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REVIEW

Industry 4.0 and healthcare: Context, applications, benefits and challenges

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Abstract

Industry 4.0 refers to the digital transformation in the manufacturing domain through new technology. Currently, it expands well beyond manufacturing, affecting many areas of life and posing implications for all types of business. This paper focuses on the relationships between Industry 4.0 and Healthcare which transitions to increased interconnectivity, automation and smart decision making. The integration context of Industry 4.0 into Healthcare is only partly understood. Little was done until now to consolidate what is known on the integration benefits and the challenges. This article reports results of a systematic mapping study that analysed 69 papers to extract knowledge about the concepts of Industry 4.0 and the emerging Healthcare 4.0., and the relationships between them. We found 10 different perspectives of Healthcare 4.0, ranging from strategic to tactical and operational levels. Next, our results show: (i) nine applications of Industry 4.0 in the Healthcare domain: Augmented Reality and Simulation, Autonomous Robotics, Cybersecurity, Big Data Analytics, Internet of Things, Cloud Computing, Additive Manufacturing and Systems Integration; and (ii) 10 benefits and nine challenges in Healthcare 4.0. The most frequently mentioned benefits are patients' diagnosis, monitoring, treatment, and financial benefits. The most researched challenges are data fragmentation, heterogeneity, complexity, and privacy.

KEYWORDS

big data, cloud computing, fourth industrial revolution, healthcare 4.0, industry 4.0, Internet of Things, mapping study, smart industry

1 | INTRODUCTION

The idea of a new industrial revolution had been proposed a long time ago, even since the last decade of the 20th century, 30 years after the introduction of the third industrial revolution. Even though the transition from the first to the second and from the second to the third required a century to be realised, the transition to the most recent one was more rapid as the third industrial revolution lasted only for 4 decades approximately.

Currently, we experience the fourth stage of this industrialisation, known as *Industry 4.0*. This term first emerged in Germany in 2011 as a collaborative effort between business associates, academic researchers and governmental representatives in order to shape the future of German manufacturing industry. It is characterised by the use of Cyber-physical Systems (CPS) and will lead to the development of smart factories, enhancement of the business and engineering processes and therefore to improved and optimised decision-making [1].

Similar initiatives in other countries were proposed subsequently. For example, in the Netherlands, the concept of *Smart Industry* was launched in 2014 with the aim to strengthen the domestic productivity and the country's industrial position. It is based on three pillars. First, the government provides businesses with knowledge and expertise in nine different sectors. Second, the establishment of networks for public-private partnerships and the exchange of skills and knowledge is promoted. In the third pillar, the Smart Industry itself serves as the framework for long-term agenda-setting and improvement of industrial and technological conditions [2, 3]. China also developed its own policy in 2015, known as *Made-in-China 2025,* which has a broader scope than the previous two and is the first stage of a three-phase plan whose goal is to make China the most powerful nation in manufacturing by 2049 [4]. Another nation with significant progress in this field is South Korea, which launched its own initiative for the fourth industrial revolution, named *Manufacturing Innovation 3.0,* that focuses on the development of Smart Factories to achieve automatisation and sustainability in manufacturing processes [5].

Scholars and practitioners agree that Industry 4.0 affects many aspects of our world and has implications for many business sectors, including Healthcare, one of the strongest sectors nowadays. In most developed countries, Healthcare accounts for more than 10% of the GDP, while global Healthcare spending is expected to reach approximately $9 trillion in 2021 [6]. With the ever increasing costs for patients and healthcare providers and the demand for more patient-centric services, the need for a digitized healthcare system where processes will be automated, physicians' efficiency will be improved and prevention will be prioritised keeps growing. Therefore, it is essential to shape a new future for Healthcare where technology will substitute or empower many human tasks.

In this context, Industry 4.0 is expanded to include the Healthcare sector as well, leading to the emergence of *Healthcare 4.0*. This concept is not limited only to manufacturing or automation but is applied in a wider scope which aims to improve the overall level of processes in manufacturing units, healthcare services provided, as well as operational matters of healthcare systems. Therefore, its focus is not on the processes solely but on the beneficiaries as well. Adoption of Healthcare 4.0 solutions can have the following effects, amongst others:

- Increased surgical accuracy,
- Faster and more secure medical data storage,
- Improved hospital resources management,
- Less patient discomfort.

Proper data management plays an important role towards Healthcare 4.0 solutions. As Healthcare is one of the sectors that produces the largest amount of data, in the form of, for example, biomedical data, Electronic Health Record (EHR) and physical records, scholars and practitioners recognise the significance of Healthcare Data Analytics to drive the realisation of organisation benefits. According to a Comprehensive Research Report by the IT trends research company Market Research Future, the global market will achieve a compound growth rate of 18.2% with an income of 81.3 billion USD by the year 2030 [7].

Over the last few years, various attempts have been made to identify the context of Healthcare 4.0 and how it is linked to Industry 4.0. Ref. [8] identifies some key Industry 4.0 technologies used in Healthcare with Cloud Computing and the Internet of Things standing out, with the conclusion that some of the relevant definitions and concepts of Healthcare 4.0 are yet to be standardized. In a more recent review, Refs. [9–12] present the main trends, challenges and benefits of Healthcare 4.0 nowadays, as well as some major challenges such as security and privacy, data requirements and lack of standardisation. Furthermore, Ref. [13] shares its findings about the current state of Healthcare 4.0 and the future research directions by pointing out nine main technologies and their contributions, as well as eight challenges. However, the above studies fail partially or fully to elaborate the framework of Healthcare 4.0 and how this emerges from Industry 4.0, how Industry 4.0 and Healthcare 4.0 components might differ from each other, and what are the characteristics of those components that lead to the rise of such opportunities and challenges.

The present literature mapping study makes a step towards bridging this knowledge gap. The aim of this work is threefold. First, to define Industry 4.0, Healthcare 4.0 and the relationship between them as this has developed in the last decade, according to selected sources. Second, to present some of the most significant applications of components of the first one to the latter with additional focus on data management. Third, to understand the benefits and main obstacles to adoption of Healthcare 4.0 solutions, according to published sources. It is expected to contribute to the literature by presenting the context within which Healthcare service providers can develop Healthcare 4.0 policies for their institutions or systems, as well as highlighting the theoretical gap that currently exists in this field.

The rest of the paper is structured as follows. Section 2 presents the Research Methodology followed, focussing on the formulation of the respective Research Questions, the search strategy and the results obtained by the selection process. In Section 3, the main findings of our literature mapping study are reported. In Section 4, a discussion and interpretation of the results are provided, followed by some prospective points for future work. It concludes with Section 5, where the main conclusions drawn are given.

2 | RESEARCH METHODOLOGY

This section presents the research method followed for searching, retrieving and analysing relevant studies. It describes the Research Questions used to analyse their contents and that this review aims to answer, the database selection strategy, the search terms, the inclusion/exclusion criteria, the strategy for critically assessing the obtained results and selecting the studies included in the review, as well as the data extraction method. This research process was inspired by the work of Ref. [14]. Its overall purpose is to retrieve a selection of studies that would help the authors to define the concepts of Industry 4.0 and Healthcare 4.0, their connections, as well as the potential opportunities and barriers that arise.

2.1 | Research questions

In order to analyse the relevant literature, three different research questions were formulated. Their objective is to assist us in the data extraction process by identifying whether or not the selected studies provide answers to any of them. This can happen either by suggesting new findings or confirming/expanding the existing ones or contradicting others. The aforementioned research questions are the following:

> ***RQ1***: How are Industry 4.0 and Healthcare 4.0 defined and how the latter is linked to or differs from the former, according to published literature?
> ***RQ2***: How do the different Industry 4.0 components apply to the Healthcare sector?
> ***RQ3***: What benefits and challenges are reported for Healthcare stakeholders from the integration of Industry 4.0 solutions and services in the published literature?

For the purpose of terminological clarity, we would like to make a note that the term 'Industry 4.0 components' in our RQ2 is not borrowed from RAMI 4.0, the Reference Architecture Industry 4.0, which was developed in 2019 by the German Electrical and Electronic Manufacturers' Association (ZVEI) to support their Industry 4.0 initiatives. RAMI 4.0 is a three-dimensional map with well-defined terminology agreed upon by the ZVEI members. In contrast to RAMI 4.0, in our paper, the term 'Industry 4.0 components' has a much broader meaning that is not linked to a particular industrial body or association.

To answer our three Research Questions, we formed a population of studies from January 2017 to January 2021, since the research was conducted in February 2021. We focussed our search on sources published after 1 January 2017, because we wanted to only get the latest results. This choice was motivated by the observation of other researchers that Healthcare 4.0 was introduced in the last 5 years, growing from Industry 4.0 and that most technological innovation happened in the recent years [15]. Hereby, and taking into account that the objective of this paper is to be fully up-to-date at least till January 2022, the aforementioned time frame was selected.

2.2 | Research strategy

We started by scoping our research strategy to online databases accessible via the University of Twente. Currently, the university has access to 105 databases. For the purposes of this research, we excluded some of them as they were classified either as irrelevant (thematic databases which contain publications on selected topics irrelevant to ICT and healthcare, such as chemistry, materials science and arts) or did not contain any articles (rather statistics, numerical data, dictionaries, patents and others). This narrowed the initial number of 105 online databases to 24, being classified as eligible. An overview of all online libraries examined is shown in Table A1 in Appendix A.

From those 24 databases, we selected Scopus, ScienceDirect and Web of Science as the most suitable ones for our review, as they fulfil most of the quality criteria indicated in Ref. [16] and can be used as principal search systems. We also quoted IEEE, since it is one of the largest and most complete databases in the field of Computer Science.

To develop a search string, we experimented with different combinations of terms that refer to the aspects of interest covered in this mapping study, namely: subject matter aspects (e.g. the '4.0' aspects) and data management aspects (i.e. big data and data analytics). This iterative experimentation was important because we wanted to find a search string that would be as inclusive and accurate as possible. In more detail, we experimented with various strings, including keywords, which the international journals and conferences on industry 4.0 and big data management were using to characterise the area. This experimentation was a learning experience, as indicated by research methodologists [17]. After a number of iterations, we ended up with the following search term:

('Smart Industry' OR 'Industry 4.0' OR 'Healthcare 4.0') AND ('Healthcare' OR 'Health') AND ('Big Data' OR 'Analytics')

The search using the above string was performed on the title, abstract and keywords of the publications. To define the boundaries of the study, the following restrictions were used:

- Publication type (e.g. conference paper or article)
- Year of publication (from 1 January 2017 onwards)
- Subject area (e.g. Computer Science, Engineering, Business Economics)

This returned in a total of 263 results from all four databases. This number was limited by the fact that the search term might have excluded from the results publications whose primary topic is none of the aforementioned or the abstract and keywords section is not quite extended.

2.3 | Selection process

Our selection process includes three steps.

Step 1: Initially, the results were screened to remove duplicates. From the retrieved studies, a total of 48 were discarded as duplicates of others. This left us with 215 publications.

Step 2: Afterwards, a list of inclusion and exclusion criteria was set in order to find the most suitable and valuable studies.

The inclusion criteria (IC) are the following:

> ***IC1***: The study is related to the topic of review. By doing this, we ensure that all included studies examine the Healthcare sector either exclusively or together with other sectors, and do propose or evaluate a relevant method in our context of interest.
> ***IC2***: The paper addresses one or more of our research questions. This eliminates studies that might be in the field of Healthcare 4.0 but their contribution is to a topic different from those addressed in our RQs.
> ***IC3***: The paper is available for download or online access. Quite often, databases may include papers where only the abstract and not the main body are available. As it is hard

to extract conclusions by reading only the abstract, we would like to have access to the whole paper.

The exclusion criteria (EC) are the following:

EC1: The study is in the field of Healthcare 4.0 but the contribution is to a topic different from those addressed in our RQs.
EC2: The paper relates to Healthcare 4.0 in its related work only.
EC3: The paper is a tutorial or poster summary only. Experience shows that tutorial or poster summaries can contain a lot of relevant keywords but might not necessarily advance the actual body of knowledge [17].
EC4: The paper is not in English.
EC5: The paper occurs multiple times in the result set. If a journal paper by the same authors on the same topic has been published after a conference or workshop paper, we consider for inclusion the most recent publication, that is, the journal paper.
EC6: The paper belongs to the so-called 'grey literature' (reports, white papers, notes and trend releases). Even though sometimes grey literature is valuable, its inclusion poses challenges such as credibility and validity [18].

Step 3: Based on the above IC, the first author reviewed and assessed all remaining studies based on their title, abstract and list of keywords. This resulted in 48 studies meeting all of those criteria, which became the initial set of papers under review. Afterwards, the process was repeated by three other co-authors as there were some doubts about the contents of certain papers and their compliance with the above inclusion criteria (especially IC2), and therefore further examination was required. Thus, additional sections or the full document were inspected. This led to increasing the size of the dataset to 77 studies.

In the third step, where all the publications were studied thoroughly, eight were discarded as they eventually did not meet all the IC by reading their main body too. Therefore, a total of 69 publications were yielded in total from four databases (IEEE, Scopus, Science Direct and Web of Science). Thirty-two publications were retrieved from Scopus, four from IEEE, six from Science Direct and 27 from Web of Science.

Finally, 40 out of the 69 selected papers were randomly split amongst three researchers for additional review. Researcher B assessed 20 papers, and researchers C and D assessed 10 papers each to counter internal validity threats. We wanted to achieve objectivity, reduce selection bias and ensure that all researchers have the same perception of the IC. Any study that was rejected by researcher B, C, or D or the researcher had doubts about, was then re-evaluated by the others based on the rationale provided. There was a disagreement on results for six papers. However, after second evaluation and discussion, all of them were included in the final corpus.

An overview of the above process is illustrated in Figure 1.

Following Ref. [14] methodology, we decided to conclude the selection process by assessing the quality of the selected studies. The purpose is to increase its rigour and reduce the selection bias. To critically appraise those studies, the following questions were formulated and applied to each study individually, with regard to the three RQs mentioned earlier. Those questions are the following:

- Does the study provide any definition or description of Industry 4.0? **(RQ1)**
- Does the study provide any definition or description of Healthcare 4.0? **(RQ1)**
- Are the aforementioned definitions/descriptions based on previous works? **(RQ1)**
- Does the study review or evaluate any previously suggested Healthcare 4.0 applications? **(RQ2)**
- Does the study propose any new method which can be applied to Healthcare 4.0? **(RQ2)**
- Is the validity of the proposed method(s) evaluated empirically in the paper? **(RQ2)**
- Does the study mention any benefits of Industry 4.0 for Healthcare? **(RQ3)**
- Does the study mention challenges for successful integration of Industry 4.0 to Healthcare? **(RQ3)**

Each quality assessment question accounts for one point. Any study that gains a score less than two points is excluded from the results. The individual and total quality scores for all 69 papers are shown in Table B1 in Appendix B.

2.4 | Data extraction

The data extraction strategy used is the following. First, we collected the general information about the document, such as the title, the authors, the publication year and the main topic. The results are displayed in Table C1 in Appendix C. For **RQ1**, we identified any definitions of Industry 4.0 and Healthcare 4.0 mentioned in the study, as well as references to the context or framework that led to the emergence of the latter one. For **RQ2,** the information collected includes any references to Industry 4.0 components and Healthcare methods/tools/frameworks based on them, definitions of those components, and whether it is a review of an existing one or a proposal for a new one. For **RQ3**, the opportunities and challenges that arise in the Healthcare sector from Industry 4.0 components were identified. A full overview of the outcomes can be found in Tables C2–C4. The above data extraction strategy has been agreed, validated and followed by all authors.

3 | RESULTS

In this section, our findings with regard to the Research Questions and objectives of this study are presented. Section 3.1 discusses the different definitions of Industry 4.0 and

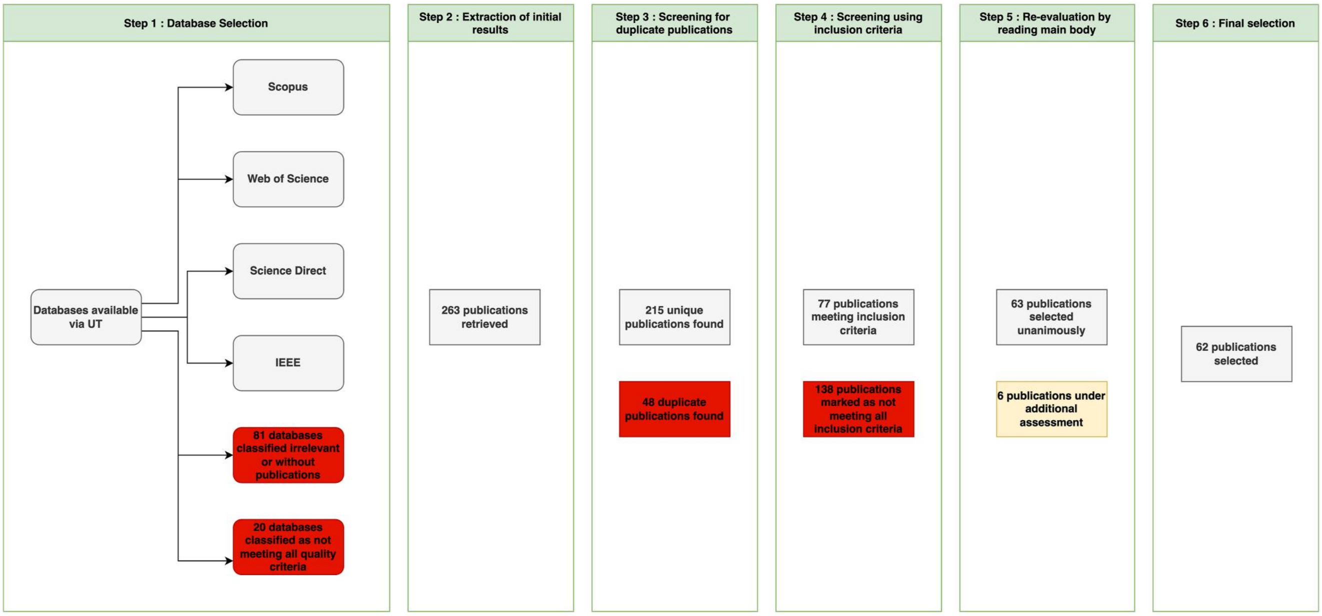

FIGURE 1 Steps involved in the research methodology

Healthcare 4.0 found in literature, as well as how the latter emerged from the former. This answers **RQ1**. In Section 3.2, we summarise the main contributions and applications that each Industry 4.0 component has to the Healthcare sector in order to answer **RQ2**. Finally, in Section 3.3, the main opportunities and challenges arising from the previous Healthcare 4.0 applications are illustrated, accompanied by the broad opportunities and challenges identified for this sector. This addresses **RQ3**.

3.1 | Industry 4.0 and healthcare 4.0 context

3.1.1 | Industry 4.0 definitions and context

In order to better understand Industry 4.0 and its framework, it is essential to provide some clear and generally accepted definitions of it. In fact, in the reviewed literature, a broad range of definitions has been suggested. This probably comes as no surprise, since when the term Industry 4.0 was first introduced in Germany in 2011, it was undefined, and thus room for different interpretations was given. Even though the definitions differ, as shown, there are some key elements or components that can be found in the majority of the relevant descriptions provided (Table 1):

- An abstract definition is given in Ref. [19], where 'Industry 4.0 is an umbrella concept for mainstream technologies, for example, CPS, Internet of Things (IoT), Cloud computing, Big Data analytics, Augmented Reality (AR)' that has several extensions.
- Ref. [20] describes Industry 4.0 as 'a new digital industrial technology where CPS can interact with each other using Artificial Intelligence, Machine Learning, Internet of Things and Big Data to increase productivity and growth'.
- Another similar definition is given in Ref. [21], where 'the industry sector is taking advantage of ICT advances such as the Internet of Things, CPS and analytics to initiate the Industry 4.0 era'.
- In Ref. [22], an effort to define Industry 4.0 in the context of the technologies used is made. Thus, it describes a state of industry which is based on nine pillars linked to five major technologies, namely Big Data Analytics, Artificial Intelligence, Cloud Computing and Internet of Things. In addition, it is highlighted that one of the main reasons that has led to the rise of Industry 4.0 is the opportunities it offers to automate the process of Big Data analysis.
- Ref. [23] follows an analogous approach and describes Industry 4.0 as a collection of technologies such as mobile devices, Internet of Things, smart sensors and Big Data analytics amongst others, that contribute towards the industrialisation and growth of economies.
- Moreover, Ref. [24] sees Industry 4.0 'as a vision for a new industrial revolution put forward by the Communication Promoters Group of the Industry–Science Research Alliance to further enhance Germany's manufacturing industry', focussing on the wider purpose and motivation for the emergence of Industry 4.0. Some of its key technologies include CPS, Internet of Things and Artificial Intelligence. It also points out a list of common characteristics of Industry 4.0 systems, such as modularity and involvement of interoperable components and virtualisation technologies.
- Ref. [25] focuses as well on the manufacturing aspect of Industry 4.0, which is three-dimensional: (i) the horizontal integration across the value creation network, (ii) the end-to-end engineering across the product life cycle and (iii) the vertical integration combined with networked manufacturing

TABLE 1 Industry 4.0 definitions & descriptions

Nr.	Industry 4.0 definition/description	Reference
1	An umbrella concept for mainstream technologies, for example, CPSs, IoT, cloud computing, big data analytics and AR	[19]
2	A new digital industrial technology where CPSs can interact with each other using AI, ML, IoT and big data to increase productivity and growth	[20]
3	The industry sector is taking advantage of ICT advances such as the IoT, CPSs and analytics to initiate the industry 4.0 era	[21]
4	IR 4.0 describes a state of industry that is based on nine pillars, linked to four major technologies, namely big data analytics, AI, cloud computing and IoT era	[22]
5	A collection of technologies such as mobile devices, IoT, smart sensors and big data analytics amongst others that contribute towards the industrialisation and growth of economies	[23]
6	A vision for a new industrial revolution put forward by the Communication Promoters Group of the Industry–Science Research Alliance to further enhance Germany's manufacturing industry era	[24]
7	It consists of three dimensions: (i) the horizontal integration across the value creation network, (ii) the end-to-end engineering across the product life cycle and (iii) the vertical integration combined with networked manufacturing systems	[25]
8	It is fuelled by the integration of intelligent automation into the manufacturing value chain, while the key characteristics and technologies driving this change are the adoption of IoT devices in the manufacturing process, also known as the industrial IoT	[26]
9	It is a governmental explicit commitment to foster a set of technologies and the cultural and legal framework necessary to harness their full potential	[27]
10	It is a part of the disruptive and exponential technologies	[28]
11	It is the era where artificial intelligence, machine learning, big data, robotics, additive manufacturing and other disruptive technologies are developed and applied in every segment	[29]
12	It is an advanced digitised manufacturing, where internet of things is implemented within the manufacturing process	[30]

systems. Technologies such as CPS, Internet of Things and Big Data are vital.

- The study of Ref. [26] identifies manufacturing as the cornerstone of Industry 4.0. 'Industry 4.0 is fuelled by the integration of intelligent automation into the manufacturing value chain, while the key characteristics and technologies driving this change are the adoption of IoT devices in the manufacturing process, also known as the Industrial IoT'.
- Likewise, Ref. [27] approaches this concept 'as a governmental explicit commitment to foster a set of technologies and the cultural and legal framework necessary to harness their full potential'. It has been developed around CPS and relies on three pillars: Internet of Things, Big Data Analytics and Cloud/Fog Computing.
- Two concepts worth pointing out are the so-called Disruptive Technologies and Exponential Technologies. Disruptive technologies include a list of technologies that contribute towards digitalisation and improved R&D. In this framework, Ref. [28] considers Industry 4.0 as part of those technologies, reliable on the others.
- Ref. [29] characterises Industry 4.0 as the era where 'Artificial Intelligence, Machine Learning, Big Data, Robotics, Additive Manufacturing and other Disruptive Technologies are developed and applied in every segment', by examining it under the scope of Disruptive Technologies.
- Ref. [30] tries to address the gap of lack of proper Industry 4.0 definition, as it is a topic still under research. It proposes a new definition to overcome those limitations. According to the authors, 'Industry 4.0 is an advanced digitalised manufacturing, where Internet of Things (IoT) is implemented within the manufacturing process'.

3.1.2 | Healthcare 4.0 definitions and context

Next, we consider that the concept of Healthcare 4.0 should be described too. As highlighted earlier, Industry 4.0 is a wide framework whose main focus is on the manufacturing sector, but it has expanded to include others too. Healthcare, Logistics, Education and Cities are just some of them. In this subsection, the different definitions and the concept of Healthcare 4.0 will be provided. The aim is to reveal the reasons that led to the development of the latter and how it is linked to or differs from Industry 4.0. Table 2 summarises the definitions that were found in our selected studies:

- Ref. [31] identifies six Industry 4.0 principles applied to the Healthcare sector: interoperability, visualisation, decentralisation, real-time capability, service orientation and modularity.

TABLE 2 Healthcare 4.0 definitions & descriptions

Nr.	Healthcare 4.0 definition/description	Reference
1	Interoperability, visualisation, decentralisation, real-time capability, service orientation and modularity enable the integration of the industry 4.0 in healthcare, with cloud computing and IoT being the key enabling technologies	[31]
2	The key difference between industry 4.0 and healthcare 4.0 is that in healthcare the main interaction is between humans and humans and not between humans/machines and machines	[32]
3	It is characterised by the adoption of internet of things, cloud computing and big data-based solutions and has an intrinsic multidisciplinary nature but differs from smart health	[27]
4	It is the implementation of integrated healthcare platforms with progressive virtualized, distributed and real-time healthcare services for patients, professionals and formal and informal caregivers	[21]
5	It must enable gradual virtualisation to support personalised health services near real-time for patients, workers, and formal and informal caregivers	[33]
6	It is a framework where service providers collect data generated by individual users in their daily lives and by medical institutions about patients and then provide customised advice and treatment to users based on the knowledge obtained through analysing a large amount of collected data	[34]
7	It refers to the shift from traditional hospital-centric care to a more virtual, distributed care that heavily leverages the latest technologies around artificial intelligence (AI), deep learning, data analytics, genomics, home-based healthcare, robotics, and others	[35]
8	It is a strategic concept for the health domain derived from the industry 4.0 concept to improve healthcare service and connectivity between healthcare stakeholders using technology	[36]
9	It is a continuous but disruptive process of transformation of the entire healthcare value chain, ranging from medicine and medical equipment production, hospital care, non-hospital care, healthcare logistics, and healthy living environment to financial and social systems	[37]
10	Modern healthcare systems will be based on exponential technologies, which will establish a patient-centric, personalised healthcare system	[29]

They enable the integration of the fourth industrial revolution in Healthcare, with cloud-based design and manufacturing systems and the Industrial Internet of Things being the key enabling technologies.

- Ref. [32] makes an effort to connect Industry 4.0 and Healthcare 4.0. It presents some of the key components of Industry 4.0 and how those are integrated into the Healthcare domain. It can be utilised by developing applications, methods or tools based on technologies such as Data Integration, Virtual Reality, 3D Printing, Internet of Things, Robotics, Big Data, Artificial Intelligence and Cybersecurity. The key difference, however, is that in Healthcare, the main interaction is between humans and humans and not between humans/machines and machines.
- Another description falling into this category is provided by Ref. [27], where Healthcare 4.0 is characterised by the adoption of Internet of Things, Cloud Computing and Big Data solutions and has an intrinsic multidisciplinary nature. This differs from the term Smart Health, since the authors believe the latter has a wider scope and refers to ICT-based healthcare solutions in general.
- Ref. [21] provides a definition of Healthcare 4.0 that results from the adaptation of Industry 4.0 to the Healthcare domain. It can be defined 'as the implementation of integrated healthcare platforms with progressive virtualized, distributed and real-time healthcare services for patients, professionals and formal and informal caregivers. It focuses on supporting, enabling and optimising collaboration, coherence, and convergence to move healthcare services from being based on 'empirical data to precision medicine' (i.e. personalised healthcare services) as one direction for enhancement'. It is characterised by the previous technologies, which enable the creation of a smart health network consisting of patients, devices, healthcare providers and medical suppliers.
- Moreover, the study of Ref. [33] makes this connection too, as it claims that it 'must enable gradual virtualisation to support personalised health services near real-time for patients, workers, and formal and informal caregivers'.
- Ref. [34] follows a human-centred approach to Healthcare 4.0, as a framework 'where service providers collect data generated by individual users in their daily lives and by medical institutions about patients and then provide customised advice and treatment to users based on the knowledge obtained through analysing a large amount of collected data'.
- Another category of descriptions focuses on the evolution of the healthcare system that Healthcare 4.0 brings. In this

direction, Ref. [35] states that 'Healthcare 4.0 refers to the shift from traditional hospital-centric care to a more virtual, distributed care that heavily leverages the latest technologies around artificial intelligence (AI), deep learning, data analytics, genomics, home-based healthcare, robotics, and 3D printing of tissue and implants'.

- Likewise, Ref. [36] defines Healthcare 4.0 briefly as 'a strategic concept for the health domain derived from the Industry 4.0 concept, which can be described as a phenomenon to improve healthcare service and connectivity between healthcare stakeholders using technology'. It revolves around three pillars: people, technology and design.
- Ref. [37] shares the belief that it is hard to be defined due to its fuzziness. However, it provides a rough definition of it as 'a continuous but disruptive process of transformation of the entire healthcare value chain ranging from medicine and medical equipment production, hospital care, non-hospital care, healthcare logistics, healthy living environment to financial and social systems, where a vast number of cyber and physical systems are closely combined through the IoT, intelligent sensing, big data analytics, AI, cloud computing, automatic control, and autonomous execution and robotics to create not only digitalised healthcare products and technologies but also digitalised healthcare services and enterprises'.
- Ref. [29] attempts to elaborate why the Healthcare domain is in need of innovation and how this can be achieved. In this sense, it shares the opinion that modern Healthcare systems will be based on exponential technologies, which will establish a patient-centric, personalised Healthcare system.

3.2 | Industry 4.0 applications to the healthcare domain

This section discusses the main findings about the integration of Industry 4.0 into the Healthcare domain. Earlier, the presence of numerous key enabling technologies of Industry 4.0 was highlighted. For the purposes of this review, we will use the categorisation that several authors [38–40] mention in their work. In this framework, Industry 4.0 key enabling technologies can be split into nine main pillars, as illustrated in Figure 2: Big Data & Data Analytics, Simulation, Internet of Things, Augmented Reality, Cloud Computing, Additive Manufacturing, (Autonomous) Robotics, Cybersecurity and Systems Integration. In Table 3, a categorisation of the different applications per each of the nine pillars can be found. Concepts such as Artificial Intelligence, 5G Networks and Virtual Reality can also be found in the literature, but we appraise them as supporting technologies of the above. As shown in the respective subsections, there are certain applications which combine characteristics of multiple technologies, which is a great example of the overall concept of Industry 4.0 and how it brings them together to further enhance them.

3.2.1 | Cloud computing

The use of Cloud Computing in Healthcare is gaining increasing popularity due to its advantages. The most significant one is the powerful capabilities in terms of storage and computation that exceed those of a typical, physical server. According to Ref. [27], its main drivers are the scalability, the convenience in data sharing and its financial benefits. It can be defined as 'a paradigm in which information is permanently stored in servers on the internet and cached temporarily on clients that include desktops, table computers, notebooks, wall computers, handhelds, sensors, monitors, etc.' [79]. As mentioned by Ref. [41], the four primary Cloud models are Private, Public, Hybrid and Community. Different alternatives of Cloud Computing have also emerged to overcome some of its pitfalls, such as Fog Computing and Mobile Edge Computing:

- A significant Cloud Computing application is to support and perform Data Analytics. Ref. [42] presents a system for patients' rehabilitation where a private Cloud acts as the host of its web services. Moreover, Ref. [31] deals with the concept of Cloudlets, which are virtual machines hosted close to the wireless devices, linked to Mobile Edge Computing. They can be used to collect and transfer medical data, while also performing some low-level Data Analytics on it. Ref. [43] focuses on the aspect of performing Analytics on the Cloud, for example, on data collected from patients with neurological disorders or during Ambient Assisted Living (AAL). In the healthcare system that Ref. [44] develops for the monitoring of diabetes patients, wearable devices collect data, which is stored and aggregated on a Cloud for future analysis.
- Another contribution of Cloud Computing in Healthcare is to the provision of telemedicine services. Ref. [45] mentions that this technology acts as the intermediate level between patients and healthcare providers for the transmission of data to a Cloud-based server. Ref. [50] proposes a Cloud and Fog-based platform that can be used for telemonitoring of elderly people, which generates and collects data from IoT devices and then forwards it to the Fog and Cloud layer for further analysis. A similar framework is also proposed by Ref. [51] that relies on the concept of Digital Twin and can offer real-time monitoring or early diagnosis.
- According to Ref. [21], even though it is seen as a separate technology, Cloud Computing is required in the majority of Healthcare applications. For example, it can be used for hospital resources management, storing EHRs and analysing medical images. To this end, Ref. [46] proposes a Cyber-physical System to improve healthcare services, where the contribution of Cloud Computing lies in the integration of a computing environment that provides the required computational resources. Similarly, Ref. [27] identifies some Cloud-based health IT systems to share patients data and clinical records in hospitals, store and process physiological signals used for real-time

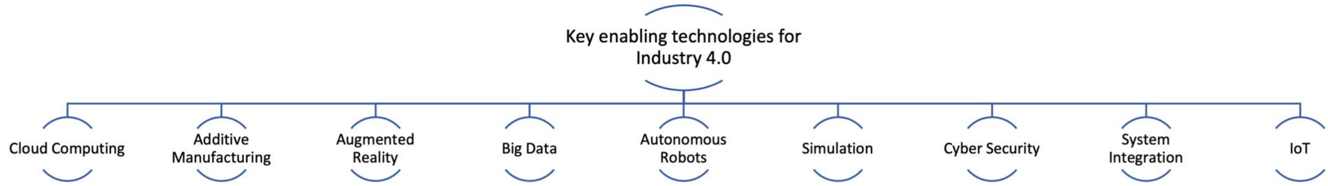

FIGURE 2 Industry 4.0 key enabling technology classification based on Refs. [38–40]

TABLE 3 Industry 4.0 applications in the Healthcare domain

Nr.	Industry 4.0 component	References
1	Cloud computing	[21, 27, 31, 41–49]
2	Additive manufacturing	[20, 24, 29, 32, 49]
3	Autonomous robotics	[24, 25, 27, 28, 32, 37, 47, 49]
4	Internet of things	[19–21, 24, 25, 27–29, 32–34, 36, 37, 44, 46, 48–63]
5	Augmented reality	[23, 32, 36, 51, 64]
6	Simulation	[21, 25, 26, 46, 48, 51, 65–68]
7	Systems integration	[21, 27, 31, 33, 36, 46, 64, 69, 70]
8	Cybersecurity	[20, 21, 26–28, 31, 34, 43, 50, 54, 55, 58, 66, 68, 69, 71–74]
9	Big data & data analytics	[21, 22, 31, 32, 35, 45, 56, 65, 75, 76]., [24, 27, 28, 33, 37, 42, 43, 49–53, 55, 58–62, 67, 68, 73, 77, 78]

patients monitoring or provide the infrastructure to support AAL.

- The belief shared in Ref. [47] is that in the near future, online medical databases for clinical trials can be created based on Cloud Computing designs.
- Focussing on Fog Computing, Ref. [43] highlights that Fog Computing services in Healthcare can be well combined with IoT devices to reduce response times and create a prediction system for hypertension attacks. In addition, Ref. [48] suggests a healthcare framework (called UbeHealth) where Cloud and Fog Computing (together with Mobile Computing) are two of its main enabling technologies. It consists of four layers, where the second and the fourth are the Cloudlet and Cloud layers, respectively, and is used for the development of a networked healthcare system.

3.2.2 | Additive Manufacturing

One of the key objectives of Industry 4.0 is the enhancement and evolution of the manufacturing process using smart production systems. Industry 4.0 has provided businesses with the capability to move their manufacturing and supply chains to a new epoch and use some of its novel technologies to reduce costs, make better management of raw materials or create products not feasible by conventional methods and techniques.

Additive Manufacturing is closely related to the concept of 3D Printing. It can be described 'as a technique of blending materials by either fusion, binding, or solidifying materials such as liquid resin and powders. Terminologies such as 3D printing (3DP), rapid prototyping (RP), direct digital manufacturing (DDM), rapid manufacturing (RM), and solid freeform fabrication (SFF) can be used to describe additive manufacturing (AM) processes' [80]. It was introduced for the first time during the 1980's and found numerous applications in Healthcare, based on 3D Printing, 3D Bioprinting and quite recently, 4D Printing [81]. Production of medical devices and tools or even human organ models and implants are two major reasons that lead to its adoption:

- Development of implants and organs has been realised by Additive Manufacturing. As Ref. [32] highlights, 3D-printed dental prosthetics and implants are a concept that has been on the market for quite a few years. While Ref. [24] also demonstrates different examples of 3D implants (e.g. knees and hips). Their advantage compared to conventional ones is that 3D printing offers greater flexibility to design more complex and cheap implants. However, we are still some years away from producing organs using 3D printing that can be successfully transplanted to humans. Implant production is mentioned in Ref. [29] too, as an instance of how exponential technologies can shape the future of Healthcare.
- Additive Manufacturing can also be used for surgical purposes. It is possible to 3D print pre-surgical replicas of a patient's organs, which enables physicians to gain a clear idea of his anatomy, perform precise operations and offer concrete recommendations [24], while also educating the patients about their medical condition [27].
- Concerning equipment manufacturing, 3D Printing has already been applied to this domain. Ref. [20] mentions an effort initiated by the University of Johannesburg that has led to the design of 3D printed mechanical ventilators and

head shields used to treat COVID-19 patients. Moreover, in the domain of laboratory work, inexpensive equipment such as tools or other small parts can be produced [27].
- Another essential contribution of Additive Manufacturing in Healthcare is in the educational field. 3D Printing can be used to print anatomical material or human organs for the purpose of study by medical students [32].

3.2.3 | Autonomous Robotics

In the set of our selected papers, we found many examples of Autonomous Robotics that indicate how Industry 4.0 transforms the manufacturing process. Robotics solutions can perform precise actions, advanced functions and reduce errors and production costs, while also increasing the quality of the delivered products. They operate with minimal outer intervention, which also frees up human resources. In the near future, it is expected that they will be more 'intelligent' and able to interact with other devices.

In the Healthcare domain, their integration takes place in a different context. The human factor cannot be fully replaced and therefore even though their use is increasing, they cannot perform all the tasks that medical personnel can do. Furthermore, many of those Robotic devices are not fully autonomous as not all processes that they can be involved in can be entirely automated. However, they still find amble applications:

- Autonomous Robotics solutions are able to perform surgeries. Ref. [47] mentions the *Da Vinci* robot, which is already used in some routine surgeries with partial human intervention in it. Nevertheless, over the next years or decades, it is expected that the upcoming technologies will lead to the development of such autonomous or semi-autonomous robots. Surgical robots are also mentioned in Ref. [37], as they can be more flexible than the human hand and perform operations with very small cuts, and by Ref. [27], that highlights that teleoperation is now possible via robotics, which can be monitored remotely by the surgeon. In addition, catheter robots 'can intervene in a patient's blood vessels without the need of open surgery'.
- Apart from their surgical purpose, robotics in Healthcare can contribute to provision of medical care. As mentioned in Ref. [24], patient diagnosis is now possible with the use of robots in rural and small hospitals that can be controlled remotely. Some of them even have the ability to navigate autonomously. A well-known case is the wireless capsule endoscopy [27], which has the size of a pill and can transmit images of the patient's gastrointestinal tract.
- Other authors ([24, 32]) identify one of its main application in the field of hospital and laboratory management. Robots can be used to transport materials or food in hospitals, which can reduce the risk of accidents and involve the medical personnel in other tasks. This application is also demonstrated in Ref. [25], where the authors review a framework for the integration of lean manufacturing in healthcare and equipment transportation in a hospital. What is more, in the case of laboratories, they can perform some routine tasks such as processing samples and preparing DNA samples [24], or administering injections [27].
- Nowadays, robotics can also be used to support elderly people who live independently in activities such as walking and eating or assist in the treatment of patients with neurological disorders [24]. In this direction, robotics-based solutions can also be used for the communication of elderly people with their relatives or physicians [27].
- Similarly, two studies ([28, 32]) mention that robots are used to fight COVID-19, for example, to track and disinfect laboratories and patient rooms. A special category of them, known as drones, are utilised to reach areas heavily infected by COVID-19 to minimise human contact and thus the risk of further transmission [28].
- Finally, prosthetics constitute one more example of applications of robotics to this domain. Various prosthetics are supplied with minor semi-autonomous robotics parts that can operate with medium or minimal external intervention [27].

3.2.4 | Internet of Things

Internet of Things (IoT) is considered the main enabling technology of Industry 4.0. A detailed technical definition is given by Ref. [82], which defines it 'as global network and service infrastructure of variable density and connectivity with self-configuring capabilities based on standard and interoperable protocols and formats [which] consists of heterogeneous things that have identities, physical and virtual attributes, and are seamlessly and securely integrated into the Internet'. In contrast, Ref. [83] defines it 'as a world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these "smart objects" over the Internet, query their state and any information associated with them, taking into account security and privacy issues'.

IoT finds applications in numerous fields, including healthcare. Quite often, in such cases, a distinction is made and special instances of IoT emerge, called the Internet of Medical Things, the Internet of Health Things, the Internet of Nano Things and the Internet of mobile-health Things [27]. As Ref. [36] mentions, the linkage between IoT, smart devices and CPS will result in the delivery of a cheaper and more personalised healthcare.

The concept of IoT is closely related to Cloud Computing and Big Data. The intersection among these three concepts is known as the *Data of Things* and can be defined as 'a service of the large-scale data on massive IoT devices on Cloud Computing to accelerate the usability of IoT devices' [52]. Some of the main applications of IoT in the Healthcare domain, as mentioned in the papers examined, are:

- IoT enables activities such as monitoring of physical parameters, compliance with treatment, statistical data generation, chronic disease management and others [19, 27] via sensors and wearables. The latest fall into the category of Wireless Body Area Networks (WBAN) or Body Sensors Networks (BSN) which are capable of establishing a wireless communication link, monitoring human body functions and facilitating chronic disease treatments [27, 53, 54]. The IoT communication protocol of Low Power Wide Area Networks (LPWAN) finds numerous applications in healthcare too, such as patient monitoring and periodic updates and rehabilitation with infrequent updates [48].

- IoT sensors connected to wireless networks can be used to monitor the health condition of COVID-19 patients remotely [20], while wearables can measure physiological parameters such as the heart rate, blood pressure and body temperature [21, 32, 34, 48]. Smart IoT devices are the main data source for PHR [55]. Ref. [33] illustrates an IoT-based network which collects data from hospital patients and transfers it afterwards via other IoT devices. Other examples of such wearables include a pair of headphones for monitoring sleeping activity, a wearable that can detect sleep apnoea, a finger clip sensor to measure the pulse rate and haemoglobin [24], gyroscopes, accelerometers and glucose sensors [27]. Personalised healthcare services are offered by devices such as fall detectors, insulin pumps and implantable or ingestible sensors which collect, analyse and transmit data [27, 29].
- In the reviewed literature, a variety of relevant applications for patient monitoring and provision of healthcare services were identified. Ref. [56] proposes systems to track Activities of Daily Living and provide physicians with insights. Ref. [57] suggests an IT-enabled framework based for the enhancement of Traditional Chinese Medicine. Ref. [58] introduces a framework for AAL of elderly people, and Ref. [59] a design for the healthcare system of Saskatchewan, Canada, which focuses on four healthcare services. Ref. [60] puts forward an interactive healthcare system in which biosensors collect biomedical and emotional data from patients. Ref. [28] proposes a framework for COVID-19 analysis, where IoT and IoMT devices collect data from patients quarantined at home or at hospitals. A set of smart IoMT devices for informing and alerting diabetes patients is presented in Ref. [44]. Ref. [46] proposes a Deep Neural Network-driven IoT Healthcare 4.0 system for the analysis and classification of heart signals.
- Apart from patient monitoring, pervasive and preventive healthcare will be valuable in Healthcare 4.0 and transform the health services provided. In this direction, smart and unobtrusive sensors will be connected to a patient's body and his living environment to offer real-time data and prevent illnesses or diseases [37].
- The contribution of IoT in the operation of laboratories is also notable. Ref. [61] proposes a device based on IoT concepts, with the purpose to operate as a smart fully integrated lab, which can perform analytical/diagnostic procedures outside a conventional laboratorial facility.
- Sensors can be deployed for Early Warning Systems [20]. In the case of predictive maintenance, their use in systems and equipment can provide useful information about their health and thus enhance their maintenance or replacement [21]. The importance of predictive maintenance is also mentioned by Ref. [62], where a methodology based on data collected by IoT enabled devices to assist laboratory personnel in assessment of medical equipment performance is highlighted. In the lean manufacturing-based framework proposed in Ref. [25] for healthcare logistics performance, IoT is one of the key technologies.
- Regarding IoT and Cloud/Fog Computing fusion, in the work of Ref. [63], a model for optimal selection of Virtual Machines in Cloud-IoT health services applications is proposed, where stakeholders make requests for medical tasks using IoT devices. Likewise, Ref. [50] demonstrates that the first layer of Fog Computing architectures can be defined as the IoT devices layer. Based on their characteristics, they propose a platform for remote monitoring of elderly people. IoT is also one of the key enabling technologies for the design of *CloudDTH* platform of Ref. [51].

3.2.5 | Augmented Reality

Augmented Reality is one of the most promising technologies of Industry 4.0. Roughly speaking, according to Ref. [84] 'Augmented Reality is characterised by adding a computer-generated context information layer into the real world, which leads to enhanced reality'. Initially, it was mostly applied for military or flight simulations but recently its scope has expanded. It uses smart devices to combine physical and digital elements, so a digital effigy of an object can be developed and studied. Ref. [23] identifies Augmented Reality as follows: (1) blend of genuine world and virtual items, (2) synchronisation of genuine and virtual items, (3) very intuitive, keep running in 3D progressively. It differs from Virtual Reality however in the sense that the latter does not augment the reality, and thus it focuses more on creating a 'virtual' and not 'real' world:

- Even though it has yet to be fully applied in this domain, certain use cases were identified. Ref. [64] suggests that digital transformation (where Augmented Reality is one of the key enabling technologies) can soon be applied to premature infant monitoring and brain tumour monitoring. Moreover, it is anticipated that surgical operations performed through smart glasses or digital contact lenses will also benefit [36]. Currently, it has a supportive role, like in the system developed by Yokohama City University, which superimposes images of the vascular system. One more application is mentioned by Ref. [23], which believes that Augmented Reality can be used for the education of medical students (with respect to human anatomy).
- Another concept emerging from Augmented Reality is the Digital Twin. It can be described as a virtual representation of physical objects, processes, systems or even human environment which monitors them in real-time, lying in the intersection of Augmented and Virtual Reality [32, 64]. Currently, its main applications can be found in product

design, manufacturing and equipment monitoring. However, it can also be integrated into the Healthcare domain, mainly for hospital management and patient healthcare services [51]. In this sense, a framework for elderly monitoring enabled by Digital Twin is proposed in Ref. [51]. In this framework, a Digital Twin of the patient's body is created, enabling physicians and therapists to provide more accurate treatment and be better prepared for a potential surgery.

3.2.6 | Simulation

Simulation in Industry 4.0 is used to simulate a virtual environment where a process can be run and evaluated. It is not a new concept, since such techniques have been known for many decades. It is performed using real-time data, so businesses can analyse the performance of a system before implementing it in reality. The main benefits include cost and risk reductions. It is mostly used in manufacturing, where the interaction of the system with its environment is simulated. It is closely related to other Industry 4.0 pillars and technologies such as Augmented Reality, Systems Integration and IoT. The latter has led to the development of the Internet of Simulation (IoS), which enables the interconnection of simulations [26].

In the Healthcare domain, simulation is used not only for the above purposes but also to evaluate the accuracy and performance of various models, frameworks, tools and techniques, especially when access to the required resources can be difficult or high-priced. By exploring and comparing different approaches and their feasibility, stakeholders will be able to take better decisions before implementing them [21]. Major applications include medical surgery training, medical equipment design, resource allocation optimisation and business process, clinical trials etc. [51]:

- A case of such an application of simulation is demonstrated in Ref. [25]. The proposed framework is tested in a French hospital, where the flow from medicine reception to their storage is simulated, as well as the overall hospital operation after using Automated Intelligent Vehicles for dispatching food and medicine to evaluate the framework's success. In Ref. [48], this method is used to model the operation of a Saudi Arabian healthcare system. Ref. [65] proposes a model for predicting and mitigating a COVID-19 outbreak. In this paper, the authors perform a simulation using real-time data from Cape Town. Likewise, simulation is also used in Ref. [46] to estimate the performance of a Deep Neural Network-driven Iot Healthcare 4.0 solution. Furthermore, Ref. [68] develops a healthcare Chatbot (which in fact is an interactive simulation system), while in the proposed framework of Ref. [51], simulation using the concept of Digital Twin Healthcare is a key enabling technology as it can create various testing simulation scenarios.
- Simulations have also been used to analyse the decision-making process of health centres and hospital personnel [66] or to reformulate the financial aspect of a healthcare Project Financing investment for evaluation of a proposed business plan [67].

3.2.7 | Systems integration

CPSs are considered as the backbone of Industry 4.0. Some authors even claim that Industry 4.0 is mainly enabled by CPS [27]. They are defined as 'engineered systems that are built from, and depend on, the seamless integration of computational algorithms and physical components' [31] or 'transformative technologies for managing interconnected systems between its physical assets and computational capabilities' [85] and are characterised by the ability to perform computations and interact with the physical world [86]. Thus, they are a key feature for systems integration, both horizontal and vertical. Horizontal integration refers to the inter-company integration that ensures close partnerships and establishment of networks between companies, while vertical refers to the integration of the different systems (either human or machines) that exist in the organisation itself [87]:

- Medical CPS are used to utilise interaction between software/signals (cyber) and equipment/patients (physical) to provide patient monitoring and treatment services and for applications related to resource management and healthcare systems management. Deep brain simulators, cardiac pacemakers and bio-instruments are three examples mentioned by Ref. [21]. In a similar sense, Ref. [36] argues that microdevices, digestible sensors, diagnostic tools and augmented reality-based tools, amongst others, can all be classified as examples of medical CPS. IoT-driven sensors that have the characteristics of CPS can increase the quality of services provided to patients. With this objective, Ref. [46] proposes such a CPS for measuring heart signals.
- According to Ref. [33], healthcare CPS are the cornerstone of medical services such as measuring the glucose levels or body motion of a patient. The findings of this research suggest that CPS equipment can also be used to offer treatment to tuberculosis patients.
- CPS are also mentioned in Ref. [69], where the authors provide a case study of a healthcare industry that has a strong CPS consisting of IoT devices to evaluate their framework for privacy protection in those organisations.
- Furthermore, CPS can be used to recreate the Digital Twins required to perform activities like fault detection, fault analysis and cost benefit analysis, which are necessary for the digital transformation of a healthcare organisation in the context of Industry 4.0 [64].

3.2.8 | Cybersecurity

With the emergence and continuous development of Industry 4.0, billions of devices are interconnected in smaller or bigger networks and exchange information. This exponential growth has led to numerous cyberattacks. In this context, Cybersecurity has risen to become an important component of Industry 4.0. Different definitions or descriptions of it have been proposed, but a quite inclusive one is given as 'the collection and organisation of resources, processes and structures used to protect cyberspace and cyberspace-enabled systems from occurrences that misalign de jure from de facto property rights' [88].

Especially in the Healthcare domain where data is very sensitive and more users need access to the systems, it is quite essential. According to Becker's Hospital Review, data breaches can cost the healthcare industry more than $5 billion every year [89]. Different techniques or tools have been developed to mitigate the risk of cyberattacks in healthcare systems, since those can have grave repercussions such as unauthorized access to sensitive data (i.e. patients' EHRs).

- Ref. [31] identifies the importance of Cybersecurity for healthcare Big Data Analytics in Cloudlets. Some of the methods that can ensure Cybersecurity are the training of users, antimalware and antispyware software, cryptographic techniques, disaster recovery etc. In this sense, it elaborates how they can be applied to the Cloudlets for this purpose.
- International standards, protocols and regulations can be followed to enhance Cybersecurity for digital health in the era of Industry 4.0. Two approaches identified in the literature are the Role-Based Access Control (RBAC) framework, which used to be the most used control framework till recently, and the GDPR policy that the EU launched in 2016 for compliance with security and privacy regulation [72]. Similar standards (HIPPA and DICOM) are used in the AAL system of Ref. [58], in Ref. [68] for a chatbot-based healthcare service (AES) and in Ref. [55] (IEEE 101073) for data security, encryption and confidentiality.
- One of the most important Cybersecurity technologies is Blockchain. It is based on the concept of cryptocurrency Bitcoin and can be described as 'a decentralised database containing sequential, cryptographically linked blocks of digitally signed asset transactions, governed by a consensus model' [90]. In this context, Blockchain can be used to ensure secure and non-modifiable storing of data, transparent transactions and patient privacy protection, thus leading to fair collaborations between healthcare organisations [21].
  Ref. [71] deals with Blockchain in the Healthcare domain. It reviews an application called Healthchain, which was developed using the principles of Blockchain for authorised user access and secure data transactions. Another application of Blockchain is mentioned by Ref. [28], to integrate and standardise the Healthcare system of the proposed COVID-19 analysis framework. Likewise, Ref. [66] illustrates a lifecare service platform. The role of Blockchain here is to establish a safe network for standardized encryption. Ref. [54] discusses the potential of using it as a platform for reliability and security of IoT devices in Healthcare. Finally, its importance as a method for securing personalised health data is also briefly touched by Ref. [26].
- Cybersecurity can also be enhanced by the use of other Industry 4.0 (or even Industry 3.0) technologies. As per Refs. [20, 43], AI algorithms are developed to detect cyberattacks. Moreover, the authors of three studies ([27, 43, 50]) argue that Fog Computing and Edge Computing (as an alternative to Cloud Computing) can contribute by adopting a distributed instead of a federal system. Ref. [43] mentions additional techniques as well, such as securing the sensors used to collect the data, utilising SDN and NFV and including Security as a Service solutions in the health IoT devices.
- Other applications of Cybersecurity in Healthcare can be found in the proposed model of Ref. [34] for secure health data collection from smart sensors, the one suggested by Ref. [69] for privacy preservation in 5G-enabled IoT devices and in the predictive maintenance model for healthcare services by Ref. [73].

3.2.9 | Big Data & Data Analytics

The interconnection of multiple devices leads to generation of big amounts of data from different sources and in different formats, often semi-structured or even unstructured. It is estimated that currently a person generates approximately 1.7 MB of data/second [91]. In the era of Industry 4.0, the concept of *Big Data* has emerged to describe this data. Many definitions have been proposed to describe Big Data, but most of them agree on five common characteristics, known as the five V's: *Velocity* (refers to the increasing speed the data is generated and processed), *Variety* (refers to the different formats and structures), *Volume* (refers to the size), *Veracity* (refers to the quality and accuracy) and *Value* (refers to the value they generate) [92].

As per Ref. [31], Big Data Analytics has five stages split into two subprocesses: (1) modelling and analysis, (2) interpretation, (3) acquisition and recording, (4) extraction, cleaning and annotation, (5) integration, aggregation and interpretation. Below, we present our findings regarding the applications based on Big Data Analytics.

- Main relevant applications based on Big Data include but are not limited to the following sub-areas of Healthcare: biomedical image processing [32] and image classification [22], conventional or mobile diagnosis [24, 37, 43], monitoring physiological and pathological signals [27], AAL [27], matching treatments with outcomes [37], modelling and identification of patterns of diseases or health issues [21], personalised health services [27]. Other contributions can be found in evidence-based medicine, genomic analysis and fraud detection [27], real-time alert generation and rehabilitative systems [43] and profiling of patients [52, 93].
- Moreover, we found relevant applications concerning the design of tools, methods and techniques. In the work of Ref. [31], WBANs collect patient data forwarded to Cloudlets where preliminary Big Data Analytics algorithms are applied to it. Ref. [56] collected and analysed accelerometry data

through smartphones to build a human activity recognition system and Ref. [44] from smart sensors to develop a system for monitoring of diabetes patients. Big Data is one of the main pillars of the elderly healthcare services framework of Ref. [51] and for the platform for remote monitoring of elderly people through near real time data processing of Ref. [50]. Using data collected from sensors and analysed afterwards using Hadoop MapReduce techniques [58] suggests a framework for AAL. In the field of personalised healthcare services, its contribution can be found in the model for health risk assessment of patients with chronic diseases of Ref. [55].

- Data Analytics is also a key enabling technology for the healthcare chatbot framework of Ref. [68], as well as for the personalised telerehabilitation system of Ref. [42]. Next, Ref. [61] proposes a smartphone-based application that acts as a mobile laboratory which can perform Data Analytics and be used for diagnosis and monitoring of various diseases.
- Big Data and Data Analytics can be the driver for Business Analytics and Business Intelligence operations. Production optimisation and predictive maintenance [32] and identification of the most clinically and cost-effective treatment [35] are some successful examples, as well as the analysis and comparison of different drugs [24]. In addition, the proposed framework of Ref. [59] aims to improve decision making, actionable insights and reporting services in a smart Healthcare system.
- Furthermore, other contributions can be found in the financial and organisational aspect of healthcare organisations. Ref. [67] explores how Big Data and Data Analytics can be used to evaluate the quality and sustainability of Project Finance (FP) investments. Ref. [73] proposes a model for predictive maintenance for biomedical devices using Big Data. Predictive maintenance is also the purpose of the methodology elaborated by Ref. [62], where Big Data is used for the development of a predictive algorithm for equipment performance assessment.
- Another category of Big Data-based applications is predictive and prescriptive analytics. Ref. [65] used Big Data to develop a model for mitigating the outbreak of COVID-19 and Ref. [28] to produce statistics about COVID-19 outbreaks and their spread. Ref. [45] proposes a system that collects Big Data using wearables and applies AI techniques to predict the potential risk for a patient's health and Ref. [76] refers to a few study cases such as the early cancer detection or mortality risk for patients with acute leukaemia. A further predictive model has been proposed by Ref. [77] for breast cancer detection. Ref. [60] develops a data acquisition scheme and a medical system which analyzes medical data and predicts the disease risk of a patient. In addition, Ref. [33] discusses how certain Big Data Analytics methods and techniques can enable the early detection and prevention of infectious diseases, such as tuberculosis. Finally, predictive analytics is the topic of discussion in Ref. [53], where the authors identify how it can be applied to predict emergency cases of elderly people.

3.3 | Benefits and challenges for the healthcare domain

In this section, the main benefits and challenges as identified in the reviewed literature will be highlighted.

3.3.1 | Benefits

Our set of selected papers collectively reported 10 benefits (see Table 4). The most frequently mentioned benefits are financial in nature, plus patient's benefits such as monitoring and diagnosis (each mentioned in 14 papers). In what follows, we present each type of benefits.

Automation

Various processes can be automated by facilitating the use of equipment by CPS [21]. This includes tasks that the medical personnel perform and their planning, setting up repetitive processes better. Hence, this will lead to improved efficiency and faster execution.

Robotics and IoT devices can also automate much of the manufacturing or supply chain processes, or even some of the routine tasks performed by healthcare professionals. Two great examples of such tasks in Healthcare 4.0 are the medicine and medical equipment production [37] and the delivery of equipment in hospitals [24, 25]. Another process falling in this category is the sample processing in laboratories [24].

The objective is to create autonomous systems able to implement many activities without human aid, leading to the concept of Smart Factories [26].

Allocation of resources

By analysing historic or near real-time data, healthcare institutions can optimise the allocation of their resources. Therefore, not only the institute will benefit from a better internal organisation but also the patients who will enjoy more enhanced services [21]. Indeed, the use of methods for remote monitoring of patients (mainly based on IoT, Cloud Computing and Big Data) will exploit the time of therapists who will be able to assist more patients remotely or prioritise those who are more seriously ill [29, 42].

This can also be achieved by combining the above technologies to develop frameworks or models for better data management in hospitals or other healthcare organisations, which can enhance task scheduling and optimise resources [63].

Business' organisation and decision-making

In another aspect, Big Data and Business Analytics can support business operations in many ways. It can be a driver for healthcare organisations to understand the industry better, as well as the characteristics of the market, improve margins, optimise revenue streams and provide market feedback of the revenues [35, 67]. The use of Data Analytics and the interconnectivity of devices can decrease unnecessary visits to hospitals and the pressure to the healthcare system they cause,

TABLE 4 Benefits of industry 4.0 for healthcare

Nr.	Benefit	References
1	Automation	[24–26, 37]
2	Resources allocation	[21, 29, 42, 63, 94]
3	Business' organisation and decision-making	[28, 35, 67, 76]
4	Business' financial aspects	[21, 27, 30, 32, 43, 48–50, 60, 62, 67, 69, 72]
5	Patients' and medical personnel risk	[21, 28, 29, 32, 51, 62, 73, 76]
6	Scientific knowledge and expertise	[23, 32, 47]
7	Patients' diagnosis, monitoring and treatment	[19, 21, 24, 37, 42, 44, 45, 47, 49, 56, 58, 59, 68, 95]
8	Patients' satisfaction	[36, 42, 44, 57, 59, 71]
9	Disease prevention	[21, 27, 33, 44, 46, 49, 52, 53, 65, 76, 77]
10	Data storage and exchange	[26, 43, 50, 54, 59, 71, 96]

while also limiting the negative impact that no-shows or last-minute cancellations have [28, 76].

Business' financial aspects

Next, another potential opportunity arises for the financial operation of an organisation or healthcare system. Data collected by IoT devices can be analysed and used not only to monitor the current state of machines and equipment, but also to predict their future state. Thus, downtime costs can be reduced, which in the Healthcare sector very often can be quite high, while also bringing upon monetary profits [32, 62].

Moreover, by analysing complete patients' health records or other Big Data generated within hospitals and clinics and using AI-enabled models, Healthcare providers can reduce the costs of excessive or unnecessary tests and treatment variations [21, 60]. Other costs that can be reduced are the energy and labour costs by using IoT devices or Fog Computing solutions, as per [30, 67, 69]

The use of Data Analytics can contribute to fraud detection, which is quite often the case for excessive healthcare services reimbursements claims [27].

Cloud, Edge and Fog Computing can also have a positive impact on the operational costs of every healthcare business or organisation since they will be able to access powerful computational and storage resources on reduced latency without paying excessive amounts of money for ownership or maintenance [27, 41, 43, 48, 50, 72]. Additive Manufacturing can reduce production and warehousing costs, as well as make the organisation less dependent on suppliers [32].

Patients' and medical personnel risk

The use of certain technologies can also reduce various risks related to involvement of patients or medical personnel to healthcare services. In this sense, the use of robotics, for instance, can mitigate the risk of exposure of physicians/nurses to infectious diseases such as COVID-19 or reduce accidents in hospitals [28, 32].

Furthermore, it is possible to keep track of the health risk of patients constantly, especially in the case of those with chronic diseases, by collecting and processing real-time data [55, 66]. Concepts like Cloud Computing, Big Data Analytics and Simulation also provide the opportunity to test medicines and treatments at virtual environments and thus reduce their risks and side effects for patients [21, 51, 76].

Big Data-based predictive maintenance increases the quality of life for patients and healthcare staff, since it can enhance the safety and quality of equipment used at hospitals or home care and reduce the exposure to radiation [62, 73].

Scientific knowledge and expertise

Technologies such as Additive Manufacturing, Simulation and Augmented Reality have made it possible to simulate medical environments and recreate advanced human components for the training of medical students and doctors or testing of new methods and tools [23, 32]. This can make professionals more expert in human anatomy and physiology and therefore able to offer better services. In addition, Cloud Computing can be used to create online databases and communities for the exchange of medical data for further research or sharing of techniques [47].

Patients' diagnosis, monitoring and treatment

The advantages that Industry 4.0 has brought to patients and their treatment are already apparent. Nowadays, it is easier for physicians to monitor their patients remotely and more efficiently, which can also further reduce costs and times for both parties. IoT and Big Data-based systems can detect and monitor daily activities, support telemedicine services or remote rehabilitation processes, offer medical care services to rural areas or hospitals, monitor the intake of medicines by patients, offer AAL services and monitor measures such as fever and heart rate [19, 24, 27, 42, 44, 45, 56, 58, 59, 95]. Cloud-based solutions also allow Healthcare professionals to access their patients' records remotely, which reduces potential delays [21].

In the field of diagnosis, scientists have already taken advantage of Big Data, Cloud Computing and IoT potential to develop new methods to diagnose various accidents, abnormalities, illnesses or diseases and suggest the most efficient treatments, often within a few minutes [24, 68].

Similarly, the use of IoT devices is instrumental to emergency medical teams about the condition of a patient so they can be equipped with prior knowledge [59].

Essential activities such as surgeries will be undertaken more efficiently by the use of robotics, which can perform movements that humans are not able to or smaller incisions [37, 47]. 3D printing can also be used to develop anatomical models of the patient's organs, so doctors can examine them before conducting the operation [24].

Patients' satisfaction

One of the main objectives of Industry 4.0 integration is to make healthcare services more patient-centric. In the context of Health 4.0, the treatment that patients receive will be more personalised as they will be directly or indirectly involved in the process [36, 42]. Thus, their satisfaction will increase as they will feel that the services are made by themselves for themselves.

Next, by the home care they receive after leaving the hospital, not only their quality of life will improve, but they will also feel that their health is closely monitored and thus build a strong relationship with their healthcare provider [59].

In addition, they can also benefit financially. Remote monitoring or treatment systems can reduce the hospitalisation costs and insurance fees as the patients will be admitted to hospitals less often and stay for shorter periods [44, 57].

In a sense, patients' satisfaction is also enhanced by the use of Blockchain technology, which provides the sense of security that they need for their personal, sensitive data [71].

Disease prevention

Apart from personalised healthcare, another key concept of Health 4.0 is preventive healthcare. Descriptive research will transform into predictive and prescriptive with the aim to prevent as soon as possible [27]. The treatment will transit from cure to prevention [27].

Therefore, one of the most significant benefits and object of research in the era of Industry 4.0 is the prevention of diseases. Nowadays, it is possible to collect data (usually using IoT devices) and apply advanced Big Data Analytics techniques on it to develop models which can find patterns to predict the outbreak of illnesses or diseases or create databases that provide better understanding of common diseases [21]. Notable cases include COVID 19 [65], various types of cancer [76, 77], tuberculosis [33], diabetes [44], and heart diseases [52].

Moreover, thanks to Industry 4.0, various systems have been developed which can predict faster and more accurate emergency cases, leading to their prevention [46, 53].

Data storage & exchange

Security has always been one of the greatest challenges in Healthcare. Fortunately, Industry 4.0 can bring upon many opportunities for tackling this issue, if applied successfully. Technologies such as Blockchain, Cloud Computing, Fog and Edge Computing ensure the security, authentication and privacy required for accessing and handling the sensitive medical data. In addition, they enable confidentiality and privacy between all parties involved and transparency and integrity of transactions [26, 43, 50, 54, 59, 71].

Methods based on Cloud Computing and Big Data are also developed to assess the credibility and sensitivity of patient medical data and thus avoid its leakage [96].

3.3.2 | Challenges

Our review found nine challenges that the authors of the reviewed papers in our corpus indicate. These are presented in Table 5. It shows that the most frequently mentioned challenge is data fragmentation, heterogeneity, complexity and uncertainty. This challenge is indicated in 16 papers. The second most mentioned challenge refers to privacy and security (stated in 14 papers). Below, we report our findings with regard to the challenges in more detail.

Data privacy and security

The majority of medical data is either sensitive or with limited access. Organisations must follow or create certain approaches to ensure the rights and privacy of individuals, while complying with rules and regulations that prevent the misuse of this data [21, 30, 99]. As Ref. [37] mentions, the success of Healthcare 4.0 policies are highly dependable on the privacy of users and the legal framework around their data. Likewise, Ref. [24] states that the border between feasible and acceptable is not always clear. Even though other issues exist too, privacy and security are the main ones concerning Big Data [97].

The main problem is not the information leakage itself, but who is affected by this. Hackers can steal sensitive patients' data, such as bank account or social security numbers and health records, endangering their privacy and safety, as well as raising questions about the trustworthiness of hospitals [96].

The concern about data privacy and security can be quite strong in the Cloud or Fog Computing, since the owner or user of this data does not have its full ownership, but it is outsourcing it and is dependent on the services provider [27, 34, 98].

Cyberattacks are very common in the Healthcare domain. DOS, botnets or phishing attacks are connected with Big Data such as users' credentials or medical information [20]. Cyberattacks usually target either IoT devices that acquire this data directly or the Cloud that it is later forwarded and/or stored into [32]. As data centres increase, distributed denial-of-service (DDOS) attacks from IoT devices should be inhibited [26].

Even though the presence of strict regulations and methods that ensure security and privacy is essential, it can cause other issues. In fact, they set many limitations to the medical data that is eventually available for scientific research [33]. What is more, confidentiality might be enforced, but at the expense of limiting the data values and types that can be analysed [26].

Data fragmentation, heterogeneity, complexity and uncertainty

Another major concern related to Medical Big Data derives from its characteristics. The Healthcare domain is one of the

TABLE 5 Challenges for successful integration of Industry 4.0 for Healthcare

Nr.	Challenge	References
1	Data privacy and security	[20, 21, 24, 26, 27, 30, 32–34, 37, 96–99]
2	Data fragmentation, heterogeneity, complexity and uncertainty	[21, 26, 27, 29, 32, 47, 49, 55, 60, 65, 67, 68, 75, 93, 98, 100]
3	Legal framework and legislative initiatives	[36, 43, 47, 49, 59]
4	Closer collaboration	[36, 37, 47, 57]
5	Knowledge and skills gap	[20, 23, 30, 31, 37, 64, 73, 100]
6	Users' acceptance and adaptation	[29, 36, 37, 50, 58]
7	IoT known issues	[27, 43, 48, 49, 52, 54, 59, 63, 69, 101]
8	Implementation costs	[29, 30, 73]
9	Standardisation	[21, 30, 32, 41, 100]

richest in terms of data. However, as the amount of data increases, so does its complexity [68].

It is common to come across fragmented and heterogeneous data from different sources and in various formats [27, 55, 67]. Currently, most healthcare systems rely on data silos sparsely connected to each other, setting barriers to their communication [29]. This makes data integration and analysis more hard and demanding [21, 32, 65]. Moreover, as pointed out by Ref. [27], Big Data techniques can bring upon the challenge of opacity and a lack of transparency when working with unparalleled and unknown-before data. To overcome those issues, it is essential to apply different data fusion techniques to reduce ambiguity and combine and interpret data coming from multiple sources [75].

The variety and volume of Big Data is another point of discussion. Processing significant amounts of data coming from several sources requires advanced IT infrastructure for storage and analysis and the knowledge to convert it to structured [27]. Currently, approximately 80% of medical data is unstructured [60], with notable examples including physicians' notes and medical multimedia files [100]. Scalability derives directly from the concept of volume and refers to the capability of organisations to store those volumes of Big Data as they increase. Their size can exceed the storage limit and capability of the organisation [26, 98]. In addition, variety and volume might be the cause of what is known as the *curse of dimensionality*: it will be hard to decide which data is worthy and which should be discarded [26]. Dealing with incomplete or biased data might affect the whole analytics process [93].

As per Ref. [47], the complexity and the ever increasing quantity of data are one of the main reasons that Healthcare is one of the sectors with the slower integration of Big Data Analytics.

Legal framework and legislative initiatives

Numerous questions have also been raised about the legal framework and how it is applied, especially when it comes to ethics or data ownership and exchange.

Refs. [36, 47, 59] indicate that it can be unclear to determine if the patient or the healthcare provider is the real owner of medical data and that this ownership is hard to be defined by regulatory policies. Likewise, ethical concerns are also expressed. Most of them are related to whether or not the consent of the data owner is required and the difficulty of providing access rights in the case of a lack of necessary resources [27, 59].

Nevertheless, there are differences in policies and regulations not only between different nations, but quite often, also between different states of the same nation [27].

Law and regulatory policies should also be applied for the deployment of IoT devices. These will ensure the safety and privacy of users and their safety since they can be a source of accidents or other dangers (i.e. radiation) [43].

Closer collaboration

Integration of Industry 4.0 will be harder without the collaboration of all parties. A major concern is the limited data sharing between organisations. They rarely exchange data, as they are cautious about who, how and why they can access it [47]. In addition, frequently, those data transactions take place through more manual processes such as phone calls and e-mail messages.

Two studies ([37, 57]), among those in our review, also suggest a closer inter-disciplinary collaboration. In the era of Industry 4.0, the role of scientists coming from other fields, especially Computer Science, will increase. This requires joint efforts between them and the medical professionals to produce valuable services out of the Healthcare system needs and requirements. This collaboration is required not only at a technical level but also at others, such as the political and the legal. There is a whole context of stakeholders involved, from governments and academic institutions to industries and therapists.

Moreover, as Healthcare now will be more patient-centric, the relationship between therapists and their patients must be strengthened as they are dependent on each other [36].

Knowledge and skills gap

Eight papers in our selected set acknowledge that Industry 4.0 is a relatively new concept. Many nations or organisations are still not capable of realizing the potential and benefits of Healthcare 4.0. Moreover, businesses do not possess the required education and skills, both in terms of quality and quantity [30]. In order to integrate Industry 4.0 in their sector and improve their skill set, Healthcare organisations and professionals need to be educated and trained sufficiently to understand and implement it [23, 64]. This should take place not only within businesses but also, at an earlier phase, in academic institutions [37].

Many Big Data and IoT-enabled applications require expertise in Data Science and IT due to their complexity, which the majority of healthcare professionals do not possess [73].

Furthermore, a great challenge for scientists is to properly understand the data they have and select the right tools and methods for their analysis. This requires hours of training and experience [31].

As Ref. [100] highlights, Big Data integration is a process that cannot be fully automated. Since end users like doctors and nurses have limited IT skills, it would be hard to help them access heterogeneous data.

Users' acceptance and adaptability

As Healthcare services will be more digitised and new technologies will become part of the patients' and therapists' life, this transition will be rapid and significant. All stakeholders need to adjust to new environments, which is a demanding process. Thus, it is quite likely that their productivity will initially decrease.

This issue becomes more evident with the use of robotics. There is a redundancy towards their adoption based on the common belief that they cannot fully replace humans, especially in healthcare where critical thinking is important [37].

Big Data and AI algorithms are black boxes. Most practitioners can understand their results but not the process that led to them. Consequently, there is a lack of will to accept a method that they are not able to comprehend and explain to their patients [29].

Likewise, some applications might not be accepted by patients, especially the elderly, who feel more aware of traditional methods where the use of IT systems is limited or rely on their strong bonds with their physician [50, 58]. What is more, as argued in Ref. [36], there might be conflicts between what a patient describes as his symptoms and what the Industry 4.0 technologies perceive.

IoT known issues

There has been a lot of speculation about IoT devices. Their potential is great, but numerous relevant issues arise.

Such an issue is mentioned by Ref. [63], which underlines that processing of Big Data in Cloud environments collected from IoT devices requires many resources and great execution time. This can have serious effects since Healthcare providers wish to collect, store and process data in the shortest possible time.

Moreover, Ref. [27] presents four principal challenges regarding the use of IoT devices in Healthcare. Those are the energy optimisation, the scalability, the availability and the security. Energy optimisation is based on three pillars (energy efficiency, demand response and fuel switching) and is essential because it can cause energy deficiency [69]. According to Refs. [43, 52, 101], other potential issues that surround IoHT systems are the low latency and power operation, privacy and security, their ability to operate at (near) real-time, reliability, mobility and the need for regular updates.

Two studies ([27, 59]) examine an additional perspective, the heterogeneity and interoperability of IoT devices. The design and development of healthcare services requires the use of multiple items, such as wearables and sensors. However, due to the limited ICT skills and the complexity of the healthcare framework those devices are often quite heterogeneous, which also leads to the generation of very diverse data.

There are numerous threats to Iot which affect availability and privacy. Ref. [54] classifies them into five broad categories, namely generalized threats, threats to the physical/perception layer, threats to the MAC/adaptation/network layer, threats to the application layer and threats to the semantics layer.

To overcome those issues, solutions using middleware layers or Cloud Computing services have been suggested [41, 59]. However, they should take into account the fact that implementation of Cloud Computing has its own challenges as well (reliability, latency, bandwidth, security & privacy etc.) [48].

Implementation costs

Three papers in our corpus acknowledge that even though Industry 4.0 can decrease the operational costs in the long term, the initial costs can be quite high. This is a deterrent factor for many organisations, which may not be willing to invest in the purchase of the required technologies and equipment [30].

Besides, as the work of [72] shows, there is uncertainty amongst healthcare providers not only about the high initial costs but also about the Return on Investment. Thus, the purchase and installation of such infrastructure requires a detailed cost-benefit analysis to maximise the potential profits [73].

Implementation costs are not only related to equipment but also to human resources. New roles will emerge and organisations will need to hire additional personnel whose expertise lies in the Healthcare or IT sector, or both. Roles such as biomedical engineers and developers will be essential for the successful integration of Industry 4.0 technologies [29].

Standardisation

Another known challenge is the lack of standards. This is evident not only in the case of IoT devices and their interconnectivity [30, 32, 41], but also in the data representation models and interfaces that different applications use [21]. Even though some efforts towards this direction have already been made—for example, one of the most important advances in the IoT has been the development, standardisation, and widespread use of the MQTT protocol, there are still standardisation-related issues yet to be fully addressed.

In fact, it has been noticed that there is still a gap in data standards or overlapping between them, which makes the use of universal ones harder [100].

4 | DISCUSSION

4.1 | Descriptive statistics

In this section, we present some notable characteristics of the corpus of reviewed literature and answer a few explanatory questions to shed more light into the extracted insights. The full details of the reviewed papers can be found in Tables C1–C4.

How is the literature distributed over the timeframe examined?—As shown in Figure 3, the majority of the papers were published in the years 2019 and 2020. The rise in the number of publications from 2017 to 2018 and from 2018 to 2019 is remarkable, with the increase rate exceeding 100% in both cases. This observation suggests that the interest in this topic has been increasing significantly, and it seems realistic to expect it to attract many researchers over the next few years. We also notice that the number of papers published in 2019 and 2020 is nearly the same. We think that the lack of an increase in the volume of the 2020 published papers versus those in 2019, could possibly be traceable to the COVID-19 pandemic, which affected many industries and research organisations during that year.

Which are the most dominant Industry 4.0 components and technologies identified in the corpus?—Our findings reveal that Big Data & Data Analytics and the Internet of Things are the most common Industry 4.0 components that the authors dealt with in their works, either exclusively or amongst other topics. This probably comes as no surprise, since they are two of the major enabling technologies (as defined in the majority of papers that provided a definition or description of Industry 4.0, see Table 1). It is also worth mentioning the great frequency of references to Artificial Intelligence. Even though it is not considered amongst the nine pillars of Industry 4.0, it finds applications in many of those pillars, particularly in Big Data & Data Analytics. On the other hand, components such as Edge Computing and Additive Manufacturing were rarely mentioned (less than 10%). A summary of those results is shown in Figure 4.

4.2 | Answers to research questions

- **Answers to Research Question 1**: Our findings suggest that there is no full consensus in the definition of Industry 4.0. Some points of view examine the technologies and components that comprise Industry 4.0 or its structure and others-the purpose it serves or the innovations it is expected to bring in the industrial sector. However, amongst the descriptions that rely on the components of Industry 4.0, most of them agree on the following enabling technologies: Internet of Things, Big Data, CPS and Cloud Computing as the key enabling technologies.

Similarly, a variety of approaches to the concept of Healthcare 4.0 were identified. The majority of them, however, were abstract descriptions. Unlike Industry 4.0, in the case of Healthcare 4.0, the authors focus less on the key enabling technologies and more on the way it contributes to Healthcare. Indeed, our selected papers refer to Healthcare 4.0 as a framework where Healthcare services are more patient-centric and personalised to the needs and requirements of Healthcare providers and receivers.

This makes us think that Healthcare 4.0 is in fact a beneficiary of the technology developments happening within Industry 4.0 and not so much a creator of technology in itself. For healthcare practitioners and for IT consultants working in the healthcare sector, the fact that there is a framework for designing, experimenting with and introducing personalised services means that they could much more easily now translate the knowledge of their own healthcare ecosystem into working solutions for patient service delivery. As the technology choices (provided by Industry 4.0 components) are available, the IT consultants in healthcare could prioritise alternative solutions based on the balance between the known benefits and respective challenges. To researchers, the presence of a framework has a theoretical implication. That the framework has been traceable to various application contexts within the sub-areas of the Healthcare domain, indicates realism and helps build a body of empirical evidence hinting to possible generalisability across application scenarios [102]. More real-world evaluations would, of course, be very welcome to understand those parts of the framework that are common across healthcare sub-areas and those that are context-specific.

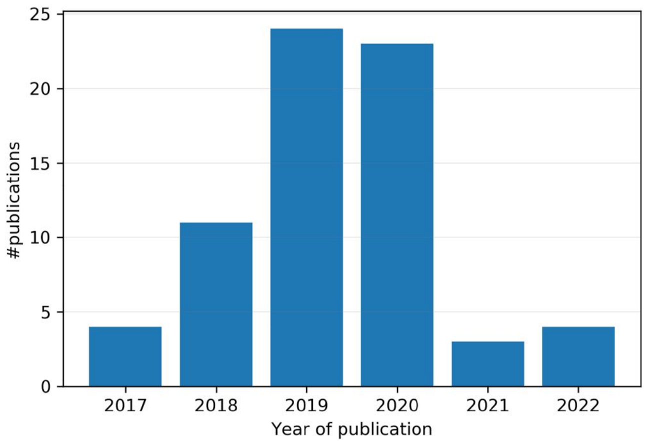

FIGURE 3 Chronological distribution of corpus

- **Answers to Research Question 2**: An immense range of Industry 4.0 applications to the Healthcare domain were reviewed or proposed in the corpus, which are summarised in Table 6. Most of them are based on the IoT, Big Data & Data Analytics and Cloud Computing. IoT enables the collection of medical or other information. Big Data & Data Analytics are essential to convert unstructured information into valuable insights and Cloud Computing is the main technology used for safe and efficient data transmission, storage or even analysis. Amongst others, they vary from applications used for patients' diagnosis and monitoring, to hospital management and operation and equipment design.

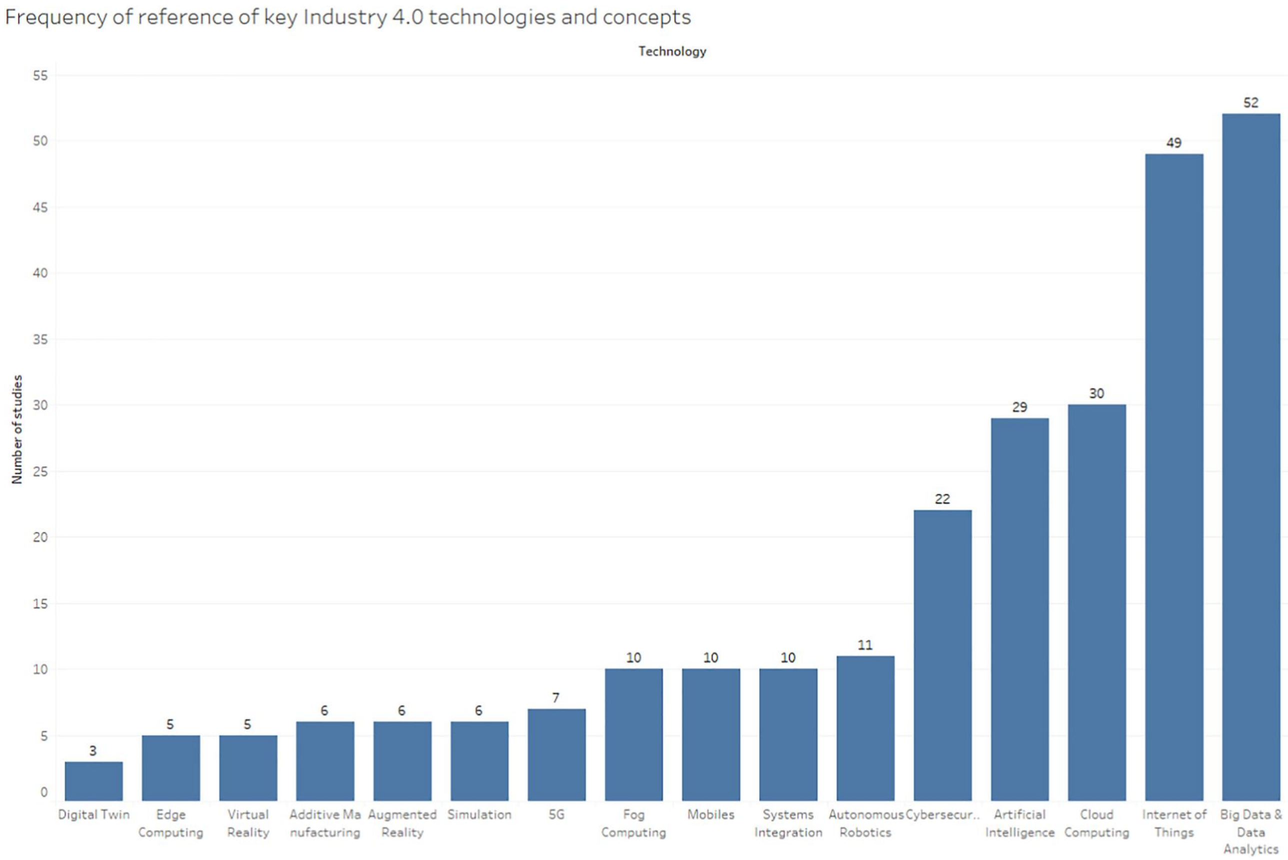

FIGURE 4 Frequency of references to Industry 4.0 components

The presence of working technology in real-world contexts is a hint that the field of Healthcare 4.0 is beginning to mature from the perspective of technical infrastructure development. For healthcare practitioners and consultants, this means that they could now focus much more on creating new processes for healthcare service delivery based on the various technology configurations, with improved accessibility and stronger attention to health equity. As Ref. [103] indicates, we might well expect the digital divide to further diminish due to the increased use of patient-centric information technologies. To healthcare systems engineering researchers, the presence of technology infrastructure means the availability of a solid backbone for carrying out empirical evaluation research [102]. This is needed in order to do meta-analyses across application cases and learn what patient-centric processes might possibly work better than others and in what context.

- **Answers to Research Question 3**: Numerous opportunities for the Healthcare domain by the integration of Industry 4.0 were identified. We have been able to split them into nine main categories. Their beneficiaries are the Healthcare service providers, the Healthcare professionals and the patients themselves. Moreover, not all opportunities are equally well explored. This calls for more research, specifically regarding the benefits of resource allocation and of improved decision-making (Table 4).

Furthermore, barriers to the development of Healthcare 4.0 were also illustrated. The majority of them are related to the technologies used (such as Big Data and IoT), the maturity level of Healthcare providers and the uncertainty surrounding some of the aspects of Industry 4.0, especially privacy and security. It was found that some of the opportunities that were expected to bring benefits (Table 4) that could be easily turned into challenges if not dealt with caution.

- **Comparison to related work:** By comparing the content of current research to related work, it is our understanding that our mapping study provides further value to research, as the selected corpus is quite extensive to include and present more Industry 4.0 technologies and a variety of applications to the healthcare sector. For example, while our findings agree with Ref. [15] regarding the observation that Industry 4.0 is instrumental to the introduction of standards and cloud computing-based solutions in the healthcare domain, our results expand these authors' results in at least two important ways: first, our findings point out to seven more application domains, for example, augmented reality, cybersecurity and robotics-based applications, to name just a few. Second, in our work, a connection is made between those applications and potential benefits and challenges, an aspect which is not covered extensively by the majority of related studies (e.g. Refs. [10, 15]). In contrast, the present

TABLE 6 Industry 4.0 applications to the healthcare domain

Sr.	Application area	References
1	Data storing EHRs, healthcare data collecting for analytics & predictions	[21, 22, 27, 28, 31–33, 37, 43–46, 52, 53, 55, 60, 61, 65, 93]
2	Telemedicine services	[45, 50]
3	Patient rehabilitation	[42, 43]
4	Hospital resource management	[21, 24, 25, 27, 32, 46]
5	Hospital and laboratory routine task management	[24, 27, 51]
6	Hospital and laboratory work monitoring	[61]
7	Online medical databases	[47]
8	Performing surgeries	[24, 37, 47, 61]
9	Patients diagnosis and monitoring	[20, 21, 24, 27–29, 32, 33, 35, 36, 42, 44, 46, 48, 50, 51, 55–58, 64, 68, 69]
10	Prosthetics	[27]
11	Development of implants and human organs	[24, 29, 32]
12	Surgical preparation	[24]
13	Chronic diseases monitoring	[19, 27, 53, 54]
14	Patients rehabilitation	[48]
15	Provision of pervasive and preventive healthcare	[33, 37, 45, 76, 77]
16	Predictive maintenance through early warning systems	[20, 21, 32, 62, 73]
17	Educating medical students and specialists	[32]
18	Virtual representation of physical objects	[32, 51, 64]
19	Medical equipment design, optimisation of resource allocation and clinical trials	[23–25, 32, 35, 46, 48, 51, 59, 65, 68]
20	Enhance the decision-making process of healthcare organisations	[66, 67, 73]
21	Analysing and comparing drugs and therapies	[24]
22	Evaluating the quality and sustainability of healthcare services	[67, 73]
23	Securing healthcare data and detecting cyberattacks	[20, 21, 26–28, 31, 34, 43, 50, 54, 55, 58, 69, 71, 72]

work only focuses on the nine main pillars of Industry 4.0, hence concepts such as Artificial Intelligence, Machine Learning and Virtual Reality are not covered in depth, while also does not make a classification of the reviewed studies based on their contribution to Healthcare 4.0 environment.

4.3 | Limitations to validity

The main limitation that this study faced was related to our search process. Since different terms are used to describe Industry 4.0 and Healthcare 4.0, this study might have overlooked to include in the list of reviewed literature papers that refer to Industry 4.0 using a different concept. To mitigate this risk, different keywords and Boolean operators were included in the search terms. Moreover, as indicated in Section 2.2, the scope of our search for primary studies was determined by two types of aspects, namely subject matter aspects and data management aspects. It could therefore be that our search string, while being focussed on both, might have missed some relevant Healthcare 4.0 work in which the authors might have failed to use the necessary key words for characterising the big data management aspect.

In addition, a similar limitation might result from the process followed for selecting the relevant literature. It is possible that by defining the selection criteria and research questions described in the relevant section, papers that could be valuable were rejected for different reasons (i.e. not written in English or their title, abstract and keywords did not provide any valuable information, unlike the main body of the publication).

Moreover, the authors of this paper enquired online databases that are available via the Online Portal of University of Twente. Even though the majority of prime databases are accessible via this portal, it is likely that certain studies not included in any of them which could add further value have been overlooked.

Furthermore, another threat to validity is the bias of selection. Thus, we might have rejected papers that other researchers would find relevant to the subject. To counter it, we set a series of quality evaluation questions to critically assess the papers, as described in Section 2.3. We also had multiple researchers apply the IC to the same set of papers. This helped further reduce the risk of selection bias.

Finally, we acknowledge the limitation inherent to any mapping study that filters the publications returned by the respective databases by taking into account title, abstract and keywords only. It might be possible that some papers did not have their central contribution explicitly stated in their abstracts. We think, however, that this threat is minimal as some journals and conferences use the so-called 'structured abstract' which prompts the authors of the published work to explicitly report their results and contributions.

4.4 | Future work

First, nearly all the proposed methods and applications whose focal point is patients' diagnosis, prevention, monitoring or treatment, deal with physical illnesses and diseases only. While diseases such as COVID-19, cancer, heart diseases or neurological disorders were frequently studied, a limited number of studies focused on mental health issues, such as depression or anxiety disorders. These sub-areas of healthcare are relatively unexplored and offer a line for future research.

Second, the potential of Industry 4.0 technologies such as Additive Manufacturing, Augmented Reality and Autonomous Robotics was not entirely explored. We think that researchers could work on developing and evaluating applications, focussed much more on the supply chain, logistics or manufacturing.

Third, we observed that the issue of privacy and security as related to the Healthcare domain was addressed by many authors as a point for improvement in their proposed applications. Therefore, future studies could examine this concept further and suggest methods for enhancing it.

Fourth, we believe that researchers could also inspect more in depth the possibility of real-time applications. In certain cases, early diagnosis and prevention or predictive maintenance may not suffice due to the velocity that characterises Big Data. Consequently, applications that can monitor the present state and adapt quickly to any changes occurring in the environment or their setup would be valuable for healthcare systems.

Next, the potential of Big Data prescriptive and predictive analytics can be further explored, with the aim to optimise the organisation and operation of hospitals.

One trend noticed was to evaluate and validate the highlighted applications by experiments or case studies. However, additional work needs to be done with regard to medical Big Data collection, evaluation and fusion for designing and testing methods and tools.

Finally, our findings revealed that the prospect of Industry 4.0 for Healthcare is substantial. Even though it has not reached a fully mature level yet, and in many cases, some of the technologies and applications are still under development, many of its benefits are already evident. In fact, it is expected that it would further transform the whole industry over the next few years and will increase the quality of Healthcare services, patients' satisfaction and the convenience of therapists, medical personnel or other stakeholders in the industry. On the other hand, though, different challenges and risks arise from the integration of Industry 4.0 to Healthcare, which need to be tackled efficiently in order to ensure that its full potential will be unleashed. More research on the available options to tackle the challenges is therefore urgently needed. Only then we will know how to realize the indicated benefits in a more consistent way.

5 | CONCLUSION

In this article, the current state of the art on the topic of Healthcare 4.0 was examined by reviewing relevant publications published after 2017. A systematic mapping study was carried out to answer three research questions, such as how are the concepts of Industry 4.0 and Healthcare 4.0 defined, which are some significant applications of the latter and what opportunities & challenges arise for healthcare organisations.

We found that the concept of Industry 4.0 is well-defined or described in 13 out of 69 papers, while Healthcare 4.0 is defined on fewer occasions and usually not so clearly or strictly (10 out of 69). This may be traceable to the fact that it is a relatively new field that has not been fully explored yet, and therefore the role of the Industry 4.0 in Healthcare is still partially unclear. In both cases, the majority of definitions focus on the technologies used, the structure of this concept or its main objectives.

We observe that despite the quite recent history of Healthcare 4.0, various relevant applications have already been proposed or released. Big Data, the Internet of Things and Cloud Computing are the three key enabling technologies. We believe that one of the main reasons is the fact that their potential has already been extensively examined in other domains, and thus their integration into the Healthcare domain requires fewer adjustments or further research. Overall, 43.5% and 45.2% of the reviewed papers address the Internet of Things and Big Data as one of their main topics, respectively. On the other hand, limited applications based on Autonomous Robotics or Additive Manufacturing were found.

Moreover, concerning the opportunities, we think that their beneficiaries are mainly three parties: Healthcare organisations, Healthcare professionals and the patients themselves. It is our understanding, however, that not all of the benefits have the same level of feasibility, since some require close collaboration between all three parties or further research so organisations can reach the required maturity level. To achieve this, numerous challenges should be overcome. The most significant ones are related to the characteristics of Big Data (especially their size, complexity and security) and the Internet of Things, the reluctance of organisations and people to make the transition to Healthcare 4.0 services and the lack of regulations or standards.

We conclude that the potential that the Healthcare domain holds for Industry 4.0 is notable. Applications and methodologies focussing on the design of advanced medical equipment, provision of precise and accurate Healthcare services and early diagnosis or prevention of diseases would improve not only the quality of life of the patients but also the business processes or professional work undertaken in this domain. Thus, the long-term benefits outweigh the barriers, and organisations & research institutions should further explore this possibility.

AUTHOR CONTRIBUTIONS

Konstantinos Kotzias: Conceptualization; Data curation; Funding acquisition; Investigation; Visualization; Writing – original draft; Writing – review & editing. **Faiza Bukhsh**: Data curation; Investigation; Methodology; Resources; Supervision; Writing – original draft; Writing – review & editing. **Jeewanie Jayasinghe**: Investigation; Methodology; Supervision; Writing – review & editing. **Maya Daneva**: Investigation; Methodology; Project administration; Supervision; Writing – original draft; Writing – review & editing. **Abhishta Abhishta**: Methodology; Supervision; Writing – review & editing.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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APPENDIX A: LIST OF DIGITAL LIBRARIES EXPLORED

TABLE A1 Digital libraries overview

Sr.	Name of library	Description	Evaluation result
1	ABC Business Directories	General	Not containing publications
2	ACM Digital Library	Information technology and computing machinery	Not meeting all quality criteria
3	ACS full text	Chemistry	Not relevant
4	AIS electronic library	Information technology	Not meeting all quality criteria
5	Analytical Abstracts Online	Chemistry	Not relevant
6	APS Journals	Physics	Not relevant
7	arXiv.org	Natural sciences, information technology and economics	Not meeting all quality criteria
8	Astrophysics Data System	Astrophysics	Not relevant
9	Beeld en Geluid op School	Education	Not containing publications
10	BrowZine	General	Not meeting all quality criteria
11	Business Source Elite	Economy & business	Not relevant
12	Chemiekaarten	Chemistry	Not relevant
13	CiteSeerX	Chemistry	Not relevant
14	Civil Engineering Database	Civil engineering	Not relevant
15	Collection of Computer Science Bibliographies	Computer science & information technology	Not containing publications
16	Company Dashboard	General	Not containing publications
17	Dictionaries Van Dale (online)	General	Not containing publications
18	Dictionaries Van Dale (for download)	General	Not containing publications
19	Directory of Open Access Journals	General	Not meeting all quality criteria
20	Documentatiecentrum Nederlandse Politieke Partijen	Politics	Not relevant
21	EconLit	Economics	Not relevant
22	EDventure/Onderwijsdatabank	Education	Not relevant
23	Emerald Insights	Operations & logistics	Not relevant
24	Encyclopaedia of Earth	Environmental studies	Not relevant
25	Encyclopaedia of Geography	Geography	Not relevant
26	Encyclopaedia of Materials: Science and Technology	Materials science	Not relevant
27	Encyclopaedia of Philosophy	Philosophy	Not relevant
28	Encyclopaedia of Science, Technology and Ethics	Science & technology	Not relevant
29	Encyclopaedia of Smart Materials	Engineering	Not relevant
30	ERIC	Education	Not relevant
31	Espacenet	Other	Not relevant
32	Essential Science Indicators	Science & technology	Not containing publications
33	EUR-Lex	Law	Not relevant
34	Eurostat	General	Not containing publications
35	FindUT	Other	Not relevant

TABLE A1 (Continued)

Sr.	Name of library	Description	Evaluation result
36	Geobase	Earth sciences	Not relevant
37	Google Scholar	General	Not meeting all quality criteria
38	GreenFILE	Environmental studies	Not containing publications
39	Historical Parliamentary documents	Politics	Not relevant
40	Hydrotheek	Environmental sciences	Not relevant
41	IDEAS	Economics	Not relevant
42	IEEE Explore Digital Library	Science & technology	Acceptable
43	Instructional Design	Education	Not relevant
44	International Encyclopaedia of Communication	Communication studies	Not relevant
45	International Encyclopaedia of the Social Sciences	Social sciences	Not relevant
46	IOPScience	Physics	Not relevant
47	IP Key	Information technology	Not containing publications
48	Journal Citation Reports	Other	Not relevant
49	JSTOR	General	Not meeting all quality criteria
50	Kirk-Othmer Encyclopaedia of Chemical Technology	Chemistry	Not relevant
51	Knovel	Engineering	Not containing publications
52	Legal Intelligence	Law	Not relevant
53	Library, Information Science & Technology Abstracts	Library and information management	Not relevant
54	MathSciNet	Mathematics	Not relevant
55	MatWeb	Materials science	Not relevant
56	MEDLINE	Health sciences	Not meeting all quality criteria
57	MERLOT	Education	Not relevant
58	NARCIS	General	Not meeting all quality criteria
59	NEN Connect	Business & operations	Not relevant
60	Newspaperindex	General	Not meeting all quality criteria
61	Nexis Uni	General	Not relevant
62	NIST	Physics & chemistry	Not relevant
63	OECD Statistics	General	Not containing publications
64	OpenAIRE	Science & technology	Not containing publications
65	ORBIS	Business & operations	Not relevant
66	Overheid	General	Not meeting all quality criteria
67	Oxford Journals	General	Not meeting all quality criteria
68	Patents Database US	Other	Not relevant
69	Philosopher's Index	Philosophy	Not relevant
70	PhilSci Archive	Philosophy of science	Not relevant
71	Physical Review Online Archive	Physics	Not relevant
72	Plastics Technology Online	Materials science	Not relevant
73	PsycArticles	Psychology	Not relevant

(Continues)

TABLE A1 (Continued)

Sr.	Name of library	Description	Evaluation result
74	Psychology and Behavioural Sciences Collection	Psychology	Not relevant
75	PsycINFO	Psychology	Not relevant
76	Pubmed	Health sciences	Not meeting all quality criteria
77	Pubs OnLine Informs	General	Not meeting all quality criteria
78	Regional Business News	General	Not meeting all quality criteria
79	Research Professional	Business & economics	Not relevant
80	Routledge Encyclopaedia of Philosophy	Philosophy	Not relevant
81	SAGE Journals Online	General	Not meeting all quality criteria
82	ScienceDirect	General	Acceptable
83	SciFinder	Chemistry	Not relevant
84	SciTech	Science & technology	Not meeting all quality criteria
85	Scopus	General	Acceptable
86	Siam Journals Online	Applied mathematics	Not relevant
87	SPIE Digital Library	Physics	Not relevant
88	SpringerLink	General	Not meeting all quality criteria
89	SpringerMaterials	Materials science & engineering	Not relevant
90	Stanford Encyclopaedia of Philosophy	Philosophy	Not relevant
91	Statista	General	Not containing publications
92	StatLine	General	Not containing publications
93	Stevens' Handbook of Experimental Philosophy	Philosophy	Not relevant
94	Taylor & Francis	Science, technology, medicine and social sciences	Not meeting all quality criteria
95	TRID Online	Traffic & transportation	Not relevant
96	Ullmann's Encyclopaedia of Industrial Chemistry	Chemistry	Not relevant
97	Ulrichsweb	Other	Not relevant
98	UT Research Information	Other	Not relevant
99	Van Dale dictionaries (online)	Other	Not relevant
100	Van Dale dictionaries (for download)	Other	Not relevant
101	Web of Science	General	Acceptable
102	Wijsbegeerte in Nederland	General	Not containing publications
103	Wiley Online Library	Science, technology, medicine and social sciences	Not meeting all quality criteria
104	World Data on Education	Education	Not relevant
105	World Factbook	General	Not containing publications

APPENDIX B: REVIEWED LITERATURE QUALITY ASSESSMENT

TABLE B1 Quality assessment results

Reference	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	Total score
[99]	0	0	0	1	0	0	0	1	2
[20]	1	0	1	1	0	0	1	1	5
[31]	0	1	1	1	0	0	1	1	5
[32]	1	1	0	1	0	0	1	1	5
[65]	0	0	0	0	1	1	1	0	3
[56]	0	0	0	1	1	1	1	0	4
[45]	0	0	0	1	1	1	1	0	4
[75]	0	0	0	1	0	0	1	1	3
[21]	1	1	0	1	0	0	1	1	5
[76]	0	0	0	1	0	0	1	0	2
[64]	1	0	0	1	0	1	1	1	5
[35]	0	0	0	1	0	0	1	0	2
[23]	1	0	0	1	0	0	1	1	4
[47]	0	1	0	1	0	0	1	1	4
[30]	1	0	1	0	0	0	1	1	4
[36]	0	1	1	1	0	0	1	1	5
[22]	1	0	0	1	1	0	1	0	4
[57]	0	0	0	1	1	1	1	1	5
[42]	0	0	0	1	1	1	1	0	4
[63]	1	0	0	1	1	1	1	1	6
[37]	1	1	1	1	0	0	1	1	6
[24]	1	0	0	1	0	0	1	1	4
[71]	0	0	0	1	0	0	1	1	3
[33]	0	0	0	1	0	0	1	1	3
[27]	1	1	1	1	0	0	1	1	6
[28]	1	0	1	1	1	0	1	1	6
[72]	0	0	0	0	0	0	1	1	2
[25]	1	0	1	0	1	1	1	0	5
[49]	0	0	0	1	0	0	1	1	3
[66]	0	0	0	1	1	1	1	0	4
[96]	0	0	0	1	1	1	1	1	5
[43]	0	0	0	1	0	0	1	1	3
[58]	0	0	0	1	1	1	1	1	5
[59]	0	0	0	1	1	0	1	1	4
[60]	0	0	0	0	1	1	1	1	4
[67]	0	0	0	1	0	0	1	1	3

TABLE B1 (Continued)

Reference	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	Total score
[50]	0	0	0	1	1	0	1	1	4
[68]	0	0	0	1	1	1	1	1	5
[100]	0	0	0	1	0	0	1	1	3
[51]	0	0	0	1	1	1	1	0	4
[34]	0	0	0	1	1	1	1	1	5
[97]	0	0	0	1	0	0	1	1	3
[44]	0	0	0	1	1	1	1	0	4
[52]	0	0	0	0	0	0	1	1	2
[73]	0	0	0	1	1	0	1	1	4
[95]	0	0	0	1	0	0	1	0	2
[98]	0	0	0	0	0	0	1	1	2
[41]	0	0	0	0	0	0	1	1	2
[61]	0	0	0	0	1	1	1	0	3
[29]	1	0	0	1	0	0	1	1	4
[62]	0	0	0	1	1	1	1	0	4
[26]	1	0	1	1	0	0	1	1	5
[55]	0	0	0	1	1	1	1	1	5
[101]	0	0	0	0	0	0	1	1	2
[93]	0	0	0	1	0	0	1	1	3
[77]	0	0	0	1	1	1	1	0	4
[19]	1	0	1	1	0	0	1	0	4
[46]	0	0	0	1	1	1	1	1	5
[69]	0	0	0	1	1	1	1	1	5
[53]	0	0	0	1	1	1	1	1	5
[54]	0	0	0	1	0	0	1	1	3
[48]	0	0	0	1	1	1	1	1	5

APPENDIX C: DATA EXTRACTION FROM LITERATURE FOR RESEARCH QUESTIONS

TABLE C1 Reviewed papers details

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
1	d'Agostino Panebianco, M. and Capoluongo, A. [99]	Data processing in a Healthcare National System: (With the analysis of the Italian HNS)	2021	0	Artificial intelligence; balancing; big data; data privacy; data science; professional aspects	Conference paper	This article describes how big data is processed in healthcare sector, with special focus on how we have moved from big to smart data, their legal framework and a case study
2	Hoosain, M.S. and Paul, B.S. and Ramakrishna, S. [20]	The impact of 4IR digital technologies and circular thinking on the United Nations sustainable development goals	2020	0	Digital technologies, industry 4.0; circular economy; circular economy tools; new paradigms for the future	Article	This article describes how industry 4.0 and some of its technologies (IoT, big data, blockchain, robotics) contribute in various ways to the society, with respect to UN sustainable development goals
3	Javid, T. and Faris, M. and Beenish, H. and Fahad, M. [31]	Cybersecurity and data privacy in the Cloudlet for preliminary healthcare big data analytics	2020	0	Cloudlet; medical big data analytics; mobile edge cloud; cybersecurity and data privacy; wireless biosensor network; wireless body area network	Conference paper	This paper outlines cybersecurity and data privacy aspects for communications of measured patient data from wearable wireless biosensors to nearby cloudlet host server in order to facilitate the cloudlet based preliminary and essential complex analytics for the medical big data
4	Lhotska, L. [32]	Application of industry 4.0 concept to health care	2020	0	Industry 4.0; health 4.0; artificial intelligence; internet of things; virtual reality; monitoring	Article	In this paper, various concepts of industry 4.0 are analysed and their opportunities for businesses. Then, certain applications of them in the healthcare sector are shown, accompanied with potential challenges
5	Bagula, A. and Maluleke, H. and Ajayi, O. and Bagula, A. and Bagula, N. and Bagula, M. [65]	Predictive models for mitigating COVID-19 outbreak	2020	0	COVID-19; epidemic modelling; ordinary differential; equations; healthcare 4.0; predictive modelling	Conference paper	In this paper, the authors propose a model that can be used to estimate the number of infections, peak infection day, infection increase rate etc. of COVID-19, including a case study for it
6	Ali, S.E. and Khan, A.N. and Zia, S. and Mukhtar, M. [56]	Human activity recognition system using smart phone based accelerometer and machine learning	2020	0	HAR; ADL; mobile application; accelerometer; data analytics	Conference paper	This paper describes and validates using experiments a ML model to monitor activities of daily living, by collecting data via smartphones, and explains how this can have a significant contribution in neurological health monitoring systems

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
7	Massaro, A., and Ricci, G. and Selicato, S. and Raminelli, S. and Galiano, A. [45]	Decisional support system with artificial intelligence oriented on health prediction using a wearable device and big data	2020	0	Wearable IoT sensors; big data, health prediction; artificial intelligence; decision support systems; support vector machine; LSTM	Conference paper	In this paper, an AI model that is fed with medical data via wearable sensors is developed and analysed. The purpose is to predict the patient's health status and can be used to create a multi-dimensional risk map for it
8	Kalamkar, S. and Mary, G.A. [75]	Clinical data fusion and machine learning techniques for Smart Healthcare	2020	0	Data fusion; sensor fusion; internet of things; big data; healthcare; analytics	Conference paper	This paper focuses on the importance of data fusion in healthcare 4.0 and what opportunities it can provide for healthcare/clinical big data collected by sensors, while also presenting relevant various data fusion models and techniques
9	Al-Jaroodi, J. and Mohamed, N. and Abukhousa, E. [21]	Health 4.0: On the way to realizing the healthcare of the future	2020	0	Health 4.0; industry 4.0; healthcare systems; service-oriented middleware; service integration; health cloud; health fog; internet of health things; medical cyber-physical systems; COVID-19	Article	This article analyses the concept of industry 4.0 and how it is applied to health. It defines the main objectives of healthcare 4.0, discusses applications, as well as potential opportunities and challenges arising from the rise and adoption of healthcare 4.0
10	Lopes, J. and Guimarães, T. and Santos, M.F. [76]	Predictive and prescriptive analytics in healthcare: A survey	2020	0	Healthcare; predictive; prescriptive; analytics; data mining; machine learning	Conference paper	The contribution of this paper is to show how prescriptive and predictive analytics can take advantage of medical big data to enhance healthcare services for patients, doctors or managers
11	Bayoumi, A.-M. and Matthews, R.M.C. and Abdel Fatah, A.A. [64]	The fourth industrial revolution: Digital transformation and industry 4.0 applied to product design, manufacturing and operation	2020	0	Digital transformation; health monitoring; industry 4.0; predictive maintenance	Conference paper	The aim of this paper is to provide an overview of digital transformation and industry 4.0, and the various benefits its adoption can have in product design, manufacturing and operation, with special focus on education and research
12	Ratia, M. and Myllärniemi, J. and Helander, N. [35]	The potential beyond IC 4.0: The evolution of business intelligence towards advanced business analytics	2019	3	Decision-making; private healthcare; intellectual capital; business intelligence; business analytics; future potential	Article	This article underlines the opportunities arising and the needs by the realisation of industry 4.0 via business analytics, BI and BA for private healthcare sector, examining Finnish market as a case study

(Continues)

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
13	Rath, D. and Satpathy, I. and Patnaik, B.C.M. [23]	Augmented reality (Ar) & virtual reality (Vr)—a channel for digital transformation in industrialisation fostering innovation and entrepreneurship	2019	8	Augmented reality (AR); virtual reality (VR); engineering technology; medicine; healthcare; tourism; entrepreneurship; innovation; industry 4.0; skill development	Article	In this article, it is analysed how VR and AR are two industry 4.0 concepts that find applications in various fields, as well as the value industry 4.0 can offer to industries and what measures can be taken by educational institutions to achieve this
14	Wehde, M. [47]	Healthcare 4.0	2019	7	Healthcare; data analytics; artificial intelligence; digital platform; Robotic surgery	Article	This article analyses the concept of healthcare 4.0, by describing why it is important to make the transition to it, what are some of the greatest benefits for healthcare arising by certain components of industry 4.0 and the potential challenges
15	Ojra, A. [30]	Revisiting industry 4.0: A new definition	2019	7	Industry 4.0; cyber-physical; smart factory; internet of things; cloud manufacturing	Conference paper	In this paper, the concept of industry 4.0 is discussed, by reviewing the definitions given for it, the challenges and benefits that emerge from it, as well as some of its key enabling technologies
16	Bause, M. and Khayamian Esfahani, B. and Forbes, H. and Schaefer, D. [36]	Design for health 4.0: Exploration of a new area	2019	0	Health 4.0; design for health; user centred design; design for X (DfX); industry 4.0	Conference paper	The aim of this paper is to examine health 4.0, including its opportunities and challenges, under three different perspectives (people, technology and design) and determine the role of the latest in its realisation
17	Jameel, S.M. and Hashmani, M.A. and Alhussain, H. and Budiman, A. [22]	A fully adaptive image classification approach for industrial revolution 4.0	2019	6	Industrial revolution 4.0; image classification; concept drift; self adaptability	Conference paper	In this paper, a ML model for image classification is proposed, with the aim to be used in industry 4.0. The study merely focuses on the technical design and implementation of the model
18	Fong, S. and Zhuang, Y. and Hu, S. and Song, W. and Liu, L. and Moutinho, L. A. [57]	Longitudinal ambient mobile sensor monitoring for TCM-oriented healthcare assessments: Framework, challenges and applications	2019	0	Healthcare application; data mining; mobile apps	Conference paper	This paper describes how certain industry 4.0 components (namely mobile apps, big data, wearables and sensors) can be fused into the principles of TCM healthcare system, in order to enhance it
19	Caggianese, G. et al. [42]	Serious games and in-cloud data analytics for the virtualisation and personalisation of rehabilitation treatments	2019	3	Data analytics; decision support systems (DSS); neuromotor rehabilitation; serious games; telerehabilitation	Article	In this paper, a new telerehabilitation system for stroke patients based on serious games and in-cloud data analytics is

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
							proposed, accompanied by a pilot study of this model application
20	Elhoseny, M. and Abdelaziz, A. and Salama, A.S. and Riad, A.M. and Muhammad, K. and Sangaiah, A.K. [63]	A hybrid model of internet of things and cloud computing to manage big data in health services applications	2018	97	Big data; industry 4.0; cloud computing; internet of things; health services; genetic algorithm; particle swarm optimisation	Article	In this article, the authors propose a model based on cloud computing and IoT to manage the ever-increasing amount of big data and its applications in healthcare, by optimising virtual machine selection
21	Pang, Z. and Yang, G. and Khedri, R. and Zhang, Y.-T. [37]	Introduction to the special section: Convergence of automation technology, biomedical engineering, and health informatics toward the healthcare 4.0	2018	31	Caregiving home; convergence; healthcare 4.0; healthcare robotics; human–robot symbiosis; industry 4.0	Article	In this article, the concept of industry 4.0 is analysed and how healthcare 4.0 has emerged from it, which is based on automation technology, biomedical engineering and healthcare informatics
22	Soler, C. [24]	Health 4.0 oriented to non-surgical treatment	2018	0	Industry 4.0; artificial intelligence; 3D printing; robotics; big data; internet of things; augmented reality	Conference paper	The aim of this article is to describe how industry 4.0 is applied to the healthcare sector. It also presents different examples of non-surgical treatment or healthcare systems management based on this technologies
23	Ahram, T. and Sargolzaei, A. and Sargolzaei, S. and Daniels, J. and Amaba, B. [71]	Blockchain technology innovations	2017	116	Blockchain; business; cloud computing; cloud services; control systems; cybersecurity; DevOps; finance; government; healthcare; IoT; industry 4.0	Conference paper	The authors of this paper examine the potential that blockchain technology holds from the cybersecurity perspective. Moreover, they present a healthcare industry application based on blockchain, healthchain
24	Sudana, D. and Emanuel, A. W.R [33]	How big data in health 4.0 helps prevent the spread of tuberculosis	2019	2	Big data; health 4.0; monitoring; prevention; tuberculosis	Conference paper	In this paper, the authors review different cases of how big data is used in health 4.0 to support infectious prevention, while also focusing on the case of tuberculosis in Indonesia
25	Aceto, G. and Persico, V. and Pescapé, A. [27]	Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0	2020	50	N/A	Article	In this article, the industry 4.0 applied to healthcare 4.0 are introduced, certain applications of healthcare 4.0 are highlighted, as well as the main benefits and challenges of it
26	Abdel-Basset, M. and chang, V. and Nabeeh, N.A. [28]	An intelligent framework using disruptive technologies for COVID-19 analysis	2020	1	Covid-19; blockchain; internet of medical things (IoMT); industry 4.0; healthcare; 5G	Article	The authors of this article describe how disruptive technologies can assist in the fight against COVID-19, and propose a

(Continues)

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
							framework to be developed that can be used to achieve this results
27	Stephanie, L. and Sharma, R.S. [72]	Digital health eco-systems: An epochal review of practice-oriented research	2019	2	Electronic medical records; digital transformation of healthcare; health informatics	Article	In this article, the authors review the topic of digitalisation of health (especially regarding medical records), which can be split into three different epochs. In the most recent one, the focus is on industry 4.0 technologies, and mainly cloud computing
28	Dossou, P.E. and Pereira, R. and Cristiane, S. and Joao, C.J. [25]	How to use lean manufacturing for improving a healthcare logistics performance	2020	0	Lean manufacturing; serialisation; performance improvement	Article	The aim of this article is to propose a framework for defining and implementing logistics in healthcare 4.0, based on lean manufacturing
29	Aceto, G. and Persico, V. and Pescapé, A. [49]	The role of information and communication technologies in healthcare: Taxonomies, perspectives, and challenges	2018	54	Healthcare; ICTs; e-health; m-Health; pervasive health; WBAN; cloud computing; internet of things; fog; big data; genomics; health monitoring; privacy; security; interoperability	Article	This article analyses the role of ICTs in transformation of healthcare, and how its pillars and the industry 4.0 components find applications there and create new challenges and opportunities
30	Jung, H. and Chung, K. [66]	Social mining-based clustering process for big-data integration	2020	1	Social mining; ambient intelligence; big-data integration; cluster process; healthcare; machine learning; lifecare	Article	In this article, the authors propose a social mining-based cluster process for big data integration. This clustering process can be used to predict the health risk of patients, based on their characteristics
31	Shi, M. and Jiang, R. and Hu, X. and Shang, J. [96]	A privacy protection method for health care big data management based on risk access control	2019	3	Health care big data; health care management science; privacy protection; risk, access control	Article	The authors of this article review existing work and propose a new risk access control model to ensure data protection for medical big data, based on the fuzzy theory
32	Qadri, Y.A. and Nauman, A. and Bin Zikria, Y. and Vasilakos, A.V. and Kim, S.W. [43]	The future of healthcare internet of things: A survey of emerging technologies	2020	25	H-IoT; WBAN; machine learning; fog computing; edge computing; blockchain; software defined networks	Article	This article describes the impact of IoT in healthcare and how other industry 4.0 components are supporting and transforming H-IoT systems
33	Liyakathunisa, S. and Saima, J. and Manimala, S. and Abdullah, A. [58]	Smart healthcare framework for ambient assisted living using IoMT and big data analytics techniques	2019	13	Ambient assisted living (AAL); big data analytics; internet of medical things (IoMT); machine learning techniques; physical activities; wearable sensors	Article	This article focuses on AAL, and how IoMT has revolutionised this field. Moreover, the authors propose a framework based on IoMT, big data and ML for faster analysis, decision-making and better treatment suggestions

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
34	Onasanya, A. and Lakkis, S. and Elshakankiri. M [59]	Implementing IoT/WSN based smart Saskatchewan healthcare system	2019	3	Business analytics; cancer care services; emergency services; operational services; IoT; healthcare system	Article	The goal of this paper is to propose four IoT-enabled healthcare services that will be modelled for the newly established Saskatchewan health authority and compare it to existing ones
35	Bhuiyan, A.R. and Ullah, R. and Das, A.K. [60]	iHealthcare: Predictive model analysis concerning big data applications for interactive healthcare systems	2019	3	HCI; healthcare big data; cloud; HPC; MapReduce; data warehouse	Article	In this paper, the authors develop and propose a model that can be used to collect, acquire and analyse medical/biological big data based on data warehousing, and used to provide predictions
36	Moro Visconto, R. and Morea, D. [67]	Big data for the sustainability of healthcare project financing	2019	2	Healthcare informatics; networks; internet of health; public-private partnership; value chain; business model innovation; data mining; predictive analytics; interoperability; healthcare management	Article	This article examines if and how big data can improve the quality and timeliness of information in infrastructural healthcare PF investments, making them more sustainable
37	Alexandru, A. and Coardos, D. and Tudora, E. [50]	IoT-based healthcare remote monitoring platform for elderly with fog and cloud computing	2019	2	Internet of things (IoT); big data analytics; fog computing; cloud computing; health	Conference paper	In this paper, the authors propose a new elderly remote monitoring platform that can be based to perform big data analytics on data collected from IoT sensors, based on capabilities of cloud and fog computing
38	Chung, K. and Park, R.C. [68]	Chatbot-based healthcare service with a knowledge base for cloud computing	2019	18	AI smart health; chatbot framework; chatbot health; medical data mining; cloud computing	Article	The aim of this article is to propose a chatbot-based healthcare services, implemented by IoT, big data and cloud computing, which provide fast treatment to patients after accidents and in response to changes of condition to patients with chronic diseases
39	Dhayne, H. and Haque, R. and Kilany, R. [100]	In search of big medical data integration solutions—a comprehensive survey	2019	2	Big data; data integration; healthcare data	Article	In this article, the authors define the framework around data integration in healthcare, why it is important, what solutions can be adopted and which are the potential challenges
40	Liu, Y. et al. [51]	A novel cloud-based framework for the elderly healthcare services using digital twin	2019	24	Digital twin; elderly healthcare; personal health management; cloud computing; precision medicine; interaction; convergence	Article	In this paper, the authors explore the digital twin technology, its contribution in healthcare and how a cloud-based framework using digital

(Continues)

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
							twin can be used to provide healthcare services, especially to elderly people
41	Kim, J. W. and Jang, B. and Yoo, H. [34]	Privacy-preserving aggregation of personal health data streams	2018	1	N/A	Article	In this paper, the authors examine the issue of data privacy in healthcare (with special focus on cloud environments) and propose a method based on the LDP for the safe transmission of data
42	Manjunath, P. and Prakruthi, M. K. and Shah, P.G. [97]	IoT driven with big data analytics and block chain application scenarios	2018	1	Big data analytics; block chain; IoT architectures; IoT-smart city; security	Conference paper	The purpose of this paper is to describe the context between big data and data analytics, internet of things and blockchain and how they can be incorporated and solve each other's constraints
43	Saravanan, M. and Shubha, R. [44]	Non-invasive analytics based smart system for diabetes monitoring	2018	2	Diabetes monitoring; non-invasive method; sensors and devices; PSO algorithm; mobile app	Conference paper	In this paper, the authors try to explore IoT for medical devices concept and propose a model based on a set of three wearable devices for continuous monitoring of diabetes patients
44	Patgiri, R. and Nayak, S. [52]	Data of things: The best things since sliced bread	2018	2	Internet of things; data of things; smart things; issues and challenges; web of things; big data; cloud computing	Conference paper	In this paper, the authors explore the concept of DoT, which is the big data generated by IoT and transmitted/stored via cloud computing, as well as the models that are available for DoT and the potential challenges
45	Coban, S. and Gokalp, M.O. and Gokalp, E. and Eren, P.E. and Kocyigit, A. [73]	Predictive maintenance in healthcare services with big data technologies	2018	4	Conference paper	N/A	This paper focuses on the importance of predictive maintenance in healthcare, while the authors also propose an architecture based on IoT, big data and cloud computing to work towards predictive maintenance
46	Knickerbocker, J.U. et al. [95]	Heterogeneous integration technology demonstrations for future healthcare, IoT, and AI computing solutions	2018	9	N/A	Conference paper	In this paper, the authors describe the technologies and advancements to heterogeneous integration technology tools, materials and processes that provide differentiating electronics for future healthcare diagnostics tools and sensors

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
47	Joshi, N. and Kadhiwala, B. [98]	Big data security and privacy issues—a survey	2017	9	Big data; data security; data privacy	Conference paper	In this paper, the challenges around the use of big data are discussed with a special focus on security and privacy
48	Dhirani, L.L. and Newe, T. and Lewis, E. and Nizamani, S. [41]	Cloud computing and internet of things fusion: Cost issues	2017	4	Internet of things; cloud computing; pricing; virtual machines	Conference paper	The theme discussed in this paper is how IoT and cloud computing can be merged so the limitations of IoT can be overcome while also discussing the relevant cost issues
49	Golmohammadi, H. and Hamzei, Z. and Hosseinifard, M. and Ahmadi, S.H. [61]	Smart fully integrated lab: A smartphone-based compact miniaturised analytical/diagnostic device	2020	0	Fully integrated lab; internet of things; point-of-care; portable diagnostics; smartphone-based analytical devices	Article	In this article, the authors propose a device that can be used to perform analytical/diagnostic procedures based on the concepts of internet of things, fog computing and smartphones
50	Friebe, M.H. [29]	Healthcare in need of innovation: Exponential technology and biomedical entrepreneurship as solution providers	2020	2	Healthcare innovation; biodesign; exponential technologies; prevention; healthcare 4.0; biomedical entrepreneurship; healthcare ethics; biomedical engineering education; Healthtec innovation management	Conference paper	The purpose of this paper is to present the evolving concept of healthcare 4.0 and the important role that biomedical engineers play into it
51	Packianather, M.S. and Munizaga, N.L. and Zouwail, S. and Saunders, M. [62]	Development of soft computing tools and IoT for improving the performance assessment of analysers in a clinical laboratory	2019	0	Predictive condition-based maintenance (CBM); statistical process control (SPC); data mining; machine learning; K-Nearest Neighbour (KNN) classifier; soft computing; internet of things (IoT); big data; industry 4.0	Conference paper	This study focuses on the importance of predictive maintenance in healthcare that becomes more challenging with the development of industry 4.0, and proposes a model for predictive maintenance of laboratory equipment
52	McKee, D.W. and Clement, S. J. and Almutairi, J. and Xu, J. [26]	Massive-scale automation in cyber-physical systems: Vision & challenges	2017	20	Cloud; SOA; services; big data; stream processing; smart cities; HPC; Edge; fog; security; simulation; workflows; IoT; IoS; SIMaaS; WFaaS; industry 4.0	Conference paper	In this paper, the authors explore the topic of automation in cyber-physical systems through the use of industry 4.0 components across different sectors, including healthcare
53	Chung, K. and Yoo, H. and Choe, D.-E. [55]	Ambient context-based modelling for health risk assessment using deep neural network	2020	15	Ambient context; data mining; big data; deep learning; deep neural network; healthcare	Article	In this study, a context computing model is proposed for the health risk assessment of patients with chronic diseases, using big data collected from different sources, using different methods
54	Fu, H. et al. [101]	Tracing knowledge development trajectories of the internet of things domain: A main path analysis	2019	37	Internet of things; knowledge development; main path analysis; scientometric	Article	In this article, the authors investigate systematically and comprehensively the evolution of knowledge in the domain of IoT and

(Continues)

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
							determine its applications in the three main domains, including healthcare
55	Hariri, R.H. and Fredericks, E.M. and Bowers, K.M. [93]	Uncertainty in big data analytics: Survey, opportunities, and challenges	2019	14	Big data; uncertainty; big data analytics; artificial intelligence	Article	This article deals with the issue of uncertainty in big data and how this can be mitigated with the use of AI techniques
56	El-Rahman, S.A. and Al-Montasheri, A. and Al-Hazmi, B. and Al-Dkaan, H. and Al-Shehri, M. [77]	Machine learning model for breast cancer prediction	2019	0	Genetic mapping; big data; data mining; machine learning; breast cancer	Conference paper	In this study, the authors propose an algorithm based on big data and machine learning techniques for early detection of breast cancer
57	Diaz, R.A.C. and Ghita, M. and Copot, D. and Birs, I. R. and Muresan, C. and Ionescu, C. [19]	Context aware control systems: An engineering applications perspective	2020	0	Self-sustainability; global economy; intelligent manufacturing systems; self-optimisation; context estimation; adaptive control; context-aware control; event-based control; deep learning; random forest; iterative learning control; digital twin; cyber physical systems; societal challenges	Article	This article discusses the concept of context-aware systems, an important element of cyber-physical systems, and applications based on them in sectors emerging from development of industry 4.0, including healthcare
58	Patan, R. and Ghantasala, G.S. P. and Sekaran, R. and Gupta, D. and Ramachandran, M. [46]	Smart healthcare and quality of service in IoT using grey filter convolutional based cyber physical system	2020	5	Internet of things (IoT); deep neural networks; grey filter; Bayesian; convolution neural network	Article	In this article, the authors propose a AI-driven IoT e-health architecture that can bring improvements to aspects such as response time, accuracy and overhead
59	Humayun, M. et al. [69]	Privacy protection and energy optimisation for 5G-Aided industrial internet of things	2020	0	5G; energy optimisation; industrial internet of things; privacy; security	Article	In this article, the topic of discussion is the privacy protection and energy optimisation of 5G-enabled IIoT devices, accompanied with the proposal of a relevant framework
60	Elsayad, A.S. and El Desouky, A.I. and Salem, M.M. and Badawy, M. [53]	A deep learning H_2O framework for emergency prediction in biomedical big data	2020	0	Deep learning; H_2O framework; healthcare; neural networks; optimisation; whale optimiser	Article	The aim of this study is to propose a framework for finding the optimal subset of features and minimise the classification error during prediction of emergency cases
61	Makhdoom, I. and Abolhasan, M. and Lipman, J. and Liu, R.P. and Ni, W. [54]	Anatomy of threats to the internet of things	2019	26	Threats to the IoT; internet of things; malware attacks on the internet of things; attack methodology; security and privacy; IoT security framework; security guidelines	Article	In this article, the authors focus on the different types of threats to IoT systems and devices (including healthcare IoT devices), with special attention to malware attacks

TABLE C1 (Continued)

Sr.	Author	Title	Year	Cited	Keywords	Document type	Description
62	Muhammed, T. and Mehmood, R. and Albeshri, A. and Katib, I. [48]	UbeHealth: A personalised ubiquitous cloud and edge-enabled networked healthcare system for smart cities	2018	48	Cloudlets; deep learning; internet of things (IoT); mobile edge computing; mobile healthcare; preventive healthcare; traffic classification; traffic prediction; survey; fog computing; cloud computing; multimedia applications; smart cities	Article	In this study, the authors share some benefits and challenges of using mobile cloud computing solutions in healthcare and propose an ubiquitous framework that leverages different industry 4.0 components to address those challenges

TABLE C2 Data extraction for research question 1

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
1	d'Agostino Panebianco, M., Capoluongo, A. [99]	Data processing in a Healthcare National System: (With the analysis of the Italian HNS)	N/A	N/A
2	Hoosain, M.S. and Paul, B.S. and Ramakrishna, S. [20]	The impact of 4IR digital technologies and circular thinking on the United Nations sustainable development goals	In this fourth technological wave in industry, known as industry 4.0, cyber-physical systems can interact with one another using artificial intelligence (AI), machine learning (ML), big data, and the internet of things (IoT), etc. Industry 4.0 will increase productivity and growth	N/A
3	Javid, T. and Faris, M. and Beenish, H. and Fahad, M. [31]	Cybersecurity and data privacy in the Cloudlet for preliminary healthcare big data analytics	4IR or industry 4.0 which is a concept to integrate automation and knowledge for manufacturing	The terms health 4.0, healthcare 4.0, healthcare industry 4.0, and medical industry 4.0 refers to 4IR in healthcare. Technologies associated with 4IR are cloud-based design and manufacturing system and the industrial internet of things
4	Lhotska, L. [32]	Application of industry 4.0 concept to health care	The industry 4.0 concept is based on distributed control and decision-making, into which various systems are integrated. It is reflected in the concept of intelligent production that is not closed in a particular factory environment. It also considers external factors, such as logistics, energy, and requirements, plans or orders from the customers. Further, it is connected with mobility, intelligent homes and buildings, social web systems, etc. It is also called internet of things, services and people	Health 4.0 reflects the development in the industry where the concept industry 4.0 was introduced in 2011
5	Bagula, A. and Maluleke, H. and Ajayi, O. and Bagula, A. and Bagula, N. and Bagula, M. [65]	Predictive models for mitigating COVID-19 outbreak	N/A	N/A

(Continues)

TABLE C2 (Continued)

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
6	Ali, S.E., Khan, A.N., Zia, S., Mukhtar, M. [56]	Human activity recognition system using smart phone based accelerometer and machine learning	N/A	N/A
7	Massaro, A., and Ricci, G. and Selicato, S. and Raminelli, S. and Galiano, A. [45]	Decisional support system with artificial intelligence oriented on health prediction using a wearable device and big data	N/A	N/A
8	Kalamkar, S. and Mary, G.A [75]	Clinical data fusion and machine learning techniques for Smart Healthcare	N/A	N/A
9	Al-Jaroodi, J. and Mohamed, N. and Abukhousa, E. [21]	Health 4.0: On the way to realizing the healthcare of the future	The industry sector uses technologies like the internet of things (IoT), cyber-physical systems (CPS), and analytics to initiate the industry 4.0 era. Industry 4.0 aims to enhance operations, reduce costs and improve quality through optimisation, industrial automation, and the use of intelligent services	Health 4.0 can be defined as the implementation of integrated healthcare platforms with progressive virtualized, distributed and real-time healthcare services for patients, professionals and formal and informal care givers. It focuses on supporting, enabling and optimising collaboration, coherence, and convergence to move healthcare services from being based on 'empirical data' to 'precision medicine' (i.e. personalised healthcare services) as one direction for enhancement
10	Lopes, J. and Guimarães, T. and Santos, M.F. [76]	Predictive and prescriptive analytics in healthcare: A survey	N/A	N/A
11	Bayoumi, A.-M. and Matthews, R.M. C. and Abdel Fatah, A.A. [64]	The fourth industrial revolution: Digital transformation and industry 4.0 applied to product design, manufacturing and operation	Industry 4.0 can be embraced to attain greater levels of business, asset and product life management. This transformation is applied to all areas of a product's life cycle which involves the design, manufacturing and use (condition-monitoring) of a product	N/A
12	Ratia, M. and Myllärniemi, J. and Helander, N. [35]	The potential beyond IC 4.0: The evolution of business intelligence towards advanced business analytics	N/A	N/A
13	Rath, D. and Satpathy, I. and Patnaik, B.C.M. [23]	Augmented reality (Ar) & virtual reality (Vr)—a channel for digital transformation in industrialisation fostering innovation and entrepreneurship	I4 is characterised by like mobile devices, internet of things (IoT) platforms, location detection technologies, advanced human-machine interfaces, authentication and fraud detection, 3D printing, smart sensors, big data analytics and advanced algorithms, multilevel customer interaction and customer profiling, augmented & virtual reality/wearables, cloud computing, fog computing, artificial intelligence, machine learning, robotics automation etc.	N/A

TABLE C2 (Continued)

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
14	Wehde, M. [47]	Healthcare 4.0	N/A	Healthcare 4.0, which refers to the shift from traditional hospital-centric care to a more virtual, distributed care that heavily leverages the latest technologies around artificial intelligence (AI), deep learning, data analytics, genomics, home-based healthcare, robotics, and 3D printing of tissue and implants
15	Ojra, A. [30]	Revisiting industry 4.0: A new definition	Industry 4.0 is an advanced digitalised manufacturing, where internet of things (IoT) is implemented within the manufacturing process	N/A
16	Bause, M. and Khayamian Esfahani, B. and Forbes, H. and Schaefer, D. [36]	Design for health 4.0: Exploration of a new area	N/A	Health 4.0 is defined as a strategic concept for the health domain derived from the industry 4.0. It can be described as a phenomenon to improve healthcare service and improve connectivity between health care stakeholders using technology. It will allow patients or 'consumers' to be the sole managers of our health, as well as being a movement designed to increase interconnectivity. It is based on three pillars: People, design and technology
17	Jameel, S.M. and Hashmani, M.A. and Alhussain, H. and Budiman, A. [22]	A fully adaptive image classification approach for industrial revolution 4.0	IR-4.0 describes a future state of industry, which is characterised through the digitisation of economic and production flows. The nine pillars of IR-4.0 are dependent on big data analytics, artificial intelligence, cloud computing technologies and internet of things (IoT)	N/A
18	Fong, S. and Zhuang, Y. and Hu, S. and Song, W. and Liu, L. and Moutinho, L.A. [57]	Longitudinal ambient mobile sensor monitoring for TCM-oriented healthcare assessments: Framework, challenges and applications	N/A	N/A
19	Caggianese, G. et al. [42]	Serious games and in-cloud data analytics for the virtualisation and personalisation of rehabilitation treatments	N/A	N/A
20	Elhoseny, M. and Abdelaziz, A. and Salama, A.S. and Riad, A.M. and Muhammad, K. and Sangaiah, A. K. [63]	A hybrid model of internet of things and cloud computing to manage big data in health services applications	N/A	N/A
21	Pang, Z. and Yang, G. and Khedri, R. and Zhang, Y.-T. [37]	Introduction to the special section: Convergence of automation technology, biomedical engineering, and health informatics toward the healthcare 4.0	Industry 4.0 (also sometimes spelled as industrie 4.0) is a vision for a new industrial revolution put forward by the Communication Promoters Group of the Industry–Science Research Alliance to further enhance	Healthcare 4.0 has been used to denote the trend that more and more technologies incubated in manufacturing industries driven by industry 4.0 are being adopted in healthcare industries and services. It is a continuous but

(Continues)

TABLE C2 (Continued)

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
			Germany's manufacturing industry. It is characterised by some key technologies, namely cyber-physical systems, internet of things, internet of services, cloud computing and artificial intelligence	disruptive process of transformation of the entire healthcare value chain ranging from medicine and medical equipment production, hospital care, non-hospital care, healthcare logistics, healthy living environment to financial and social systems, where vast amount of cyber and physical systems are closely combined through the IoT, intelligent sensing, big data analytics, AI, cloud computing, automatic control, and autonomous execution and robotics to create not only digitalised healthcare products and technologies but also digitalised healthcare services and enterprises
22	Soler, C. [24]	Health 4.0 oriented to non-surgical treatment	N/A	N/A
23	Ahram, T. and Sargolzaei, A. and Sargolzaei, S. and Daniels, J. and Amaba, B. [71]	Blockchain technology innovations	N/A	N/A
24	Sudana, D. and Emanuel, A.W.R [33]	How big data in health 4.0 helps prevent the spread of tuberculosis	N/A	Health 4.0 is a tactical deployment and managerial model for health care inspired by industry 4.0. Health 4.0 must enable gradual virtualisation to support personalised health services near real-time for patients, workers, and formal and informal caregivers
25	Aceto, G. and Persico, V. and Pescapé, A. [27]	Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0	The concept of industry 4.0 can be seen as a governmental explicit commitment to foster a set of technologies and the cultural and legal framework necessary to harness their full potential. It is based on the concept of cyber-physical systems and relies on the internet of things, cloud and fog computing and big data analytics	Healthcare 4.0 is deeply characterised by the adoption of three main paradigms: The internet of things, big data, and cloud computing that together are revolutionising eHealth and its whole ecosystem, like industry 4.0 is doing for the manufacturing sector
26	Abdel-Basset, M. and chang, V. and Nabeeh, N.A. [28]	An intelligent framework using disruptive technologies for COVID-19 analysis	Industry 4.0 augments industry advancements based on the focus on environmental conditions and the development of related technologies. Industry 4.0 relied on the technology of IoT that provides organisations with resilient services	N/A
27	Stephanie, L. and Sharma, R.S. [72]	Digital health eco-systems: An epochal review of practice-oriented research	N/A	N/A
28	Dossou, P.E. and Pereira, R. and Cristiane, S. and Joao, C.J. [25]	How to use lean manufacturing for improving a healthcare logistics performance	Industry 4.0 was defined for implementing new technologies, tools and organisations in companies in order to define their future	N/A

TABLE C2 (Continued)

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
29	Aceto, G. and Persico, V. and Pescapé, A. [49]	The role of information and communication technologies in healthcare: Taxonomies, perspectives, and challenges	N/A	N/A
30	Jung, H. and Chung, K. [66]	Social mining-based clustering process for big-data integration	N/A	N/A
31	Shi, M. and Jiang, R. and Hu, X. and Shang, J. [96]	A privacy protection method for health care big data management based on risk access control	N/A	N/A
32	Qadri, Y.A. and Nauman, A. and Bin Zikria, Y. and Vasilakos, A.V. and Kim, S.W. [43]	The future of healthcare internet of things: A survey of emerging technologies	N/A	N/A
33	Liyakathunisa, S. and Saima, J. and Manimala, S. and Abdullah, A. [58]	Smart healthcare framework for ambient assisted living using IoMT and big data analytics techniques	N/A	N/A
34	Onasanya, A. and Lakkis, S. and Elshakankiri. M [59]	Implementing IoT/WSN based smart Saskatchewan healthcare system	N/A	N/A
35	Bhuiyan, A.R. and Ullah, R. and Das, A.K. [60]	iHealthcare: Predictive model analysis concerning big data applications for interactive healthcare systems	N/A	N/A
36	Moro Visconto, R. and Morea, D. [67]	Big data for the sustainability of healthcare Project financing	N/A	N/A
37	Alexandru, A. and Coardos, D. and Tudora, E. [50]	IoT-based healthcare remote monitoring platform for elderly with fog and cloud computing	N/A	N/A
38	Chung, K. and Park, R.C. [68]	Chatbot-based healthcare service with a knowledge base for cloud computing	N/A	N/A
39	Dhayne, H. and Haque, R. and Kilany, R. [100]	In search of big medical data integration solutions—a comprehensive survey	N/A	N/A
40	Liu, Y. et al. [51]	A novel cloud-based framework for the elderly healthcare services using digital twin	N/A	N/A
41	Kim, J. W. and Jang, B. and Yoo, H. [34]	Privacy-preserving aggregation of personal health data streams	N/A	N/A
42	Manjunath, P. and Prakruthi, M. K. and Shah, P.G. [97]	IoT driven with big data analytics and block chain application scenarios	N/A	N/A
43	Saravanan, M. and Shubha, R. [44]	Non-invasive analytics based smart system for diabetes monitoring	N/A	N/A
44	Patgiri, R. and Nayak, S. [52]	Data of things: The best things since sliced bread	N/A	N/A
45	Coban, S. and Gokalp, M.O. and Gokalp, E. and Eren, P.E. and Kocyigit, A. [73]	Predictive maintenance in healthcare services with big data technologies	N/A	N/A
46	Knickerbocker, J.U. et al. [95]	Heterogeneous integration technology demonstrations for future healthcare, IoT, and AI computing solutions	N/A	N/A

(Continues)

TABLE C2 (Continued)

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
47	Joshi, N. and Kadhiwala, B. [98]	Big data security and privacy issues—a survey	N/A	N/A
48	Dhirani, L.L. and Newe, T. and Lewis, E. and Nizamani, S. [41]	Cloud computing and internet of things fusion: Cost issues	N/A	N/A
49	Golmohammadi, H. and Hamzei, Z. and Hosseinifard, M. and Ahmadi, S.H. [61]	Smart fully integrated lab: A smartphone-based compact miniaturised analytical/diagnostic device	N/A	N/A
50	Friebe, M.H. [29]	Healthcare in need of innovation: Exponential technology and biomedical entrepreneurship as solution providers	The fourth industrial revolution is characterised the evolution and application of artificial intelligence/machine learning/big data in virtually every segment, widespread use of robotics, additive manufacturing and many more dubbed as exponential technologies, because of their digital-exponential-base and other attributes that can lead to more democratic access for anyone	N/A
51	Packianather, M.S. and Munizaga, N. L. and Zouwail, S. and Saunders, M. [62]	Development of soft computing tools and IoT for improving the performance assessment of analysers in a clinical laboratory	N/A	N/A
52	McKee, D.W. and Clement, S.J. and Almutairi, J. and Xu, J. [26]	Massive-scale automation in cyber-physical systems: Vision & challenges	A 4th industrial revolution dubbed industrie 4.0 is emerging, fuelled by the integration of intelligent automation into the manufacturing value chain. The key characteristics and technologies driving this change are the adoption of IoT devices in the manufacturing process, also known as the industrial IoT	N/A
53	Chung, K. and Yoo, H. and Choe, D.-E. [55]	Ambient context-based modelling for health risk assessment using deep neural network	N/A	N/A
54	Fu, H. et al. [101]	Tracing knowledge development trajectories of the internet of things domain: A main path analysis	N/A	N/A
55	Hariri, R.H. and Fredericks, E.M. and Bowers, K.M. [93]	Uncertainty in big data analytics: Survey, opportunities, and challenges	N/A	N/A
56	El-Rahman, S.A. and Al-Montasheri, A. and Al-Hazmi, B. and Al-Dkaan, H. and Al-Shehri, M. [77]	Machine learning model for breast cancer prediction	N/A	N/A
57	Diaz, R.A.C. and Ghita, M. and Copot, D. and Birs, I.R. and Muresan, C. and Ionescu, C. [19]	Context aware control systems: An engineering applications perspective	Industry 4.0 is an umbrella concept for mainstream technologies, for example, Cyber-Physical systems, internet of things (IoT), cloud computing, big data analytics, augmented reality	Health 4.0 can be seen as an extension of industry 4.0
58	Patan, R. and Ghantasala, G.S.P. and Sekaran, R. and Gupta, D. and Ramachandran, M. [46]	Smart healthcare and quality of service in IoT using grey filter convolutional based cyber physical system	N/A	N/A

TABLE C2 (Continued)

Sr.	Author	Title	Industry 4.0 definition or concept	Healthcare 4.0 definition or concept
59	Humayun, M. et al. [69]	Privacy protection and energy optimisation for 5G-aided industrial internet of things	N/A	N/A
60	Elsayad, A.S. and El Desouky, A.I. and Salem, M.M. and Badawy, M. [53]	A deep learning H_2O framework for emergency prediction in biomedical big data	N/A	N/A
61	Makhdoom, I. and Abolhasan, M. and Lipman, J. and Liu, R.P and ni, W. [54]	Anatomy of threats to the internet of things	N/A	N/A
62	Muhammed, T. and Mehmood, R. and Albeshri, A. and Katib, I. [48]	UbeHealth: A personalised ubiquitous cloud and edge-enabled networked healthcare system for smart cities	N/A	N/A

TABLE C3 Data extraction for research question 2

Sr.	Author	Title	Industry 4.0 components
1	d'Agostino Panebianco, M., Capoluongo, A. [99]	Data processing in a Healthcare National System: (With the analysis of the Italian HNS)	Big data
2	Hoosain, M.S. and Paul, B.S. and Ramakrishna, S. [20]	The impact of 4IR digital technologies and circular thinking on the United Nations sustainable development goals	Blockchain, IoT, artificial intelligence, wearables, robotics, big data
3	Javid, T. and Faris, M. and Beenish, H. and Fahad, M. [31]	Cybersecurity and data privacy in the Cloudlet for preliminary healthcare big data analytics	Big data, data analytics, cloud computing, edge computing, cybersecurity, Cloudlets
4	Lhotska, L. [32]	Application of industry 4.0 concept to health care	Digital twin, augmented reality, virtual reality, internet of things, robotics, big data, cybersecurity, artificial intelligence, 3D printing
5	Bagula, A. and Maluleke, H. and Ajayi, O. and Bagula, A. and Bagula, N. and Bagula, M. [65]	Predictive models for mitigating COVID-19 outbreak	Artificial intelligence, data analytics, simulation
6	Ali, S.E., Khan, A.N., Zia, S., Mukhtar, M. [56]	Human activity recognition system using smart phone based accelerometer and machine learning	Artificial intelligence, big data, data analytics, internet of things
7	Massaro, A., and Ricci, G. and Selicato, S. and Raminelli, S. and Galiano, A. [45]	Decisional support system with artificial intelligence oriented on health prediction using a wearable device and big data	Internet of things, artificial intelligence, big data, cloud computing
8	Kalamkar, S. and Mary, G.A [75]	Clinical data fusion and machine learning techniques for Smart Healthcare	Internet of things, big data
9	Al-Jaroodi, J. and Mohamed, N. and Abukhousa, E. [21]	Health 4.0: On the way to realizing the healthcare of the future	Internet of things, internet of services, cyber-physical systems, cloud computing, fog computing, 5G, blockchain, big data, data analytics
10	Lopes, J. and Guimarães, T. and Santos, M.F. [76]	Predictive and prescriptive analytics in healthcare: A survey	Big data, data analytics, artificial intelligence, internet of things
11	Bayoumi, A.-M. and Matthews, R.M.C. and Abdel Fatah, A.A. [64]	The fourth industrial revolution: Digital transformation and industry 4.0 applied to product design, manufacturing and operation	Digital twin, augmented reality, virtual reality, internet of things, data analytics
12	Ratia, M. and Myllärniemi, J. and Helander, N. [35]	The potential beyond IC 4.0: The evolution of business intelligence towards advanced business analytics	Big data, data analytics, artificial intelligence
13	Rath, D. and Satpathy, I. and Patnaik, B.C.M. [23]	Augmented reality (Ar) & virtual reality (Vr)—a channel for digital transformation in industrialisation fostering innovation and entrepreneurship	Augmented reality, virtual reality

(Continues)

TABLE C3 (Continued)

Sr.	Author	Title	Industry 4.0 components
14	Wehde, M. [47]	Healthcare 4.0	Artificial intelligence, big data, data analytics, robotics, 3D printing, cloud computing
15	Ojra, A. [30]	Revisiting industry 4.0: A new definition	Internet of things, cloud computing, big data, cyber-physical systems
16	Bause, M. and Khayamian Esfahani, B. and Forbes, H. and Schaefer, D. [36]	Design for health 4.0: Exploration of a new area	Internet of things, mobiles, augmented reality, big data, data analytics, artificial intelligence, cyber-physical systems
17	Jameel, S.M. and Hashmani, M.A. and Alhussain, H. and Budiman, A. [22]	A fully adaptive image classification approach for industrial revolution 4.0	Big data
18	Fong, S. and Zhuang, Y. and Hu, S. and Song, W. and Liu, L. and Moutinho, L.A. [57]	Longitudinal ambient mobile sensor monitoring for TCM-oriented healthcare assessments: Framework, challenges and applications	Mobiles, internet of things, big data
19	Caggianese, G. et al. [42]	Serious games and in-cloud data analytics for the virtualisation and personalisation of rehabilitation treatments	Big data, data analytics, cloud computing
20	Elhoseny, M. and Abdelaziz, A. and Salama, A.S. and Riad, A.M. and Muhammad, K. and Sangaiah, A. K. [63]	A hybrid model of internet of things and cloud computing to manage big data in health services applications	Cloud computing, internet of things, big data, data analytics
21	Pang, Z. and Yang, G. and Khedri, R. and Zhang, Y.-T. [37]	Introduction to the special section: Convergence of automation technology, biomedical engineering, and health informatics toward the healthcare 4.0	Cyber-physical systems, internet of things, internet of services, cloud computing, artificial intelligence, robotics, 3D printing, big data
22	Soler, C. [24]	Health 4.0 oriented to non-surgical treatment	Big data, artificial intelligence, internet of things, robotics, 3D printing, augmented reality
23	Ahram, T. and Sargolzaei, A. and Sargolzaei, S. and Daniels, J. and Amaba, B. [71]	Blockchain technology innovations	Blockchain, cloud computing, internet of things, cybersecurity, mobiles
24	Sudana, D. and Emanuel, A.W.R. [33]	How big data in health 4.0 helps prevent the spread of tuberculosis	Big data, internet of things, internet of services, cyber-physical systems
25	Aceto, G. and Persico, V. and Pescapé, A. [27]	Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0	Big data, internet of things, cloud computing, fog computing, 5G, mobiles, cyber-physical systems, artificial intelligence
26	Abdel-Basset, M. and chang, V. and Nabeeh, N.A. [28]	An intelligent framework using disruptive technologies for COVID-19 analysis	Artificial intelligence, internet of things, big data, virtual reality, robotics, 5G, blockchain
27	Stephanie, L. and Sharma, R.S. [72]	Digital health eco-systems: An epochal review of practice-oriented research	Blockchain, cloud computing, big data, data analytics, internet of things, artificial intelligence, cybersecurity
28	Dossou, P.E. and Pereira, R. and Cristiane, S. and Joao, C.J. [25]	How to use lean manufacturing for improving a healthcare logistics performance	Artificial intelligence, internet of things, robotics, blockchain
29	Aceto, G. and Persico, V. and Pescapé, A. [49]	The role of information and communication technologies in healthcare: Taxonomies, perspectives, and challenges	Internet of things, cloud computing, mobiles, robotics, big data, data analytics, 3D printing, 5G, fog computing, mobile edge computing, mobile cloud computing, artificial intelligence, cybersecurity
30	Jung, H. and Chung, K. [66]	Social mining-based clustering process for big-data integration	Internet of things, artificial intelligence, blockchain, fog computing, edge computing, simulation
31	Shi, M. and Jiang, R. and Hu, X. and Shang, J. [96]	A privacy protection method for health care big data management based on risk access control	Big data, cloud computing, blockchain
32	Qadri, Y.A. and Nauman, A. and Bin Zikria, Y. and Vasilakos, A.V. and Kim, S.W. [43]	The future of healthcare internet of things: A survey of emerging technologies	Internet of things, edge computing, fog computing, cloud computing, big data, data analytics, blockchain, 5G, cybersecurity
33	Liyakathunisa, S. and Saima, J. and Manimala, S. and Abdullah, A. [58]	Smart healthcare framework for ambient assisted living using IoMT and big data analytics techniques	Internet of things, big data, data analytics, artificial intelligence, cybersecurity

TABLE C3 (Continued)

Sr.	Author	Title	Industry 4.0 components
34	Onasanya, A. and Lakkis, S. and Elshakankiri. M [59]	Implementing IoT/WSN based smart Saskatchewan healthcare system	Internet of things, big data, data analytics, cloud computing
35	Bhuiyan, A.R. and Ullah, R. and Das, A.K. [60]	iHealthcare: Predictive model analysis concerning big data applications for interactive healthcare systems	Big data, cloud computing, internet of things
36	Moro Visconto, R. and Morea, D. [67]	Big data for the sustainability of healthcare project financing	Big data, internet of things
37	Alexandru, A. and Coardos, D. and Tudora, E. [50]	IoT-based healthcare remote monitoring platform for elderly with fog and cloud computing	Internet of things, cloud computing, fog computing, big data, data analytics, cybersecurity
38	Chung, K. and Park, R.C. [68]	Chatbot-based healthcare service with a knowledge base for cloud computing	Artificial intelligence, cloud computing, big data, cybersecurity
39	Dhayne, H. and Haque, R. and Kilany, R. [100]	In search of big medical data integration solutions—a comprehensive survey	Big data
40	Liu, Y. et al. [51]	A novel cloud-based framework for the elderly healthcare services using digital twin	Internet of things, cloud computing, big data, mobiles, simulation, digital twin
41	Kim, J. W. and Jang, B. and Yoo, H. [34]	Privacy-preserving aggregation of personal health data streams	Internet of things, cloud computing, big data, data analytics, cybersecurity
42	Manjunath, P. and Prakruthi, M. K. and Shah, P.G. [97]	IoT driven with big data analytics and block chain application scenarios	Big data, data analytics, internet of things, blockchain
43	Saravanan, M. and Shubha, R. [44]	Non-invasive analytics based smart system for diabetes monitoring	Internet of things, mobiles, cloud computing, data analytics
44	Patgiri, R. and Nayak, S. [52]	Data of things: The best things since sliced bread	Internet of things, big data, cloud computing, data analytics
45	Coban, S. and Gokalp, M.O. and Gokalp, E. and Eren, P.E. and Kocyigit, A. [73]	Predictive maintenance in healthcare services with big data technologies	Internet of things, big data, cloud computing, data analytics
46	Knickerbocker, J.U. et al. [95]	Heterogeneous integration technology demonstrations for future healthcare, IoT, and AI computing solutions	Artificial intelligence, internet of things, mobiles
47	Joshi, N. and Kadhiwala, B. [98]	Big data security and privacy issues—a survey	Big data, cloud computing, cybersecurity
48	Dhirani, L.L. and Newe, T. and Lewis, E. and Nizamani, S. [41]	Cloud computing and internet of things fusion: Cost issues	Cloud computing, internet of things
49	Golmohammadi, H. and Hamzei, Z. and Hosseinifard, M. and Ahmadi, S.H. [61]	Smart fully integrated lab: A smartphone-based compact miniaturised analytical/diagnostic device	Mobiles, internet of things, data analytics, fog computing
50	Friebe, M.H. [29]	Healthcare in need of innovation: Exponential technology and biomedical entrepreneurship as solution providers	Internet of things, artificial intelligence, robotics, blockchain, 3D printing, big data, mobiles
51	Packianather, M.S. and Munizaga, N.L. and Zouwail, S. and Saunders, M. [62]	Development of soft computing tools and IoT for improving the performance assessment of analysers in a clinical laboratory	Artificial intelligence, big data, internet of things
52	McKee, D.W. and Clement, S.J. and Almutairi, J. and Xu, J. [26]	Massive-scale automation in cyber-physical systems: Vision & challenges	Internet of things, cloud computing, edge computing, fog computing, big data, data analytics, cyber-physical systems, blockchain, robotics, simulation, cybersecurity
53	Chung, K. and Yoo, H. and Choe, D.-E. [55]	Ambient context-based modelling for health risk assessment using deep neural network	Big data, internet of things, artificial intelligence, cybersecurity
54	Fu, H. et al. [101]	Tracing knowledge development trajectories of the internet of things domain: A main path analysis	Internet of things, big data, cloud computing
55	Hariri, R.H. and Fredericks, E.M. and Bowers, K.M. [93]	Uncertainty in big data analytics: Survey, opportunities, and challenges	Big data, data analytics, artificial intelligence

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TABLE C3 (Continued)

Sr.	Author	Title	Industry 4.0 components
56	El-Rahman, S.A. and Al-Montasheri, A. and Al-Hazmi, B. and Al-Dkaan, H. and Al-Shehri, M. [77]	Machine learning model for breast cancer prediction	Big data, artificial intelligence
57	Diaz, R.A.C. and Ghita, M. and Copot, D. and Birs, I.R. and Muresan, C. and Ionescu, C. [19]	Context aware control systems: An engineering applications perspective	Internet of things, artificial intelligence, cyber-physical systems
58	Patan, R. and Ghantasala, G.S.P. and Sekaran, R. and Gupta, D. and Ramachandran, M. [46]	Smart healthcare and quality of service in IoT using grey filter convolutional based cyber physical system	Internet of things, cloud computing, fog computing, artificial intelligence, big data, cyber-physical systems, simulation
59	Humayn, M. et al. [69]	Privacy protection and energy optimisation for 5G-Aided industrial internet of things	Internet of things, 5G, cyber-physical systems
60	Elsayad, A.S. and El Desouky, A.I. and Salem, M.M. and Badawy, M. [53]	A deep learning H2O framework for emergency prediction in biomedical big data	Internet of things, big data, artificial intelligence
61	Makhdoom, I. and Abolhasan, M. and Lipman, J. and Liu, R.P and ni, W. [54]	Anatomy of threats to the internet of things	Internet of things, cloud computing, fog computing, blockchain, cybersecurity
62	Muhammed, T. and Mehmood, R. and Albeshri, A. and Katib, I. [48]	UbeHealth: A personalised ubiquitous cloud and edge-enabled networked healthcare system for smart cities	Internet of things, cloud computing, big data, artificial intelligence, robotics, 5G, Cloudlets, mobiles, simulation

TABLE C4 Data extraction for research question 3

Sr.	Author	Title	Benefits	Challenges
1	d'Agostino Panebianco, M., Capoluongo, A. [99]	Data processing in a Healthcare National System: (With the analysis of the Italian HNS)	N/A	Proper processing of data, legal framework and compliance with rules and regulations
2	Hoosain, M.S. and Paul, B.S. and Ramakrishna, S. [20]	The impact of 4IR digital technologies and circular thinking on the united nations sustainable development goals	Reduced costs, effective production	Government interventions, lack of education, collaborations and incentives towards businesses
3	Javid, T. and Faris, M. and Beenish, H. and Fahad, M. [31]	Cybersecurity and data privacy in the Cloudlet for preliminary healthcare big data analytics	Data security and privacy	N/A
4	Lhotska, L. [32]	Application of industry 4.0 concept to health care	Predictive maintenance, production planning, scheduling and management, monitoring state of machines, warehousing costs, supplier dependence, monitoring machines or environment condition, automatic quality control	Precision and accuracy, reliability, security and privacy, energy efficiency, interoperability and modularity, data fragmentation, understanding the data, IoT security threats and a lack of security standards for IoT
5	Bagula, A. and Maluleke, H. and Ajayi, O. and Bagula, A. and Bagula, N. and Bagula, M. [65]	Predictive models for mitigating COVID-19 outbreak	Pre-empty a pandemic rather than cure infected patients	N/A
6	Ali, S.E., Khan, A.N., Zia, S., Mukhtar, M. [56]	Human activity recognition system using smart phone based accelerometer and machine learning	Quick and efficient monitoring and treatment of patients	N/A
7	Massaro, A., and Ricci, G. and Selicato, S. and Raminelli, S. and Galiano, A. [45]	Decisional support system with artificial intelligence oriented on health prediction using a wearable device and big data	Improved telemedicine services	N/A

TABLE C4 (Continued)

Sr.	Author	Title	Benefits	Challenges
8	Kalamkar, S. and Mary, G.A. [75]	Clinical data fusion and machine learning techniques for Smart Healthcare	Providing better insight, combining the knowledge from multiple sources, quantitatively data can be used in various processes, data can be easily categorised, build a context-awareness model	Data heterogeneity, systems reliability, proper patient identification, need for server based data transfer, the lack of proper context-aware fusion approaches
9	Al-Jaroodi, J. and Mohamed, N. and Abukhousa, E. [21]	Health 4.0: On the way to realizing the healthcare of the future	Flexibility, scalability, reliability, agility, cost-effectiveness and quality of healthcare services and operations benefiting patients, healthcare professionals, the resource management and the healthcare systems management	Data fragmentation, standardisation, continuous and fine grain data collection, data privacy and protection, sharing and exchange of medical records, automation tools and monitoring services, integration of healthcare systems, design and evaluation of leaner process, analysis of use of resources, techniques for smart operations, change and adoption of new technologies, effective secure collaborative techniques, optimisation and automation efforts
10	Lopes, J. and Guimarães, T. and Santos, M.F. [76]	Predictive and prescriptive analytics in healthcare: A survey	Clinical decision support, public healthcare, administration and mental health	N/A
11	Bayoumi, A.-M. and Matthews, R.M.C. and Abdel Fatah, A. A. [64]	The fourth industrial revolution: Digital transformation and industry 4.0 applied to product design, manufacturing and operation	Product quality, production costs, efficiency, continuous improvement, increased ROI	Users training and education
12	Ratia, M. and Myllärniemi, J. and Helander, N. [35]	The potential beyond IC 4.0: The evolution of business intelligence towards advanced business analytics	Operational efficiency and performance excellence, data-driven evidence based decision-making, value creation, new core business, utilisation of external sources	N/A
13	Rath, D. and Satpathy, I. and Patnaik, B.C.M. [23]	Augmented reality (Ar) & virtual reality (Vr)—a channel for digital transformation in industrialisation fostering innovation and entrepreneurship	Imaging learning for human anatomy coercion, opportunities for industrialisation, enabling technovation and sociovation for business sustainability, products manufacturing	Skills gap
14	Wehde, M. [47]	Healthcare 4.0	Decision-making, convert routine patient care actions into data points for worldwide clinical trials, complex surgeries	Highly regulated, capital intensive, education requirements, data sharing, data privacy and ownership, data complexity and volume
15	Ojra, A. [30]	Revisiting industry 4.0: A new definition	Health and safety systems, labour costs, productivity, supply chains, big data management, revenues	Data security and privacy, technology standardisation, implementation costs, stability, reliability, experience
16	Bause, M. and Khayamian Esfahani, B. and Forbes, H. and Schaefer, D. [36]	Design for health 4.0: Exploration of a new area	Healthcare services precision, personalised treatment, healthcare services costs, online communities for sharing experiences	Significant and rapid change from the current system, professionals re-training, collaboration between professionals, patient sovereignity

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TABLE C4 (Continued)

Sr.	Author	Title	Benefits	Challenges
17	Jameel, S.M. and Hashmani, M. A. and Alhussain, H. and Budiman, A. [22]	A fully adaptive image classification approach for industrial revolution 4.0	Business intelligence operations in healthcare organisations	N/A
18	Fong, S. and Zhuang, Y. and Hu, S. and Song, W. and Liu, L. and Moutinho, L.A. [57]	Longitudinal ambient mobile sensor monitoring for TCM-oriented healthcare assessments: Framework, challenges and applications	Self-monitoring of health by patients, medical insurance fees	Close collaboration between IT and healthcare professionals
19	Caggianese, G. et al. [42]	Serious games and in-cloud data analytics for the virtualisation and personalisation of rehabilitation treatments	Effective, motivating, rewarded and motivated rehabilitation therapy, which is tailored to patients, patients' quality of life, social costs of rehabilitation processes	N/A
20	Elhoseny, M. and Abdelaziz, A. and Salama, A.S. and Riad, A. M. and Muhammad, K. and Sangaiah, A.K. [63]	A hybrid model of internet of things and cloud computing to manage big data in health services applications	Execution, waiting and turnaround time of medical requests, task scheduling, utilisation of resources, access to patients' data	Execution time and resource utilisation for large volume of data
21	Pang, Z. and Yang, G. and Khedri, R. and Zhang, Y.-T. [37]	Introduction to the special section: Convergence of automation technology, biomedical engineering, and health informatics toward the healthcare 4.0	Medicine production, patients' diagnosis, advanced surgical operations, assisting humans in their daily live activities	Close collaboration, data security, users privacy, users reluctance, data availability, human safety, need for education
22	Soler, C. [24]	Health 4.0 oriented to non-surgical treatment	Disease prediction, diagnosis and decision-making, remote medical care and monitoring, new treatment plans, personalised implants, surgery accuracy and efficiency, minimal invasive interventions, sample processing, development of prosthetics, rehabilitation, equipment transport, assistive solutions	Legal and ethical issues
23	Ahram, T. and Sargolzaei, A. and Sargolzaei, S. and Daniels, J. and Amaba, B. [71]	Blockchain technology innovations	Agile value chains, product innovations, customer relationships, security, scalability and efficiency	Regulations, frauds, cyber crime
24	Sudana, D. and Emanuel, A.W.R. [33]	How big data in health 4.0 helps prevent the spread of tuberculosis	Monitoring patients' health, clinical research, early diagnosis of diseases, reduced hospital errors	Obtaining data for medical purposes, strict regulations about confidentiality
25	Aceto, G. and Persico, V. and Pescapé, A. [27]	Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0	Enhanced electromedical devices, interoperability, evolvability, paradigmatic model for offering of services, new insights and actionable information, infrastructure for high-level functions	Energy constraints, data privacy and security, scalability, performance monitoring, infrastructure opacity and availability, analytics opacity, data and devices heterogeneity
26	Abdel-Basset, M. and Chang, V. and Nabeeh, N.A. [28]	An intelligent framework using disruptive technologies for COVID-19 analysis	Safety of medical teams, patients' health condition monitoring and maintaining, reduced pressure on hospitals, tracking recovered COVID-19 patients to treat current ones	N/A

TABLE C4 (Continued)

Sr.	Author	Title	Benefits	Challenges
27	Stephanie, L. and Sharma, R.S. [72]	Digital health eco-systems: An epochal review of practice-oriented research	IT infrastructure and maintenance costs	Investment costs, uncertain ROI, loss of productivity, incentives misalignment, data security and privacy
28	Dossou, P.E. and Pereira, R. and Cristiane, S. and Joao, C.J. [25]	How to use lean manufacturing for improving a healthcare logistics performance	Tracking of medicines, dispatching of food and medicines in hospitals	N/A
29	Aceto, G. and Persico, V. and Pescapé, A. [49]	The role of information and communication technologies in healthcare: Taxonomies, perspectives, and challenges	Telepathology, medical status and disease monitoring, monitoring of medication intake, home-based rehabilitation, assisted living, analysis and storage of bioinformatics data, design, development and deployment of data collection and analysis systems, detection of frauds, wastes and errors, shifting medical treatment to prevention	Data security and privacy, ethical issues, data variety, heterogeneity and fragmentation, computing, software and hardware requirements, configuration of fog computing applications, interoperability, a lack consensus about jurisdiction over data, differences or lack of policies and regulations
30	Jung, H. and Chung, K. [66]	Social mining-based clustering process for big-data integration	Patients' health and disease risk	N/A
31	Shi, M. and Jiang, R. and Hu, X. and Shang, J. [96]	A privacy protection method for health care big data management based on risk access control	Decision-making for hospital managers, prediction and guidance for healthcare professionals, improvement of the healthcare management model, refined healthcare services, promotion of hospital comprehensive management capabilities	Data availability, integrity and confidentiality, moral and ethical issues, patients' personal safety
32	Qadri, Y.A. and Nauman, A. and Bin Zikria, Y. and Vasilakos, A.V. and Kim, S.W. [43]	The future of healthcare internet of things: A survey of emerging technologies	System latency and reliability, computational capabilities, real-time discover of abnormal behaviour, precision medicine	Data interoperability and security, scalability, service availability, regulatory policies, time constraints, redundancy in training datasets, integration with smart cities, integration of data from different sources
33	Liyakathunisa, S. and Saima, J. and Manimala, S. and Abdullah, A. [58]	Smart healthcare framework for ambient assisted living using IoMT and big data analytics techniques	Automation, remote monitoring, objective reporting, target-oriented medicine, interoperability, personalised healthcare services, risk factors prediction, treatment recommendations	Users' acceptance, privacy and confidentiality, data quality, data isolation
34	Onasanya, A. and Lakkis, S. and Elshakankiri. M. [59]	Implementing IoT/WSN based smart Saskatchewan healthcare system	Monitoring patients' condition, detect diseases, manage chronic illnesses, assisting people with disabilities, drug administration, streamline workflows and processes, control and monitoring of hospital assets and medical equipment, prompt access to	Government regulatory policies, device diversity and heterogeneity, security breaches, loss of signals and connectivity, power generation and capacity of connected devices, strength and security of the channels, security

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TABLE C4 (Continued)

Sr.	Author	Title	Benefits	Challenges
			patient vital statistics, confidentiality and privacy of patients' records, drug/ medicine inventory management, patients' safety	
35	Bhuiyan, A.R. and Ullah, R. and Das, A.K. [60]	iHealthcare: Predictive model analysis concerning big data applications for interactive healthcare systems	Disease prevention, minimised treatment variations, reduced unexpected costs, minimised oversight of drug prescription, reduced preventable casualties	Unstructured or semi-structured data
36	Moro Visconto, R. and Morea, D. [67]	Big data for the sustainability of healthcare Project financing	Sales planning, revenue streams optimisation, operations optimisation, supply chain optimisation, market feedback of revenues, better forecasting of input data, improved margins and cash flows, reduced risk and volatility	Data heterogeneity, security, privacy and confidentiality
37	Alexandru, A. and Coardos, D. and Tudora, E. [50]	IoT-based healthcare remote monitoring platform for elderly with fog and cloud computing	Real-time interactions, bandwidth, mobility support, geographical distribution of data analytics, interoperability, low latency and energy consumption, patient-centred practice, disease prevention, costs reduction	Data security and confidentiality, users acceptance and awareness, business model exploitation
38	Chung, K. and Park, R.C. [68]	Chatbot-based healthcare service with a knowledge base for cloud computing	Immediate response for accidents, monitoring of patients with chronic diseases	Data complexity and volume
39	Dhayne, H. and Haque, R. and Kilany, R. [100]	In search of big medical data integration solutions—a comprehensive survey	Disease prediction, selection of appropriate treatment paths	Unstructured and heterogeneous data, a lack of standards, patient privacy and security, data conflicts, lack of expertise
40	Liu, Y. et al. [51]	A novel cloud-based framework for the elderly healthcare services using digital twin	Testing of medicines, remote monitoring and diagnosis of patients, real-time monitoring and management of medical devices	N/A
41	Kim, J. W. and Jang, B. and Yoo, H. [34]	Privacy-preserving aggregation of personal health data streams	Customised advices and treatments	Data privacy
42	Manjunath, P. and Prakruthi, M. K. and Shah, P.G. [97]	IoT driven with big data analytics and block chain application scenarios	Establishment of safe network for worldwide medical data exchange	Data privacy, unstructured data
43	Saravanan, M. and Shubha, R. [44]	Non-invasive analytics based smart system for diabetes monitoring	Reduction in mortality rates, less clinic visits, less hospital admissions, shorter stays in hospitals, remote monitoring of patients, involvement of patients in treatment process, real-time prediction, early symptoms identification	N/A
44	Patgiri, R. and Nayak, S. [52]	Data of things: The best things since sliced bread	Monitoring, prevention and prediction of heart diseases, building right and accurate patients' profiles	Data heterogeneity, privacy, security, confidentiality and integrity, data partition and congestion, interoperability,

TABLE C4 (Continued)

Sr.	Author	Title	Benefits	Challenges
				availability, reliability and mobility of devices, excessive power requirements
45	Coban, S. and Gokalp, M.O. and Gokalp, E. and Eren, P.E. and Kocyigit, A. [73]	Predictive maintenance in healthcare services with big data technologies	Accuracy of biomedical devices, patients and healthcare personnel quality of life, reduced risks related to radiation or malfunction of biomedical devices, decreased likelihood of incorrect diagnosis, sharing biomedical data online, improved decision-making for hospitals	Expertise and know-how of the field, infrastructure requirements
46	Knickerbocker, J.U. et al. [95]	Heterogeneous integration technology demonstrations for future healthcare, IoT, and AI computing solutions	Chronic diseases monitoring, monitoring of activities of daily living	N/A
47	Joshi, N. and Kadhiwala, B. [98]	Big data security and privacy issues—a survey	N/A	Data integrity, availability and heterogeneity, data life cycle management, security and privacy, scalability, data visualisation
48	Dhirani, L.L. and Newe, T. and Lewis, E. and Nizamani, S. [41]	Cloud computing and internet of things fusion: Cost issues	Cost savings, convenience of resources	Processing power, storage capabilities, interoperability, scalability, security, availability, protocol support, energy efficiency, resource allocation, data locality
49	Golmohammadi, H. and Hamzei, Z. and Hosseinifard, M. and Ahmadi, S.H. [61]	Smart fully integrated lab: A smartphone-based compact miniaturised analytical/diagnostic device	Innovative services, patients' data analysis, waste recycling management, precise surgery, medical imaging, medical researches, reduced time and cost for analysis of biomedical data and data transportation	N/A
50	Friebe, M.H. [29]	Healthcare in need of innovation: Exponential technology and biomedical entrepreneurship as solution providers	Reduced visits to doctors, reduced diagnosis and treatment costs, enhanced patients treatment	The lack of non-technical skills, data segmentation, AI results may not be easily comprehensible, regulatory acceptance, ethical issues, data protection
51	Packianather, M.S. and Munizaga, N.L. and Zouwail, S. and Saunders, M. [62]	Development of soft computing tools and IoT for improving the performance assessment of analysers in a clinical laboratory	Reduced degree of danger for patients and medical personnel, customer satisfaction, monetary profits	N/A
52	McKee, D.W. and Clement, S.J. and Almutairi, J. and Xu, J. [26]	Massive-scale automation in cyber-physical systems: Vision & challenges	Reduced demand of healthcare services, secured sharing of medical records	Data security and volume, curse of dimensionality, integration of simulation, augmentation and integration of existing systems, incompatible standards, bandwidth and latency issues
53	Chung, K. and Yoo, H. and Choe, D.-E. [55]	Ambient context-based modelling for health risk assessment using deep neural network	Chronic disease prevention, early disease prevention for patients undergoing surgical treatment	Data heterogeneity

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TABLE C4 (Continued)

Sr.	Author	Title	Benefits	Challenges
54	Fu, H. et al. [101]	Tracing knowledge development trajectories of the internet of things domain: A main path analysis	Remote monitoring of patients' health, support of emergency medical devices	Security and privacy of IoT devices
55	Hariri, R.H. and Fredericks, E.M. and Bowers, K.M. [93]	Uncertainty in big data analytics: Survey, opportunities, and challenges	N/A	Data and analytics process uncertainty, unstructured, noisy and biased data
56	El-Rahman, S.A. and Al-Montasheri, A. and Al-Hazmi, B. and Al-Dkaan, H. and Al-Shehri, M. [77]	Machine learning model for breast cancer prediction	Breast cancer prediction	N/A
57	Diaz, R.A.C. and Ghita, M. and Copot, D. and Birs, I.R. and Muresan, C. and Ionescu, C.	Context aware control systems: An engineering applications perspective	Personalised advanced guidance to patients, support to ambient assisted living, early disease prediction and treatment	N/A
58	Patan, Rizwan; Ghantasala, G. S. Pradeep; Sekaran, Ramesh; et al. [46]	Smart healthcare and quality of service in IoT using grey filter convolutional based cyber physical system	Increased accuracy rate of healthy heart signals classification, reduced communication time, end-to-end response time and overhead	Connectivity and convergence between communicating parties during diagnosis of disease
59	Humayun, M. et al. [69]	Privacy protection and energy optimisation for 5G-Aided industrial internet of things	N/A	Data, identity and location privacy, energy resources optimisation
60	Elsayad, A.S. and El Desouky, A. I. and Salem, M.M. and Badawy, M. [53]	A deep learning H_2O framework for emergency prediction in biomedical big data	Prediction of emergency cases	Time and accuracy of learning process for big data applications
61	Makhdoom, Imran; Abolhasan, Mehran; Lipman, Justin; et al. [54]	Anatomy of threats to the internet of things	Transactions integrity and authentication, decentralised and unforgeable digital ledger, trustless operation	Consistency and standardisation in IoT devices, IoT devices security and privacy
62	Muhammed, T. and Mehmood, R. and Albeshri, A. and Katib, I. [48]	UbeHealth: A personalised ubiquitous cloud and edge-enabled networked healthcare system for smart cities	Lower costs for maintenance and operation, unlimited usage of resources, support of multiple devices platforms, reduced patients costs	Latency, bandwidth, energy efficiency, reliability, security