limitations inherent to systematic mapping, especially in a field as broad as this one: the number of studies considered is very large and diverse, and therefore the trends and lines of work identified in the conclusions have sufficient relevance to warrant greater depth in future studies. However, we have sufficient information to analyze previous research achievements.

The results for RQ1 suggest that a significant number of studies and efforts are related to information system architecture and specific standards and technologies. This is reasonable, as these topics constitute the foundation on which all other aspects of healthcare technology are based—in fact, they are so important that it may be necessary to adapt the rest of the healthcare environment to optimize their implementation, as indicated by Ilin et al. [38].

We can see in RQ2 that a challenge faced by complex clinical information systems is often addressed—namely, the integration of the analyzed models from a global point of view. We agree with the trend toward the use of standards for electronic health record integration, as indicated by Lin et al. [39]. In this sense, we consider there to be room for work on interoperability solutions. Research on this topic should cover healthcare organizations' integration needs, with the goal of addressing the problems inherent to integration (complexity, standardization, heterogeneous terminologies, legacy systems, and resistance to change) raised by Iroju et al. [40].

In RQ3, we see several possible lines of research: management and governance of information systems, management of technology-driven healthcare processes, semantic interoperability of healthcare environments, and data science topics (big data or artificial intelligence). However, with the continuing evolution and improvement of technology and its impact on the environment, it is difficult to foresee long-term needs in information technologies and systems. A highly disruptive technological innovation may be enough to bring about a paradigm shift that completely alters the status quo, providing solutions that force us to rethink the issues raised. As Thimbleby [41] already stated, it is essential to review and analyze technological evolution, since doing so is the basis for finding the best solutions.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

ORCID

Enrique Maldonado Belmonte (https://orcid.org/0000-0002-6366-2648)
Salvador Otón Tortosa (https://orcid.org/0000-0002-6417-1779)
Luis de-Marcos Ortega (https://orcid.org/0000-0003-0718-8774)
José-María Gutiérrez-Martínez (https://orcid.org/0000-0003-0134-1256)

References

1. Wilson IB, Cleary PD. Linking clinical variables with health-related quality of life: a conceptual model of patient outcomes. JAMA 1995;273(1):59-65. https://doi.org/10.1001/jama.1995.03520250075037

2. Benneyan JC, Lloyd RC, Plsek PE. Statistical process control as a tool for research and healthcare improvement. Qual Saf Health Care 2003;12(6):458-64. https://doi.org/10.1136/qhc.12.6.458

3. Blauwet J, Bell M. Technology's role in quality improvement and operational efficiency. Front Health Serv Manage 2018;34(3):3-15. https://doi.org/10.1097/HAP.0000000000000026

4. Pendyala VS, Figueira S. Automated medical diagnosis from clinical data. Proceedings of 2017 IEEE 3rd International Conference on Big Data Computing Service and Applications (BigDataService); 2017 Apr 6–9; Redwood City, CA. p. 185-90. https://doi.org/10.1109/BigDataService.2017.14

5. Sia SK, Tang M, Soh C, Boh WF. Enterprise resource planning (ERP) systems as a technology of power: empowerment or panoptic control? ACM SIGMIS Database 2002;33(1):23-37. https://doi.org/10.1145/504350.504356

6. Hosseini MP, Tran TX, Pompili D, Elisevich K, Soltanian-Zadeh H. Deep learning with edge computing for localization of epileptogenicity using multimodal rs-fMRI and EEG big data. Proceedings of 2017 IEEE International Conference on Autonomic Computing (ICAC); 2017 Jul 17-21; Columbus, OH. p. 83-92. https://doi.org/10.1109/ICAC.2017.41

7. Rodger JA. Discovery of medical Big Data analytics: improving the prediction of traumatic brain injury survival rates by data mining Patient Informatics Processing Software Hybrid Hadoop Hive. Inf Med Unlocked 2015;1:17-26. https://doi.org/10.1016/j.imu.2016.01.002

8. Bhagwan V, Grobbelaar SS. Development of a telemedicine system for monitoring intensive care patients. Proceedings of the 2017 International Conference on Information System and Data Mining; 2017 Apr 1–3; Charleston SC. p. 139-44. https://doi.org/10.1145/3077584.3077600

9. Gupta PK, Maharaj BT, Malekian R. A novel and secure IoT based cloud centric architecture to perform predictive analysis of users activities in sustainable health centres. Multimed Tool Appl 2017;76(18):18489-512. https://doi.org/10.1007/s11042-016-4050-6

10. Luz MP, de Matos Nogueira JR, Cavalini LT, Cook TW.

Providing full semantic interoperability for the fast healthcare interoperability resources schemas with re-source description framework. Proceedings of 2015 International Conference on Healthcare Informatics; 2015 Oct 21-23; Dallas, TX. p. 463-66. https://doi.org/10.1109/ICHI.2015.74

11. Silsand L, Ellingsen G. The implication for organisation and governance through user-driven standardisation of semantic interoperable electronic patient record systems. Proceedings of the 10th Mediterranean Conference on Information Systems (MCIS); 2016 Sep 4–6; Paphos, Cyprus.

12. Barbosa O, Alves C. A systematic mapping study on software ecosystems. Proceedings of the Workshop on Software Ecosystems; 2011 Jun 8–10; Brussels, Belgium.

13. Petersen K, Feldt R, Mujtaba S, Mattsson M. Systematic mapping studies in software engineering. Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering (EASE); 2008 Jun 26–28; Bari, Itay.

14. Engstrom E, Runeson P. Software product line testing: a systematic mapping study. Inf Softw Technol 2011;53(1):2-13. https://doi.org/10.1016/j.infsof.2010.05.011

15. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009; 339:b2535. https://doi.org/10.1136/bmj.b2535

16. Basak R. Golden ratio and Fibonacci sequence: universal footprints of the golden flow. Turk Online J Des Art Commun 2022;12(4):1092-107. https://doi.org/10.7456/11204100

17. Vargas B, Ray P. Interoperability of hospital information systems: a case study. Proceedings of the 5th International Workshop on Enterprise Networking and Computing in Healthcare Industry (HealthCom); 2003 Jun 7; Santa Monica, CA. p. 79-85. https://doi.org/10.1109/HEALTH.2003.1218723

18. Staccini P, Joubert M, Quaranta JF, Fieschi D, Fieschi M. Integration of health care process analysis in the design of a clinical information system: applying to the blood transfusion process. Proc AMIA Symp 2000:824-8.

19. Sibarani EM. Simulating an integration systems: Hospital information system, radiology information system and picture archiving and communication system. Proceedings of 2012 2nd International Conference on Uncertainty Reasoning and Knowledge Engineering; 2012 Aug 14-15; Jakarta, Indonesia. p. 62-6. https://doi.org/

10.1109/URKE.2012.6319585

20. Meyer R, Lovis C. Interoperability in hospital information systems: a return-on-investment study comparing CPOE with and without laboratory integration. Stud Health Technol Inform 2011;169:320-4.

21. McDonald CJ, Martin DK, Overhage JM. Standards for the electronic transfer of clinical data: progress and promises. Top Health Rec Manage 1991;11(4):1-16.

22. Bardhan IR, Thouin MF. Health information technology and its impact on the quality and cost of healthcare delivery. Decis Support Syst 2013;55(2):438-49. https://doi.org/10.1016/j.dss.2012.10.003

23. Kwak YS. International standards for building electronic health record (EHR). Proceedings of the 7th International Workshop on Enterprise Networking and Computing in Healthcare Industry (HEALTHCOM); 2005 Jun 23-25; Busan, South Korea. p. 18-23. https://doi.org/10.1109/HEALTH.2005.1500373

24. Lyles C, Schillinger D, Sarkar U. Connecting the dots: health information technology expansion and health disparities. PLoS Med 2015;12(7):e1001852. https://doi.org/10.1371/journal.pmed.1001852

25. Ved V, Tyagi V, Agarwal A, Pandya AS. Personal health record system and integration techniques with various electronic medical record systems. Proceedings of 2011 IEEE 13th International Symposium on High-Assurance Systems Engineering; 2011 Nov 10-12; Boca Raton, FL. p. 91-4. https://doi.org/10.1109/HASE.2011.63

26. Gattnar E, Ekinci O, Detschew V. Clinical process modeling and performance measurement in hospitals. Proceedings of 2011 IEEE 15th International Enterprise Distributed Object Computing Conference Workshops; 2011 Aug 29–Sep 2; Helsinki, Finland. p. 132-40. https://doi.org/10.1109/EDOCW.2011.21

27. De Potter P, Debevere P, Mannens E, Van de Walle R. Next generation assisting clinical applications by using semantic-aware electronic health records. Proceedings of 2009 22nd IEEE International Symposium on Computer-Based Medical Systems; 2009 Aug 2–5; Albuquerque, MN. p. 1-5. https://doi.org/10.1109/CBMS.2009.5255372

28. Zhao C, Duan H, Lu X. An integration approach of healthcare information system. Proceedings of 2008 International Conference on BioMedical Engineering and Informatics; 2008 May 27–30; Sanya, China. p. 606-9. https://doi.org/10.1109/BMEI.2008.109

29. Vida M, Lupse O, Stoicu-Tivadar L. Improving the interoperability of healthcare information systems

through HL7 CDA and CCD standards. Proceedings of 2012 7th IEEE International Symposium on Applied Computational Intelligence and Informatics (SACI); 2012 May 24–26; Timisoara, Romania. p. 157-61. https://doi.org/10.1109/SACI.2012.6249994

30. Olier I, Springate DA, Ashcroft DM, Doran T, Reeves D, Planner C, et al. Modelling conditions and health care processes in electronic health records: an application to severe mental illness with the clinical practice research datalink. PLoS One 2016;11(2):e0146715. https://doi.org/10.1371/journal.pone.0146715

31. Marcos M, Maldonado JA, Martinez-Salvador B, Bosca D, Robles M. Interoperability of clinical decision-support systems and electronic health records using archetypes: a case study in clinical trial eligibility. J Biomed Inform 2013;46(4):676-89. https://doi.org/10.1016/j.jbi.2013.05.004

32. Soteriades H, Neokleous K, Tsouloupas G, Jossif AP, Christos SN. Electronic health record diagnosis tool and a cross reference between coding standards. Proceedings of 2012 IEEE 12th International Conference on Bioinformatics & Bioengineering (BIBE); 2012 Nov 11–13; Larnaca, Cyprus. p. 30–3. https://doi.org/10.1109/BIBE.2012.6399702

33. Blazona B, Koncar M. HL7 and DICOM based integration of radiology departments with healthcare enterprise information systems. Int J Med Inform 2007;76 Suppl 3:S425-32. https://doi.org/10.1016/j.ijmedinf.2007.05.001

34. Muller ML, Ganslandt T, Eich HP, Lang K, Ohmann C, Prokosch HU. Towards integration of clinical decision support in commercial hospital information systems using distributed, reusable software and knowledge components. Int J Med Inform 2001;64(2-3):369-77. https://doi.org/10.1016/s1386-5056(01)00218-0

35. Rutherford JJ. Wearable technology: health-care solutions for a growing global population. IEEE Eng Med Biol Mag 2010;29(3):19-24. https://doi.org/10.1109/MEMB.2010.936550

36. Santos DF, Perkusich A, Almeida HO. Standard-based and distributed health information sharing for mHealth IoT systems. Proceedings of 2014 IEEE 16th International Conference on e-Health Networking, Applications and Services (Healthcom); 2014 Oct 15–18; Natal, Brazil. p. 94-8. https://doi.org/10.1109/HealthCom.2014.7001820

37. Muhamedyev RI, Kalimoldaev MN, Uskenbayeva RK. Semantic network of ICT domains and applications. Proceedings of the 2014 Conference on Electronic Governance and Open Society: Challenges in Eurasia; 2014 Nov 18–20; St. Petersburg, Russian Federation. p. 178-86. https://doi.org/10.1145/2729104.2729112

38. Ilin I, Levina A, Lepekhin A, Kalyazina S. Business requirements to the IT architecture: a case of a healthcare organization. In: Murgul V, Pasetti M, editors. International Scientific Conference Energy Management of Municipal Facilities and Sustainable Energy Technologies (EMMFT 2018). Cham, Switzerland: Springer; 2018. p. 287-94. https://doi.org/10.1007/978-3-030-19868-8_29

39. Lin CH, Lin IC, Roan JS, Yeh JS. Critical factors influencing hospitals' adoption of HL7 version 2 standards: an empirical investigation. J Med Syst 2012;36(3):1183-92. https://doi.org/10.1007/s10916-010-9580-2

40. Iroju O, Soriyan A, Gambo I, Olaleke J. Interoperability in healthcare: benefits, challenges and resolutions. Int J Innov Appl Stud 2013;3(1):262-70.

41. Thimbleby H. Technology and the future of healthcare. J Public Health Res 2013;2(3):e28. https://doi.org/10.4081/jphr.2013.e28