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RESEARCH ARTICLE

Semantic Ontologies for Complex Healthcare Structures: A Scoping Review

ALESSIO LUSCHI[1], CAMILLA PETRACCONE[1], GIUSEPPE FICO[2], (Member, IEEE), LEANDRO PECCHIA[3,4], (Member, IEEE), AND ERNESTO IADANZA[5], (Senior Member, IEEE)

[1]Department of Information Engineering, University of Florence, 50139 Florence, Italy
[2]Life Supporting Technologies, Universidad Politécnica de Madrid, 28040 Madrid, Spain
[3]School of Engineering, The University of Warwick, CV4 7AL Coventry, U.K.
[4]Department of Engineering, Università Campus Bio-Medico di Roma, 00128 Rome, Italy
[5]Department of Medical Biotechnologies, University of Siena, 53100 Siena, Italy

Corresponding author: Alessio Luschi (alessio.luschi@unifi.it)

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ABSTRACT The healthcare environment is made up of highly complicated interactions between many technologies, activities, and people. Ensuring a solid communication between them is vital to ease the healthcare management. Semantic ontologies are knowledge representation tools that implement abstractions to fully describe a given topic in terms of subjects and relations. This scoping review aims to identify and analyse available ontologies which can depict all the available use-cases that describe the hospital environment in relation to the European project ODIN and its future expansion. The review has been conducted on the Scopus database on January 13th, 2023 using the PRISMA extensions for scoping reviews. Two reviewers screened 3,225 documents emerged from the database search. Further filtering led to a final set of 32 articles to be analysed for the results. A set of 34 ontologies extracted by the identified articles has been analysed and discussed as well. The results of this study will lead to the implementation of a common integrated ontology which could hold information about healthcare entities as well as their semantic relationships, strengthen data exchange and interconnections among people, devices and applications in an expanded scenario which include Internet of Things, robots and Artificial Intelligence.

INDEX TERMS Artificial intelligence, healthcare structures, IoT, medical devices, ontologies, robotics, semantics.

I. INTRODUCTION

The hospital environment is becoming more and more complex as the technological development is advancing [1]. Nowadays, healthcare facilities incorporate different tools and technologies for empowering the efficacy and efficiency of health treatments, and for minimizing the obstacles about accessibility and cooperation, as well as strengthening safety [2], productivity and quality of the working environment [3], while preserving cost-effectiveness. Digital solutions which support services and resources are being introduced in this scenario: Internet of Things (IoT), robotics, mobile apps [4], sensors and Artificial Intelligence (AI) are increasingly becoming important in almost all healthcare processes [5], [6], [7]. These technologies aim to relieve workers from hard and time-consuming activities while also improving routine tasks. Robotics and AI play a significant role in helping human workers to perform better in urgent situations by replacing them in tasks where the human presence is not required [8]. The introduction of cutting-edge technologies, their integration into the healthcare environment, and their interaction with patients and the local community all benefit clinical workflows, medical locations, and logistics [9]. The primary issue that arises when integrating various complex technologies into an equally or even more complex and diverse environment, such as a hospital, is the

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need for a fully common layer to share the gathered data and information [10], [11]. Additionally, a comprehensive representation of every potential topic and activity at play, from which the gathered data may originate, is also required. The benefits listed above are less significant and practical if the systems are closed-boxes that cannot communicate with one another or if they do not exchange, describe, and treat data in the same way. Additionally, maintaining the sustainability of the healthcare system can be extremely difficult. In this regard, semantic ontologies are very useful tools which allow sharing as well as reusing concepts in a standardized way so that the data gathered from heterogeneous sources receive a common nomenclature [12]. They can be used to enhance the traditional approaches to healthcare facilities management [13], facilitate Healthcare Technology Management (HTM), strengthen communications, and outline every potential interaction between various roles.

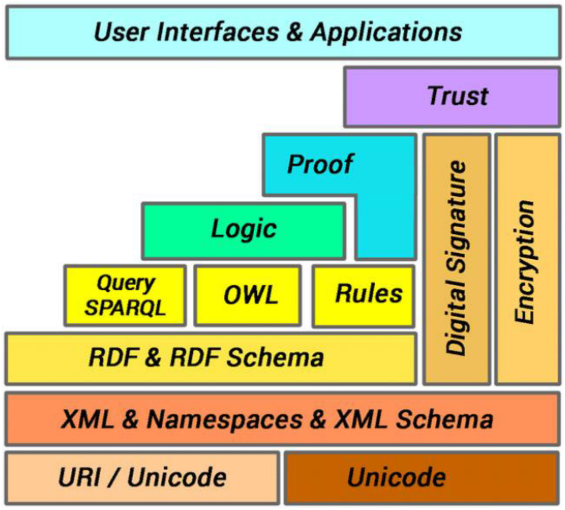

FIGURE 1. Semantic Web stack.

A. SEMANTIC ONTOLOGIES

A semantic ontology is a tool for knowledge representation built on formal collections of terms. It is used to describe and represent a field of interest (also known as a domain) clearly and consistently. The Semantic Web (Fig. 1), a World Wide Web extension created by the World Wide Web Consortium (W3C) [14] with the primary objective of enabling computers to support networked interactions, is grounded on ontologies. The Semantic Web offers a framework for data querying and ontology-based inferences using a variety of technologies. Numerous applications use ontologies and vocabularies to make it easier to integrate data from various sources and to formally organize knowledge by connecting terms through logical relationships. Drawing inferences (automatic processes that create new relationships based on the data stored in the vocabulary itself) in order to carry out reasoning procedures is also made possible by ontologies. An ontology's structure is hierarchical and is based on techniques that divide the items it contains into "classes" and "sub-classes". Individual resources may then be mutually associated, resulting in the logical association of classes and instances. Semantic ontologies are becoming increasingly important because of their capabilities to provide a common representation of a domain among different users by linking concepts and instances, supporting interoperability between heterogeneous data archives, and fostering the reuse and sharing of knowledge [15].

The W3C provides several techniques to define various forms of standard vocabularies given the broad range of operations provided by ontologies, such as Resource Description Framework (RDF), Web Ontology Language (OWL), Javascript Object Notation for Linked Data (JSON-LD), and HL7 Fast Healthcare Interoperability Resources (FHIR) [16]. According to the W3C Semantic Web, RDF is a standard model for data interchange on the Web. RDF has features that facilitate data merging even if the underlying schemas differ, and it specifically supports the evolution of schemas over time without requiring all the data consumers to be changed. RDF extends the linking structure of the Web to use Uniform Resource Identifiers (URIs) to name the relationship between things as well as the two ends of the link (this is usually referred to as a "triple"). Using this simple model, it allows structured and semi-structured data to be mixed, exposed, and shared across different applications. This linking structure forms a directed, labeled graph, where the edges define the link between two resources, represented by the graph nodes. This graph view is the easiest mental model for RDF and is often used in easy-to-understand visual explanations [17]. OWL is a language for the semantic web, designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language making it possible that knowledge expressed in OWL can be exploited by computer programs, for verifying consistency or to make explicit some implicit knowledge. OWL documents, known as ontologies, can be published in the World Wide Web and may refer to or be referred by other OWL ontologies [18]. JSON-LD is a linked data serialization recommended by the W3C. It is an extension of the JSON format that integrates Linked Data to a website. It also provides an RDF serialization format to contextualize data [19]. HL7/FHIR is a standard for exchanging electronic healthcare information allowing data requests and transfers between various healthcare systems. The main goal of FHIR is to solve a wide range of clinical and administrative healthcare problems to improve interoperability; it can be expressed as XML (eXtensible Markup Language), JSON or RDF/TURTLE encodings [20].

B. THE ODIN PROJECT AND OHIO

ODIN is a European project funded under Horizon 2020 [21] - the EU Research and Innovation program that has the aim to achieve the generation of world-class science - focused on the enhancement of hospital safety, productivity and quality. The main objective of the project is to deliver an open digital platform, supporting a suite of services and Key Enabling Resources (KERs) empowered by robotics, IoT solutions and specialised AI. These resources are tested on seven clinical use cases in leading hospitals of six European countries: Spain, France, Germany, Poland, Netherlands, and Italy [22]. They will be implemented in three reference areas of hospital interventions named eWorkers, eRobots, and eLocations. The former focuses on providing hospital workers with technologies in order to relieve them from particularly hard and time-consuming activities and to improve ordinary tasks. The second one aims at automatizing hospital processes with the aid of robotics technology to help human workers in performing their tasks, letting operators focus on core tasks. Finally, the latter enables medical locations to support hospital processes in a smart way with the aid of suitable instrumentation; medical locations are supplied with sensors, technologies interacting with humans and high connectivity to efficiently communicate with workers, robots, and devices. These areas of intervention will cover a large set of hospital aspects of interest, from logistics to robots, IoT, and disaster management, as summarized in the following Use Cases:

- UC1 - Aided logistic support
- UC2 - Clinical engineering, medical device locations real-time management and disaster preparedness
- UC3 - AI based support system for diagnosis
- UC4 - Clinical tasks and patient experience
- UC5 - Automation of clinical workflows leveraging clinical care workflows and AI technologies
- UC6 - Inpatient remote rehabilitation, follow-up and home hospitalization
- UC7 - Disaster preparedness

OHIO (Odin Hospital Indoor cOmpass) is an integrate solution which has been selected via an open call, as a sub-project to be incorporated in ODIN. It will integrate the ODIN Platform with an informative system able to empower the management of a large-scale pilot (hospital ''Le Scotte'' in Siena, Italy) in terms of clinical engineering, logistics, and disaster preparedness. OHIO will enhance the existing hospital's Computer Aided Facility Management (CAFM) system named SPOT [23], [24], [25], and an Indoor Positioning System (IPS) mobile application named HiWAY [26], [27], to improve the process of maintenance of medical equipment, streamline logistics, and support the top management in designing effective response to disasters. OHIO will be fully integrated within the ODIN Platform, as all the modules and data will be registered as KERs, thus extending the ODIN Ontology, and exploiting the offered services and features. ODIN UC2 (Clinical engineering) will particularly benefit from gaining access to provided technical documentations and reports directly on HiWAY. This feature, together with the possibility to pre-plan both scheduled and corrective maintenance interventions will ease and optimize managing of clinical engineering tasks. External suppliers will also benefit of the solution to streamline the logistics (ODIN UC1 - Aided logistic support). The proposed solution will help both internal and external users to easily reach a destination inside the hospital by knowing any of the available hospital accesses. OHIO will also benefit ODIN UC7 (Disaster preparedness), by allowing the pilot managers to use SPOT and HiWAY to create simulated scenarios for different disasters, and to analyse their impact on routes and timings [2]. OHIO has been designed and will be further developed in compliance to the main international standards (e.g., IEEE 802.11 [28], IEEE 802.16 [29], ISO 12006 [30]).

C. OBJECTIVE

This study's goal is to conduct a literature scoping review on semantic ontologies in order to map the research done in ten identified areas of interest (disease vocabulary, medical vocabulary, medical procedures, drugs, medical data, technology, human role, emergency, buildings, and services) which are consistent with ODIN's areas of intervention. Because a fundamental aspect of developing an ontology is to ensure cooperation and exchange of information at the semantic level, it is therefore important to reuse existing ontologies. Thus, the final goal is to examine semantic representations in order to choose those that are thought to be most pertinent in relation to the ODIN project and its expansion, also in consideration to the OHIO's sub-project, aiming to the creation of a unified and collective ontology that will fully represent the hospital environment.

II. METHODS

A. INFORMATION SOURCE

The literature search was carried out through the Scopus database[1] on January 13th 2023 using the PRISMA extensions for scoping reviews [31]. The initial search results were screened by two different reviewers (CP and AL) using a selection based on titles. A further evaluation was performed by the same reviewers on the basis of the abstracts for the selected results. At this stage a third reviewer (EI) ruled on possible inconsistencies. All three reviewers were involved in the final selection of full texts for potentially relevant publications. At this stage disagreements on study selection were resolved by discussion among the reviewers.

B. SEARCH

Carefully selected keywords were given as input to the Scopus search engine. They were selected according to the specific scope of the review to find and select ontologies consistent with ODIN's areas of intervention (see Section I-C). Besides, the chosen keywords must also reflect the objective of OHIO to expand the current ODIN Ontology to cover the aspects linked to clinical engineering, logistics, and disaster preparedness more adequately. The selected keywords are the following: IoT, IoT Healthcare, Drugs Robotics, Emergency, Disaster, Clinical Workflow, Surgery, Logistics, Data Collection, Staff and lastly Medical Record. All the above followed by the words ''semantic ontology''.

[1] https://www.elsevier.com/solutions/scopus

C. ELIGIBILITY AND EXCLUSION CRITERIA

The majority of the articles that were targeted for the research were those that addressed the subjects mentioned in section I, including robotics, the Internet of Things, healthcare and the hospital environment, logistics management, medical personnel, data collection, and disaster preparedness and management. The search was restricted to documents produced after the year 2000 (included), written in English and Italian, and including documents that were either articles or reviews. The included subjects are those which the authors thought to be consistent with the ten areas of intervention related to ODIN and OHIO (see Section I-C): computer science, engineering, medicine, social sciences, decision sciences, multidisciplinary, business, management and accounting, health professions, environmental science, pharmacology toxicology, and nursing. The exclusion criteria were created to prevent the selection of articles that discussed ontologies that were not be publicly accessible or that belonged to a domain unrelated to the project's goals. Only scientific articles and reviews were included, leaving outside all other academic publications and all materials and research produced by organizations outside of the academic publishing (grey literature) to provide a high level of reliability and integrity. The final Scopus database query is:

TITLE-ABS-KEY (semantic* AND ontolog*) AND TITLE-ABS-KEY (''IoT'' OR ''Health'' OR ''Healthcare'' OR ''Robot*'' OR ''Emergenc*'' OR ''Disaster*'' OR ''Clinic*'' OR ''Workflow*'' OR ''Surger*'' OR ''Logistic*'' OR ''Data*'' OR ''DATA AND Collect*'' OR ''Staff'' OR ''Medical record*'' OR ''Internet AND of AND things'') AND (LIMIT-TO (OA,''all'')) AND (LIMIT-TO (PUBSTAGE,''final'')) AND (LIMIT-TO (DOCTYPE,''ar'') OR LIMIT-TO (DOCTYPE,''re'')) AND (LIMIT-TO (SUBJAREA,''COMP'') OR LIMIT-TO (SUBJAREA,''ENGI'') OR LIMIT-TO (SUBJAREA,''MEDI'') OR LIMIT-TO (SUBJAREA,''DECI'') OR LIMIT-TO (SUBJAREA,''SOCI'') OR LIMIT-TO (SUBJAREA, ''BUSI'') OR LIMIT-TO (SUBJAREA,''ENVI'') OR LIMIT-TO (SUBJAREA,''MULT'') OR LIMIT-TO (SUBJAREA,''HEAL'') OR LIMIT-TO (SUBJAREA,''PHAR'') OR LIMIT-TO (SUBJAREA,''NURS'')) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR,2022) OR LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR,2015) OR LIMIT-TO (PUBYEAR,2014) OR LIMIT-TO (PUBYEAR,2013) OR LIMIT-TO (PUBYEAR,2012) OR LIMIT-TO (PUBYEAR,2011) OR LIMIT-TO (PUBYEAR,2010) OR LIMIT-TO (PUBYEAR,2009) OR LIMIT-TO (PUBYEAR,2008) OR LIMIT-TO (PUBYEAR,2007) OR LIMIT-TO (PUBYEAR,2006) OR LIMIT-TO (PUBYEAR,2005) OR LIMIT-TO (PUBYEAR,2004) OR LIMIT-TO (PUBYEAR,2003) OR LIMIT-TO (PUBYEAR,2002) OR LIMIT-TO (PUBYEAR,2001) OR LIMIT-TO (PUBYEAR,2000)) AND (LIMIT-TO (LANGUAGE,''English''))

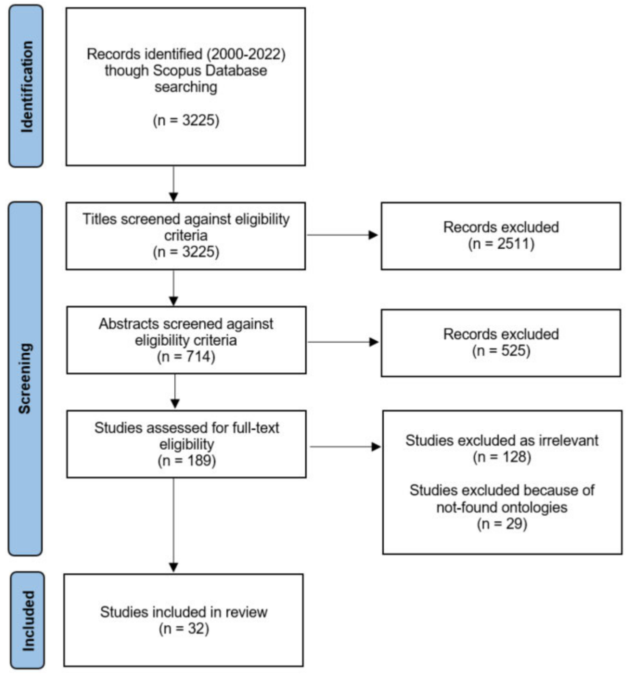

FIGURE 2. Flow diagram representing the process of selection of the included studies.

III. RESULTS

The literature search led to a total of 3,225 articles, hence a selection was performed by two reviewers (AL and CP). The flow diagram in Fig. 2 illustrates the procedure for choosing the literature that was included in the final review.

714 documents out of the records obtained from the initial search were considered relevant after reading the title. The abstracts of the articles belonging to this set of items were then analysed for an additional screening, which resulted in the selection of 183 items by both reviewers. A third reviewer (EI) ruled on the 18 discordant opinions and selected 6 publications for a total of 189 selected records. Finally, 32 documents have been selected by the reviewers after reading the full text of the remaining articles. All the articles included in the review have been produced between the years 2010 and 2023 and written in English. The main characteristics of the documents that were selected are displayed in Table 1. The columns of such table are arranged in the following order: the first column shows the first author mentioned in the article, the year of publication and the bibliography reference, the subsequent columns indicate, respectively, the title, the aim of the article under discussion, the mentioned ontologies, the semantic domain that serves as the framework for the document's coverage, and the number of citations.

A. SELECTION OF SOURCES OF EVIDENCE FOR ONTOLOGIES

The analysis of the results aims to identify public ontologies which can provide a semantic representation of the aforementioned topics and needs. Two main databases have been used to identify suitable public biomedical ontologies: Ontobee [32] and BioPortal [33].

Ontobee is a linked data server designed for ontologies that provides the query, visualization and comparison of different ontologies and ontology terms. It represents the default server for biomedical ontologies in the Open Biological Ontology (OBO) Foundry, a group of researchers that aim at establishing a set of principles to follow when developing ontologies for the biological sciences. Basic Formal Ontology (BFO) is the official top-level ontology for all OBO Foundry ontologies. BFO is frequently used as ontology top-level architecture [34] and has been approved as international standard ISO/IEC 21838–2 [35].

BioPortal is an open repository of biomedical ontologies delivered by the National Centre for Biomedical Ontology (NCBO), which was formed as part of the National Centers for Biomedical Computing network founded by the National Institutes of Health (NIH). The goal of NCBO is to support biomedical researchers by providing online tools such as BioPortal, which contains ontologies concerning anatomy, chemistry and health.

B. SYNTHESIS OF RESULTS

A total of 34 ontologies, extracted by the selected articles, have been collected and reviewed. Table 2 displays the applicable ontologies, a brief description of the represented domain, the Internationalized Resource Identifier (IRI), the source which they can be downloaded from and the main topic.

IV. DISCUSSION

As displayed in Table 1, each of the studies that were chosen is focused on a particular ontology and has been connected to a semantic domain in line with the review's objectives. Eight documents have been associated with the "Technology" area ([36], [37], [38], [39], [40], [41], [42], [43]) and are studies focusing on using semantic ontologies to allow and promote the management of processes through the implementation of Internet of Things, robotics and sensors. Four articles [39], [40], [41], [44] concern the role of semantic technologies in IoT applications and services. The first two articles present the Semantic Sensor Network (SSN) ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the used samples and the observed properties, as well as actuators. SSN was initially published by the W3C Semantic Sensor Network Incubator Group (SSNO). The current version of SSN is based on a revised and expanded version of the Stimulus Sensor Observation (SSO) pattern, namely the Sensor, Observation, Sample, and Actuator (SOSA) ontology. The ontology aims at representing sensors, their observations and all the concepts that revolve around this specific domain. SSN is very versatile and flexible, therefore applicable in a wide range of situations, like the management and control of wearable sensors for ODIN eWorkers reference area of hospital intervention, or the interconnection of devices in relation to ODIN UC2. IoT is a crucial point in the ODIN Project, because of the numerous implementations which are based upon, such as medical device real-time management. Cornejo-Lupa, et al. [38] present a complete ontology called OntoSLAM, developed to solve Simultaneous Localization and Mapping (SLAM) problems in different domains. Similar issues are also studied by Joo et al. [36] in their development of a scalable navigation framework for robots in various environments and scenarios, based on the Triplet Ontological Semantic Model (TOSM). SLAM computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within, it is a crucial problem when applying automated-guided robots inside the hospital environment, e.g., for automatic drug collection and delivery (ODIN UC1). The aspect of the implementation of technologies for assisting processes in the healthcare domain is explored by Santana da Silva et al. [42]. This study exhibits the methods and the results for designing the TEON, an ontology for the telehealth domain. TEON has been developed for obtaining a formal representation of the proper domain, such as second opinion, education, teleconsultation or telediagnosis, finding a way to let telehealth systems exchange data and integrate heterogeneous sources. The article offers a comparison between the developed ontology and other studies centred on a semantic representation of the telehealth domain, as already existing medical and clinical vocabularies (e.g., SNOMED-CT) did not provide the terms to represents crucial concepts related to this specific domain, being unable to reach the high degree of formality that TEON did. The ontology was developed based on the upper domain ontology BioTopLite2 and Ontology for Biomedical Investigations (OBI) and built following the guidelines of a set of competence questions, regarding the individuation of the subareas of telehealth, the embedded services, the roles performed by the actors and the delivered processes. The main components of TEON are `Actors` (i.e. requestors of the service), `Teleconsultants`, `Manager`, `Services` (including the delivery of selected healthcare specialties), `Time` and `Space` classes and axioms. The ODIN Ontology can benefit from incorporating and expanding its classes with the TEON ontology, especially in relation to the promotion of data-flow between home and hospitals (ODIN UC6).

The work by Prestes et al. [43], does not strictly concern healthcare, focusing on the introduction of the Core Ontology for Robotics and Automation (CORA), which is defined by the IEEE 1872-2015 standard [45]. The ISO/FDIS 8373 standard vocabulary has been adopted as one of the sources of domain knowledge for building the ontology [46].

The main aim of the ontology is to provide a semantic representation of the knowledge in the domain of robotics and automation. The result is a unified representation of a common set of definitions and relations that allow for the reasoning and communication of knowledge in this field. This ontology represents the fundamental concepts of the domain and serves as a base for more specific semantic representations. Its main concept is `Robot`, which is related to most of the remaining terminology through the sub-classes of `Device` and `Agent` (Fig. 3),

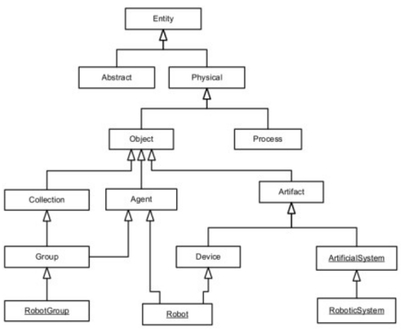

FIGURE 3. CORA ontology [47].

CORA has been selected inside the review because it is implemented within the current release of the ODIN Ontology [48] in regards to the need for a semantic representation for robots and devices in the day-to-day hospital activities depicted in ODIN UC2 (see Section I).

A set of six articles was identified as compliant with the topic of "Medical Vocabulary" [44], [49], [50], [51], [52], [53]. All of the items are focused on ontologies that represent specific medical terminologies and classification of terms related to the medical area. A formal semantic representation of the medical field is needed in every aspect concerning the progress towards the realization of a smart hospital environment. Hakimi et al. [51] aim to develop the Devices, Experimental Scaffolds and Biomaterials (DEB) ontology, a semantic representation of the domain of biomaterials. The ontology was created in order to research terms, enhance machine learning applications and provide a formal vocabulary of the domain. The reason why this semantic representation was developed was to have a tool that could cover all materials testes in a biological system to give a wider coverage of the terminology represented and to complement other existing vocabularies. In DEB, a biomaterial is defined as "A non-drug raw material or substance suitable for inclusion in systems which augment or replace the function of bodily tissues or organs" and it is one of the superclasses of the ontology. The works of Bona et al. [50] and Liu et al. [44] aim to analyse the National Cancer Institute Thesaurus (NCIT), developed by the National Cancer Institute's Centre for Bioinformatics and Office of Cancer Communications with the main objectives of providing a base terminology for cancer, creating a vocabulary that is understandable by both humans and machines and promoting the introduction of new concepts and relationships derived from research, clinical trials and other information sources.

NCIT is a thesaurus that includes a broad coverage of the cancer domain, including cancer-related diseases, findings, and abnormalities. It is defined as a controlled vocabulary organised as a list of terms and definitions. The ontology's domain includes vocabulary for clinical care, transitional and basic research, and administrative activities.

El-Sappagh et al. [53] studied a well-established standardized clinical vocabulary: the Systematized Nomenclature of Medicine Clinical Terms (SNOMED-CT).

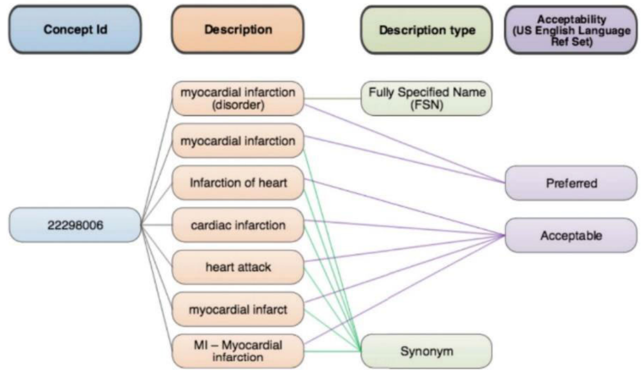

FIGURE 4. SNOMED-CT main types of components [54].

It is a clinical healthcare terminology system used for electronic healthcare records. It includes concepts representing diagnosis, procedures, physical objects, body structures and many other information about health records (Fig. 4). The main component types are:

- `Concepts`, a numeric code with clinical meaning that is not human comprehensible, but it is machine readable;
- `Descriptions`, there are two types of descriptions, the FSN-Fully Specified Name that is a description of meaning, and the synonym;
- `Relationships`

SNOMED-CT cannot be adequately represented through a semantic solution, due to inevitable issues that such translation would involve, which are addressed by the article. For these reasons, the authors introduce the SNOMED-CT Ontology (SCTO). It is a standard ontology designed on the basis of the BFO and the Ontology for General Medical Science (OGMS). It is an upper-level ontology designed to represent the concepts of SNOMED-CT through a semantic representation. Concepts are implemented by adding further axioms and logical properties, providing a standard semantic representation that offers a wide coverage of the vocabulary items. SCTO can therefore be used in environments that support electronic data exchange, thanks to the logical semantics of the ontology format. The article by Kim et al. [49] is about developing the Dietary Lifestyle Ontology (DILON) with an extensible concept structure to support the interoperability of dietary lifestyle data from different cultural contexts. Dietary concepts and their relationships in DILON are proved to be useful for resolving the challenges introduced when treating an entire diet-related data element as a single concept. DILON can help extending the SNOMED-CT vocabulary as only 54% of dietary concepts of the former are mapped to the latter. Yu et al. [52] consider two specific ontologies concerning adverse events: the Ontology of Adverse Events (OAE) and the Ontology of Drug Adverse Events (ODAE).

OAE is a semantic representation that follows the OBO Foundry principles and that collects concepts suitable for monitoring adverse events of various types, aiming at improving and organizing adverse event information. An adverse event is defined as the negative event that follows a medi-

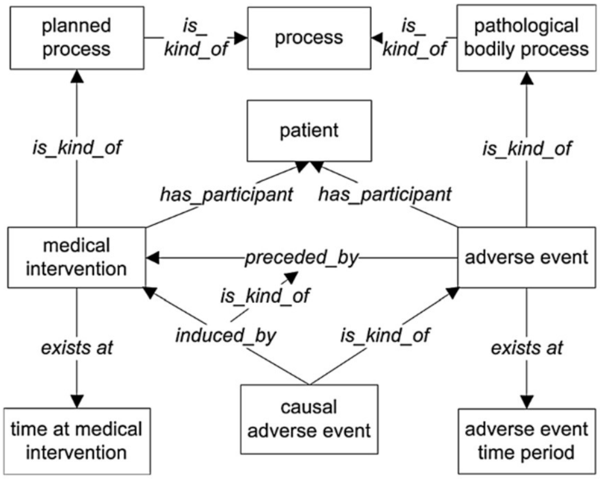

FIGURE 5. Basic design pattern of OAE adverse event and causal adverse event [55].

cal procedure and the ontology is designed to address this domain, without considering the processes that led to the event itself nor events derived from illnesses or diseases. It brings attention to the difference between adverse event and causal adverse event (Fig. 5): both occur after a medical intervention, but the second one, a subtype of the former, is used only if the event has certainly occurred as a result of the intervention itself. In addition, the ontology offers a representation of the factors that influence the adverse event outcomes. ODAE describes and represent drugs, their chemical ingredients, adverse events and how these entities are related. It also follows the OBO Foundry principles, and it reuses terms from other existing ontologies, including OAE. ODAE and OAE can be integrated within the ODIN Ontology in relation to UC2 and UC7: in particular, the ODIN Ontology could be further expanded with entities coming from both ontologies to include the possibility to map, track and trace adverse events inside the hospitals.

Six articles are about "Disease Vocabulary" [12], [56], [57], [58], [59], [60]. The former reviews the performance assessment of NCIT, SNOMED-CT, and Orphanet Rare Disease Ontology (ORDO) matching systems for FAIR (Findable, Accessible, Interoperable, Reusable) data. The aim of the study by Esfahani Misagh Zahiri et al. [57] is to provide an ontology for Multiple Sclerosis (MS) symptomatic treatment. According to the authors, a comprehensive ontological study addressing different concepts of MS symptomatic treatment is lacking. Therefore, the Symptomatic Treatment of Multiple Sclerosis Ontology (STMSO) has been developed within the objective of the study for building a knowledge base for developing Clinical Decision Support Systems (CDSS) in this domain. Silva et al. [58] study the application of ontologies and knowledge graphs in cancer research. It presents the aforementioned SNOMED-CT and NCIT, as well as the oncology subset (ICD-O) of the International Classification of Disease (ICD) and the Ontology for Biomedical Investigations, which aims to describe the terms related to biological and medical investigations. In regard to the NCIT, the authors involve an issue related to the discrepancy between most of the definitions included in the ontological form and the ones presented in the original thesaurus. The article also analyses the ICD ontology. ICD is a classification system that organizes diseases and injuries into groups based on defined criteria. International Classification of Diseases 11th revision Clinical Modification (ICD11CM) describes in numerical or alpha-numerical codes the medical terms in which the diagnoses of disease or trauma, other health problems, causes of trauma and diagnostic and therapeutic procedures are expressed. The main classes of the ontology are `Diseases and Injuries`, and `Procedures`.

The article by Robinson and Mundlos [60] concerns the Human Phenotype Ontology (HPO). The article focuses on the application of such ontology as a tool for analysing phenotypic abnormalities caused by hereditary diseases. The study of Narayanasamy et al. [12] reviews different ontologies for semantic-web applications in healthcare and virtual communications. Finally, the article by Babcock et al. [59] stresses the importance of the role of semantic representation as a powerful data-sharing tool when dealing with public health crises. The article gives a description of the Infectious Disease Ontology (IDO), which deals with the domain of infectious disease. IDO is based on the IDO-Core ontology, that takes a portion of its terminology from the OGMS and offers a general representation of the domain. It includes and defines several terms concerning the area of infections, such as infection, infectious disorder, infectious disease, process of establishing an infection. IDO also consists in the following IDO-Core extension ontologies (Fig. 6):

- VIDO represents an extension of IDO-Core and it is generally focused on the virus domain. Since it covers all the concepts in the domain of virus-induced diseases, it offers other IDO extensions, which also includes terminology that is already contained in existing OBO Foundry.
- CIDO is the Coronavirus Infectious Disease Ontology. It offers a semantic tool that allows the representation of concepts related to this specific pathology, such as known and candidate anti-coronavirus drugs, genome data, host data and vaccine. CIDO directly derives from VIDO, adopting some of its terminologies and focusing on a specification of its domain. Although much more specific than its predecessor, CIDO concerns the coronavirus infectious diseases, therefore it includes all of the species of such virus that can cause a large number of diseases.
- IDO-COVID-19 is the ontology, derived from CIDO, that specifically regards the domain of the COVID-19 disease and its cause SARS-CoV-2. It is still going through constant changes since the ongoing pandemic provides more and more items to be continuously adjourned.

The article also focuses on the problems which can originate from the application of such ontologies and their future improvement.

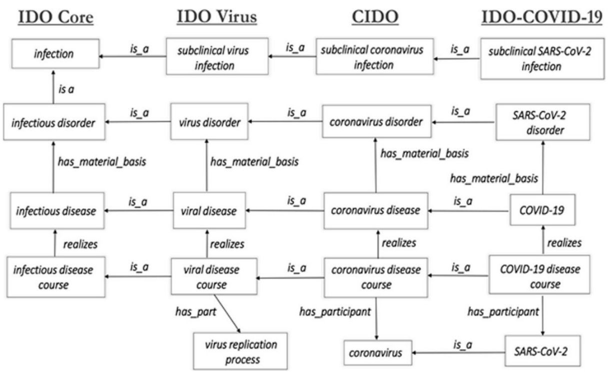

FIGURE 6. Links between VIDO, CIDO and IDO-COVID-19 ontologies [59].

Three selected articles are referenced as "Medical Data" [61], [62], [63]. The first article reports on the community effort to create the Data Management Plan (DMP) Common Standard Ontology (DCSO), with a particular focus on a detailed description of the components of the ontology. With the continuous growth of research data and the ultimate goal of sharing FAIR data, researchers face the challenge of systematically managing that data and its corresponding metadata. Data Management Plans make it easier for researchers to respond to this challenge. DMP is a formal document that outlines how data are to be handled both during a research project, and after the project is completed. The goal of a DMP is to consider the many aspects of data management, metadata generation, data preservation, and analysis before the project begins, which may lead to data being well-managed in the present, and prepared for preservation in the future. Therefore, the DCSO is taken into consideration within this review in relation to research being an integral part of medical activities and medical data management. The works by Ison [62] and McMurray [63] revolve around the description and study of ontologies that provide seamless exchange and collecting of medical data, with the purpose of enhancing interoperability between different healthcare structures and services. The former talks about the structure and scope of the EDAM (EMBRACE Data and Methods) ontology, whose main goal is to provide a semantic representation to identify and define the aspects of bioinformatics operations, which may also be understandable both by machines and humans. EDAM was developed for the EMBRACE (European Model for Bioinformatics Research and Community Education) project with the aim of offering a coherent, machine-understandable representation used within resource catalogs and to provide a common vocabulary for bioinformatics data and standards for data sharing. The main classes at the top of its hierarchy are: `Operation` represents how a piece of data is created; `Data` (which includes the additional sub-class `Identifier`), defines which data is consumed or produced by a tool; `Topic` includes the types of bioinformatics resource; `Format` for data formats. McMurray et al. [63] describe the actual lack of a system which is able to allow an effective information exchange between healthcare providers. In this regard, the Regional Healthcare System Interoperability and Information Exchange Measurement Ontology (HEIO) is proposed and described. HEIO has been designed with the specific purpose of enhancing the interoperability and information exchange among different healthcare providers, and therefore obtaining a fully integrated healthcare system. The only article in the collection that concerns the characteristics of the drugs domain is the work by Hanna et al. [64], which focuses on the process of building the Drug Ontology (DrOn), based on the standard drug terminology of the U.S. National Library of Medicine (NML) in RxNorm. The document goes through the process of the creation of the ontology itself, highlighting the building steps and the connection the developed ontology has with its precursors. The following aspects are pointed out: extraction of data and information from RxNorm, transformation of such items into a Relational Database Management System (RDBMS) and the final translation in OWL. The article also provides descriptions of both the validation and the future plans of the developed ontology.

Three articles cover the domain of the "Human Role" in the health and clinical environment. This topic is essential because of the great relevance of human interconnections and the possible reachable complexity of inner organizations in any healthcare context. Hicks et al. [65] talk about the applications, the development, and the content of the Ontology of Medical Related Social Entities (OMRSE), which aims to semantically represent entities related to demographics, roles and characteristics of health workers. It is developed in OWL and defines gender roles, legal roles, healthcare providers and organization roles and patients. Being an OBO Foundry ontology, it reuses terminology from other existing representations, including BFO. Developers extended the domain over the years, adding specification classes to represent a wider variety of concepts, such as epidemic modelling. Maitra et al. [66] focus on the domain of interpersonal connection in medicine and the representation of data about presence in hospital structures through Presence Ontology (PREO). The document describes the survey, the domain literature review and the following steps which eventually lead to the creation of the ontology. The definition of classes and relational properties of found results is also performed, together with a final evaluation and description. Finally, the work by Gordon et al. [67] describes the development of a prototype knowledge graph, analysing the potential of semantic technologies to transform the idea of "geospatial open systems" into "open knowledge networks", which incorporate spatial and aspatial information across complex organizational networks. Ontology frameworks, such as VIVO, W3C Organization Ontology, Relation Ontology and schema.org, express the richness of relationships between organizations, projects and their collaborative work produces. Particularly, the Organization Ontology is a core ontology for organisational architectures and roles across a multitude of domains, and it is actually integrated within the current release of the ODIN Ontology for representing all of the possible organisational interactions within the

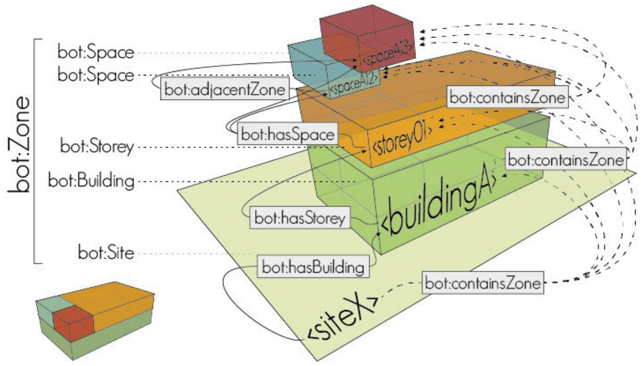

FIGURE 7. BOT Ontology - Examples of object properties linking classes [71].

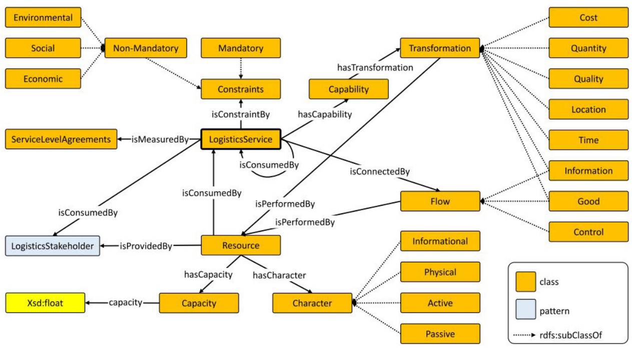

FIGURE 8. Schematic view of LoSe ODP [72].

hospital [48]. The areas represented by the ontology are the following: organizational structure, reporting structure (memberships, roles and relationships), location information and organizational history. This representation does not offer specific details of the different types of organizational structures, therefore, for this purpose, it is necessary to create extensions vocabularies. The Organization Ontology's classes are `Change Event`, `Formal Organization`, `Membership`, `Organizational Collaboration`, `Organizational Unit`, `Organization`, `Post`, `Role` and `Site`. All the above are then logically related through a multitude of properties.

Two articles are about "Buildings" [68], [69]. This topic is relevant in an accurate description of the healthcare environment, for example in terms of facility management as well as indoor localization and navigation. Donkers et al. [68] presents the Building Performance Ontology (BOP) which aims to enable the integration of topological building information with static and dynamic properties, to create a homogeneous data environment used by complex building performance assessments. Bassier et al. [69] offer an introduction of the Building Topology Ontology (BOT), with the analysis of its competence areas and applications in combination with other technologies. BOT originated from the need for the implementation of web-based applications to enhance the BIM methods. It defines the relationships between the components of a building and is used in the construction industry to promote the integration of linked data in the

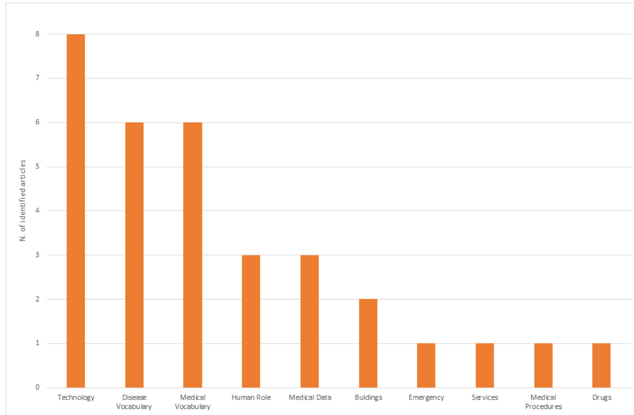

FIGURE 9. Classification of the identified 32 articles within the identified ten areas of interest.

design, planning, constructing, and maintaining a building. The classes of the ontology follow:

- `Zone` is a part of the physical world or a virtual world that is inherently both located in this world and has a 3D spatial extent;
- `Site` is a part of the physical world or a virtual world that is inherently both located in this world and having a 3D spatial extent. It is intended to contain or contains one or more buildings;
- `Building` is an independent unit of the built environment with a characteristic spatial structure, intended to serve at least one function or user activity [70];
- `Storey` is a part of the physical world or a virtual world that is inherently both located in this world and having a 3D spatial extent;
- `Space` is a part of the physical world or a virtual world whose 3D spatial extent is bounded actually or theoretically, and provides for certain functions within the zone it is contained in.

The class `Zone` is the main class of the BOT ontology, while `Site`, `Building`, `Storey` and `Space` are all sub-classes. By linking the classes and the object properties of the BOT, it is possible to create a map, at a semantic level, of the building, which represents a significant aspect in hospital management, per se (Fig. 7). ODIN's UC2 needs the integration of a BIM smart management system in hospitals, also combining AI solutions with the infrastructures and facilities. To this end, BOT is actually the picked ontology to describe hospital spaces within the ODIN Ontology itself [48]. Moreover, the proposed solution OHIO will integrate its own CAFM and IPS solutions even by directly mapping spaces, storeys, and buildings to the relative BOT entities and classes. In this context, the BOP can be selected to expand the ODIN Ontology and dynamic properties, providing a generic upper-level description for building performance assessment.

The last three documents [72], [73], [74] concern a different area of interest each: "Services", "Medical Procedure", and "Emergency", respectively. Glockner and Ludwig [72] explore the issue of lack of semantic representation of the

TABLE 1. Summary of the characteristics the selected articles.

F. Author and Year	Title	Aim of the article	Identified ontologies	Semantic Area	Citations
Cardoso 2022 [61]	DCSO: towards an ontology for machine-actionable data management plans	Presenting DMP Common Standard Ontology as a serialisation of the DCS core concepts.	DCSO	Medical Data	0
Van Damme 2022 [56]	Performance assessment of ontology matching systems for FAIR data	Assessing the performance of NCIT and ORDO ontologies, as well as SNOMED-CT vocabulary, as matching services for querying FAIR data.	NCIT ORDO	Disease Vocabulary	1
Esfahani 2022 [57]	Ontology for Symptomatic Treatment of Multiple Sclerosis	Providing an ontology for Multiple Sclerosis symptomatic treatment.	STMSO	Disease Vocabulary	0
Donkers 2022 [68]	Semantic Web Technologies for Indoor Environmental Quality: A Review and Ontology Design	Presenting the Building Performance Ontology	BOP	Buildings	0
Joo 2022 [36]	A Flexible Semantic Ontological Model Framework and Its Application to Robotic Navigation in Large Dynamic Environments	Presenting semantic navigation framework based on a Triplet Ontological Semantic Model (TOSM) to manage various conditions affecting the execution of tasks. The framework allows robots with different kinematics to perform tasks in indoor and outdoor environments.	KAON	Technology	0
Kim 2022 [49]	Developing a Dietary Lifestyle Ontology to Improve the Interoperability of Dietary Data: Proof-of-Concept Study	Developing a Dietary Lifestyle Ontology (DILON) and demonstrate the improved interoperability of questionnaire-based dietary data by annotating its main semantics with DILON.	DILON	Medical Vocabulary	0
Silva 2022 [58]	Ontologies and Knowledge Graphs in Oncology Research	Review on the last decade of works on using ontologies in cancer.	NCIT ICD-O OBI	Disease Vocabulary	1
Bona 2022 [50]	Semantic Integration of Multi-Modal Data and Derived Neuroimaging Results Using the Platform for Imaging in Precision Medicine (PRISM) in the Arkansas Imaging Enterprise System (ARIES)	Research data management system which features integrated capabilities to support semantic representations of multi-modal data from disparate sources across common image-processing stages, as well as derived results.	OBI NCIT IAO FMA NCBIT	Medical Vocabulary	3
Narayanasamy 2022 [12]	A Contemporary Review on Utilizing Semantic Web Technologies in Healthcare, Virtual Communities, and Ontology-Based Information Processing Systems	Review of using the semantic web in the domain of healthcare and virtual communities.	MedDRA PMR	Disease Vocabulary	1
Liu 2022 [37]	Semantic Association and Decision-Making for the Internet of Things Based on Partial Differential Fuzzy Unsupervised Models	Presents study and analysis of IoT semantic association and decision-making using a partial differential fuzzy unsupervised approach.	SSN	Technology	1
Cornejo-Lupa 2021 [38]	Ontoslam: An ontology for representing location and simultaneous mapping information for autonomous robots	A complete ontology to model all aspects related to autonomous robots and the Simultaneous Localization and Mapping (SLAM) problem.	CORA OntoSLAM	Technology	1
Babcock 2021 [59]	The Infectious Disease Ontology in the age of COVID-19	Description of IDO and its extensions integrated with the analysis of COVID-19 data: VIDO, CIDO and IDO-COVID-19.	CIDO IDO IDO-COVID-19 VIDO	Disease Vocabulary	12
Rahman 2021 [39]	A light-weight dynamic ontology for Internet of Things using machine learning technique	Proposal of a dynamic ontology to achieve semantic interoperability among heterogeneous devices and applications.	OneM2M IoT-Lite SSN	Technology	7

TABLE 1. ***(Continued.)*** **Summary of the characteristics the selected articles.**

Maitra 2021 [66]	Using ethnographic methods to classify the human experience in medicine: A case study of the presence ontology	Creation of a conceptual framework to describe and classify data about presence, the domain of interpersonal connection in medicine.	PREO	Human Role	2
Mazimwe 2021 [74]	Implementation of FAIR principles for ontologies in the disaster domain: A systematic literature review	Systematic search and review of publications in the disaster management domain.	Empathi Disaster-Ontology EF SOKNOS MOAC	Emergency	0
Gordon 2021 [67]	People, Projects, Organizations, and Products: Designing a Knowledge Graph to Support Multi-Stakeholder Environmental Planning and Design	Developing a prototype knowledge graph based on RDF and GeoSPARQL standards for a multi-stakeholder regional environmental planning and design initiatives.	Organization-Ontology Relation-Ontology VIVO	Human Role	2
Bassier 2020 [69]	Processing existing building geometry for reuse as Linked Data	Combine building component information extracted from 2D images and 3D building models and publish them as Linked Data.	BOT	Buildings	16
Hakimi 2020 [51]	The Devices, Experimental Scaffolds, and Biomaterials Ontology (DEB): A Tool for Mapping, Annotation, and Analysis of Biomaterials Data	Description of DEB, an open resource for organizing information about biomaterials, their design, manufacture and biological testing.	DEB	Medical Vocabulary	6
Elsaleh 2020 [40]	IoT-Stream: A Lightweight Ontology for Internet of Things Data Streams and its Use with Data Analytics and Event Detection Services	Presentation of IoT-Stream, a lightweight instantiation of the semantic sensor network (SSN) ontology to describe the key IoT concepts that allows interoperability and discovery of sensory data in heterogeneous IoT platforms.	IoT-Stream	Technology	40
Yu 2019 [52]	ODAE: Ontology-based systematic representation and analysis of drug adverse events and its usage in study of adverse events given different patient age and disease conditions	Description of ODAE and its developments.	OAE ODAE	Medical Vocabulary	4
El-Sappagh 2018 [53]	SNOMED-CT standard ontology based on the ontology for general medical science	Development of an upper-level ontology to be used as the basis for defining the terms in SNOMED-CT.	SCTO	Medical Vocabulary	41
Gibaud 2018 [73]	Toward a standard ontology of surgical process models	Presentation of the OntoSPM Collaborative Action, which serves as a platform developing ontologies in the domain of surgery, focusing on surgical process modelling in the context of Surgical Data Science.	OntoSPM	Medical Procedure	37
Haller 2018 [41]	The modular SSN ontology: A joint W3C and OGC standard specifying the semantics of sensors, observations, sampling, and actuation	Overview of the SSN, SOSA and SSNZ ontologies discussing the rationale behind key design decisions and main differences.	SSN SOSA SSNX	Technology	116
Glockner 2017 [72]	Lose ODP - an ontology design pattern for logistics services	Presentation of an ontology design pattern for logistics services	LoSe ODP	Services	1
Hicks 2016 [65]	The ontology of medically related social entities: Recent developments	Description of OMRSE and its recent developments.	OMRSE	Human Role	22
Santana 2015 [42]	Towards a Formal Representation of Processes and Objects Regarding the Delivery of Telehealth Services: The Telehealth Ontology (TEON)	Description and Presentation of TEON, elucidating its main use-case, its applicability and potential to improve information exchange, interoperability and decision support.	TEON	Technology	2

TABLE 1. *(Continued.)* Summary of the characteristics the selected articles.

McMurray 2015 [63]	Ontological modelling of electronic health information exchange	Description of the conceptual framework of health system information exchange and its related ontology.	HEIO	Medical Data	14
Hanna 2013 [64]	Building a drug ontology based on RxNorm and other sources	Description of the building and the structure of the Drug Ontology.	DrOn RxNorm	Drugs	55
Prestes 2013 [43]	Towards a core ontology for robotics and automation	Presentation of the current results of the newly formed IEEE-RAS Working Group, named Ontologies for Robotics and Automation and introduction of a core ontology that encompasses a set of terms commonly used in Robotics and Automation.	CORA	Technology	137
Ison 2013 [62]	EDAM: An ontology of bioinformatics operations, types of data and identifiers, topics and formats	Presenting EDAM, an ontology of bioinformatics operations, types of data and identifiers, data formats and topics with the goal of creating machine-understandable annotations for use within resource catalogues.	EDAM	Medical Data	152
Liu 2011 [44]	Effectiveness of lexico-syntactic pattern matching for ontology enrichment with clinical documents	Evaluate the effectiveness of a Lexico-Syntactic Pattern matching method for ontology enrichment using clinical documents.	NCIT RadLex	Medical Vocabulary	12
Robinson 2010 [60]	The Human Phenotype Ontology	Development and description of HPO to capture phenotypic information.	HPO	Disease Vocabulary	239

logistics domain with the implementation of the Logistics Service Ontology Design Pattern (LoSe ODP). LoSe ODP describes the concepts linked to the logistics services area. It is an Ontology Design Pattern, which means that it is a small ontology that can be used as a base to design more specific ontologies. Ontology Design Patterns are used as a modelling approach to unravel issues related to ontologies designs and reusability [75]. The competency questions that lead the development process of the LoSe ODP revolved around some points of interest which needed to be covered with semantic representation: the actors involved in the providing of the service, the type of logistic service, the legal constraints related to the service, the required resources, the information needed in the delivery of the service and the identification of the logistic service providers (LSP) together with the possible means of transportation. Many concepts represented by this ontology are taken from other ontologies regarding the field of the logistic supply chain. LoSe ODP reuses the notions of the differentiation between physical and informational resources, the importance of location according to the specific service provided, the objective and policies of the logistics service and the crucial role of time. As shown in Fig. 8, the top level class of the ontology is `LogisticsService` which is logically related to the `Constraints` that has to sustain, the `Resources` that needs to consume in order to achieve its objective and the `Capability` of the logistics service that always involves a transformation.

The article by Gibaud et al. [73] covers the topic of Surgical Data Science (SDC) and the OntoSPM Collaborative Action. It states that information processing is strongly needed to perform surgical tasks and how the necessity for the creation of standardized Surgical Process Models (SPM) is relevant is such scenario. Moreover, it also pinpoints that within IEEE there is lack of appropriate regulations and standards for medical and surgical applications. The document explores and analyses OntoSPM, which has been developed in the context of the European initiative OntoSPM Collaborative Action [76], with the intent of developing ontology in the domain of surgical data science, both to create modelling scenarios from descriptions of real clinical cases and to have a tool that can be reusable in other contexts. OntoSPM focuses on SPM, actions and processes including roles played by the actors, affected objects (anatomy or pathology), instruments and materials and ways of manipulations. The article then proceeds to exhibit the development of two ontologies born as sub-ontologies of OntoSPM: the Ontology for Surgical Process Models in Laparoscopy (LapOntoSPM) and the Ontology for Data Integration in Surgery (ODIS). Current applications, as well as strategies to extend OntoSPM, including possible related issues, are also explored. The authors conclude by stating their strategy for ensuring medical acceptance, including the involvement of surgeons and the adoption of OntoSPM as a model for harmonization in surgical trials. One analysed topic which could benefit from the introduction of technologies and ontologies in the healthcare environment is about the domain of emergency management during hazard crises (ODIN UC7). In such a scenario, having sufficient situational awareness information is critical. This requires capturing and combining data from sources like satellite photos, local sensors, and user-generated social media content.

TABLE 2. Table of identified ontologies.

Ontology	Description	IRI	Website	Topic	Ref.
BOP	The Building Performance Ontology aims to enable the integration of topological building information with static and dynamic properties, to create a homogeneous data environment used by complex building performance assessments.	https://alexdonkers.github.io/bop/index.html	https://alexdonkers.github.io/bop/index.html	Infrastructures	[68]
BOT	The Building Topology Ontology is a minimal ontology for describing the core topological concepts of a building.	https://w3c-lbd-cg.github.io/bot	https://w3c-lbd-cg.github.io/bot	Infrastructures	[69]
CIDO	CIDO aims to ontologically represent and standardize various aspects of coronavirus infectious diseases, including their etiology, transmission, epidemiology, pathogenesis, diagnosis, prevention and treatment.	http://purl.obolibrary.org/obo/cido.owl	https://github.com/cido-ontology/cido	COVID-19	[59]
CORA	Core Ontology for Robotics and Automation	http://purl.org/ieee1872-owl/cora	https://github.com/srfiorini/IEEE1872-owl	Robotics	[38], [43]
DCSO	The DMP Common Standard Ontology aims to represent the DMP Common Standard model, through the usage of semantic web technology. It represents the DMP Common Standard model using the Web Ontology Language (OWL).	http://semantics.id/ns/dcso/index-en.html	http://semantics.id/ns/dcso/index-en.html	Data Management	[61]
DEB	Devices, Experimental scaffolds and Biomaterials Ontology: it is an ontology built to facilitate data cataloguing in the field of medical devices, experimental scaffolds and biomaterials.	http://www.semanticweb.org/osnathakimi/ontologies/deb	https://projectdebbie.github.io	Biomaterials	[51]
DILON	The Dietary Lifestyle Ontology (DILON) aims to represent dietary lifestyle data. Concepts are pulled from Korean dietary assessment scales and English assessment scales. Concepts are labeled in English and Korean translations are also provided.	https://bioportal.bioontology.org/ontologies/DILON	https://bioportal.bioontology.org/ontologies/DILON	Dietary Lifestyle Data	[49]
Disaster Ontology	The Disaster ontology is an ontology for disaster control and it captures all the entities concerning disasters.	http://www.semanticweb.org/ontologies/2008/10/Ontology1226057991156.owl	https://onki.fi/en/browser/	Emergency Management	[74]
DRON	The Drug Ontology: it is the deposit for the Drug Ontology, an ontology of drug products, their ingredients, and their packaging.	http://purl.obolibrary.org/obo/dron.owl	https://bitbucket.org/uamsdbmi/dron/src/master	Drugs	[64]

TABLE 2. *(Continued.)* **Table of identified ontologies.**

EDAM	Bioscientific data analysis ontology and data management: EDAM is a complete ontology of well-established, entities that are widespread within computational biology and bioinformatics.	http://edamontology.org	http://edamontology.org/page	Informatics, Workflow Management	[62]
Empathi	Ontology that conceptualizes the core concepts concerning the domain of emergency managing and planning of hazard crises.	https://w3id.org/empathi/	https://shekarpour.github.io/empathi.io/	Emergency Management	[74]
HEIO	Regional Healthcare System Interoperability and Information Exchange Measurement Ontology.	http://whistl.uwaterloo.ca/heio.owl	https://bioportal.bioontology.org/ontologies/HEIO	Electronic Health Records	[63]
HPO	Human Phenotype Ontology: it provides a standardized vocabulary of phenotypic abnormalities and clinical features encountered in human disease.	http://purl.obolibrary.org/obo/hp.owl	https://hpo.jax.org/app/	Diseases	[60]
ICDO	International Classiffication of Disease Ontology: it is the ontology representation of the ICD system.	http://purl.obolibrary.org/obo/icdo/	https://github.com/icdo/ICDO	Diseases	[58]
IDO Core	Infectious Disease Ontology	http://purl.obolibrary.org/obo/ido.owl	https://www.bioontology.org/wiki/Infectious_Disease_Ontology	Infectious Diseases	[59]
IDO-COVID-19	The COVID-19 Infectious Disease Ontology: it is an extension of the Infectious Disease Ontology (IDO) and the Virus Infectious Disease Ontology (VIDO)	http://purl.obolibrary.org/obo/ido-covid-19.owl	https://www.ebi.ac.uk/ols/ontologies/idocovid19	COVID-19	[59]
LoSe ODP	Logistics Service Ontology Design Pattern: it is the ontology design pattern about logistics services.	https://github.com/Michael-Gloeckner/LoSeOn	https://github.com/Michael-Gloeckner/LoSe_ODP	Logistics	[72]
NCIT	NCI Thesaurus: it is a reference terminology that includes broad coverage of the cancer domain, including cancer related diseases, findings and abnormalities.	http://purl.obolibrary.org/obo/ncit.owl	https://github.com/NCI-Thesaurus/thesaurus-obo-edition	Human Diseases, Clinical Terminology	[44], [50], [56], [58]
OAE	Ontology of Adverse Events: it is developed to standardize adverse event annotation, integrate various adverse event data, and support computer-assisted reasoning.	http://purl.obolibrary.org/obo/oae.owl	http://www.oae-ontology.org/	Adverse Events	[52], [65]
OBI	Ontology for Biomedical Investigations: an integrated ontology for the description of life-science and clinical investigations.	http://purl.obolibrary.org/obo/obi.owl	http://obi-ontology.org/	Data Collection	[50], [58]

TABLE 2. ***(Continued.)*** **Table of identified ontologies.**

ODAE	Ontology of Drug Adverse Events: biomedical ontology in the area of drug adverse events.	https://raw.githubusercontent.com/ODAE-ontology/ODAE/master/src/ontology/odae_merged.owl	https://github.com/ODAE-ontology/ODAE	Adverse Events and Drugs	[52]
OGMS	Ontology for General Medical Science: ontology of entities involved in a clinical encounter. OGMS includes very general terms that are used across medical disciplines, including: 'disease', 'disorder', 'disease course', 'diagnosis', 'patient', and 'health-care provider'.	http://purl.obolibrary.org/obo/ogms.owl	https://github.com/OGMS/ogms	Human Diseases, Clinical Terminology	[53], [59]
OMRSE	Ontology of Medically Related Social Entities: this ontology covers the domain of social entities that are related to health care, such as demographic information and the roles of various individuals and organizations.	http://purl.obolibrary.org/obo/omrse.owl	https://github.com/ufbmi/OMRSE/wiki/OMRSE-Overview	Clinical Staff	[65]
OneM2M	OneM2M's Base Ontology constitutes a basis framework for specifying the semantics of data that are handled in oneM2M. Sub-classes of some of its concepts are expected to be defined by other bodies in order to enable semantic interworking.	https://git.onem2m.org/MAS/BaseOntology/raw/master/base_ontology.owl#resource\DescriptorLink	https://www.onem2m.org/technical/onem2m-ontologies	IoT	[39]
OntoSLAM	The ontology models all aspects related to autonomous robots and the SLAM problem.	https://github.com/Alex23013/ontoSLAM	https://github.com/Alex23013/ontoSLAM	Robots	[38]
OntoSPM	OntoSPM, a core ontology for surgical process models: motivations, working assumptions and current status.	http://medicis/spm.owl/OntoSPM	https://ontospm.univ-rennes1.fr/doku.php?id=ontology	Surgery	[73]
Organization Ontology	This ontology is designed to enable publication of information on organizations and organizational structures including governmental organizations.	http://www.w3.org/ns/org	https://www.w3.org/TR/vocab-org/	Clinical Staff	[67]
PMR	Physical Medicine and Rehabilitation: Knowledge representation related to computer-based decision support in rehabilitation.	http://purl.bioontology.org/ontology/PMR.owl	https://bioportal.bioontology.org/ontologies/PMR	Rehabilitation	[12]
PREO	Presence Ontology: it is a systematic vocabulary of terms with defined relationships that models the encounters taking place every day among providers, patients, and family members or friends in environments such as hospitals and clinics. The Presence Ontology provides a conceptual model for the human experience in medicine.	http://presence-ontology.org/ontology/	https://med.stanford.edu/presence/about.html	Clinical Staff	[66]

TABLE 2. *(Continued.)* **Table of identified ontologies.**

SCTO	Systematized Nomenclature of Medicine Clinical Terms Ontology	https://bioportal.bioontology.org/ontologies/SCTO	https://bioportal.bioontology.org/ontologies/SCTO	Clinical Terms	[53], [58]
SSN	The Semantic Sensor Network (SSN) ontology is an ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators.	https://www.w3.org/TR/vocab-ssn	https://www.w3.org/TR/vocab-ssn	Sensors	[37], [39], [41]
STMSO	The Symptomatic Treatment of Multiple Sclerosis Ontology is the first comprehensive semantic representation of symptomatic treatment of MS and provides a major step toward the development of intelligent Clinical Decision Support System (CDSS) for MS symptomatic treatment.	https://bioportal.bioontology.org/ontologies/STMSO	https://bioportal.bioontology.org/ontologies/STMSO	Diseases	[57]
TEON	Telehealth Ontology	http://www.nutes.ufpe.br/teon.owl	https://github.com/TelehealthOntology/teon	Telehealth	[42]
VIDO	The Virus Infectious Disease Ontology:The Virus Infectious Disease Ontology (IDO Virus) is an extension of the Infectious Disease Ontology (IDO).	http://purl.obolibrary.org/obo/vido.owl	https://www.ebi.ac.uk/ols/ontologies/vido	Diseases	[59]

Lack of an appropriate ontology that adequately conceptualizes this domain, gathers datasets, and integrates them, is a significant barrier to capturing, describing, and integrating such varied and diverse information. Mazimwe et al. [74] review numerous ontologies related to the disaster domain, such as Empathi, the Disaster Ontology, MOAC, Emergency Fire (EF), SMEM, SOKNOS, DOLCE. Among all the identified ontologies, Empathi, the Disaster Ontology and DOLCE appear to achieve the better average score according to the implemented FAIR principles.

V. CONCLUSION

The scoping review identified 32 studies on the use of semantic ontologies to map different aspects of the healthcare environment which are consistent with the ODIN Project's areas of intervention and with OHIO integrated solution. Studies have been classified in ten area of interests: eight documents are associated with technology area, six studies are about disease vocabulary, six articles focus on medical vocabulary, three works relate to medical data, three papers cover the domain of human role, two are about building management, and the remaining four ones are each about drugs, services, medical procedures, and emergency (Fig. 9).

A set of 34 ontologies extracted by the identified articles has been also analysed and discussed. Some of the identified ontologies (SSN, NCIT, BOT, CORA, Organization Ontology, ICD) are actually part of the current release of the ODIN Ontology [48]. Other selected ontologies (e.g., TEON, BOP, OntoSLAM, OAE, ODAE, LoSe ODP, DEB, SCTO, Disaster Ontology, DCSO) can be beneficial resources to expand the ODIN Ontology in regards to other aspects of the ODIN's hospital Use Cases, especially in consideration of the further development and enrichment which OHIO will introduce within clinical engineering, logistics, and disaster preparedness.

Although this review's primary objective is not to analyse the FAIRness of the ontologies, it is interesting to observe that only seven out of the 32 identified papers make reference to the FAIR principles [51], [52], [56], [58], [61], [67], [74]. Despite all articles agreed on the fact that ontologies actually lead to reproducible research and may improve the adoption of FAIR principles by supporting data integration, analysis, facilitating data interpretation, interoperability, and data mining, it clearly emerges that appropriate metrics to evaluate the FAIRness are still developing. As Wilkinson et al. [77] state, the FAIR principles are aspirational, in that they do not strictly define how to achieve a state of FAIRness, but rather they describe a continuum of features, attributes, and behaviors that will move a digital resource closer to that goal.

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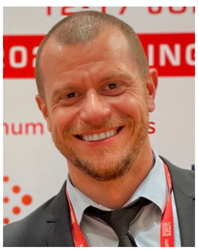

ALESSIO LUSCHI received the B.M.E., M.Sc., and master’s degrees in management in clinical engineering. He is currently a Research Fellow with the Department of Information Engineering, University of Florence, Italy. He is also a teacher in education courses on hospital safety, protection, and management, and a professional partner with several hospital campuses in Florence, Siena, and Pisa, on facility management, workplace informative systems, and natural language processing for healthcare. He is a supervisor of many graduation theses. He has tutored in postgraduate master’s degree courses on clinical engineering, healthcare engineering, and health technology assessment with the University of Florence. He is the author of more than 20 publications on international books, scientific journals, and conference proceedings. He was the Secretary of the Biomedical Committee, Association of Professional Engineers in Florence, from 2014 to 2016.

CAMILLA PETRACCONE received the B.Sc. degree in electronics and telecommunications from the University of Florence, in 2021, where she is currently pursuing the M.Sc. degree in biomedical engineering.

GIUSEPPE FICO (Member, IEEE) received the M.Sc. degree in electronic engineering from the Universitá degli Studi di Napoli Federico II and the Ph.D. degree in biomedical engineering from the Technical University of Madrid (UPM). He is currently heading the health and well-being strategic area of the Lifestyle Supporting Technology Research Group, UPM. He is also a Teacher of specialized courses in clinical and biomedical engineering with UPM. He is an expert in creating, managing, and exploiting research projects that make use of engineering and ICT methods as a catalyst for innovation, to positively impact healthcare outcomes. He is also a Technical Manager of the MOSAIC (seventh Framework Program) and Big Data 2 Decide (Horizon 2020) research projects, where personal health systems are applied to diabetes and head and neck cancer diseases, respectively. He is a Project Manager of innovation by idea project in drug utilization research (EIT for Health). Since 2012, he has been coordinating the Action Group A1 prescription and adherence to medical plans of the EIP on AHA, and leading the user empowerment A1 subgroup. He is an Official Collaborator of the Health Technology Assessment Division of the International Federation of Medical and Biological Engineering.

LEANDRO PECCHIA (Member, IEEE) received the degree in biomedical engineering and the Ph.D. degree in biomedical engineering and management of healthcare services from the University of Naples ‘‘Federico II,’’ in 2005 and 2009, respectively. In 2013, he joined The University of Warwick, U.K., as a Professor of biomedical engineering. Since 2014, he has been directing the affairs of the Applied Biomedical Signal Processing and Intelligent eHealth Laboratory (ABSPIE). He is currently a Full Professor with the Department of Engineering, Universitá Campus Bio-Medico, Rome. He has also provided support severally to the World Health Organization and the European Parliament as an expert in medical devices. He has authored more than 100 peer-reviewed papers in journals, books, and conferences in the fields of health technology assessment (HTA), the Internet of Things, and machine learning applied to healthy aging and the management of chronic diseases. He is also the President of the EAMBES, a Secretary General of the IFMBE, and a former IFMBE Healthcare Technology Assessment Division Chair, from 2015 to 2018.

ERNESTO IADANZA (Senior Member, IEEE) received the B.M.E., C.E., M.Sc., and Ph.D. degrees. He is currently a Senior Assistant Professor of bioengineering (tenure-track) with the Department of Medical Biotechnologies, University of Siena, nationally qualified as an Associate Professor of bioengineering. He is a supervisor of more than 200 graduation theses. He is the author of more than 190 publications on international books, scientific journals, volumes, and conference proceedings. He is also a member of the International Federation for Medical and Biological Engineering (IFMBE) Administrative Council and the Chair of its Council of Societies. He received the IBM Faculty Award, in 2013, and the IFMBE/CED Teamwork Award, in 2019. He is the Editor-in-Chief of the *Clinical Engineering Handbook* (Second Edition, Academic Press, 2020). He is an associate editor of many BME journals.

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