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Thesauri and Semantic Web: Discussion of the Evolution of Thesauri Toward Their Integration With the Semantic Web

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ABSTRACT Thesauri are Knowledge Organization Systems (KOS), that arise from the consensus of wide communities. They have been in use for many years and are regularly updated. Whereas in the past thesauri were designed for information professionals for indexing and searching, today there is a demand for conceptual vocabularies that enable inferencing by machines. The development of the Semantic Web has brought a new opportunity for thesauri, but thesauri also face the challenge of proving that they add value to it. The evolution of thesauri toward their integration with the Semantic Web is examined. Elements and structures in the thesaurus standard, ISO 25964, and SKOS (Simple Knowledge Organization System), the Semantic Web standard for representing KOS, are reviewed and compared. Moreover, the integrity rules of thesauri are contrasted with the axioms of SKOS. How SKOS has been applied to represent some real thesauri is taken into account. Three thesauri are chosen for this aim: AGROVOC, EuroVoc and the UNESCO Thesaurus. Based on the results of this comparison and analysis, the benefits that Semantic Web technologies offer to thesauri, how thesauri can contribute to the Semantic Web, and the challenges that would help to improve their integration with the Semantic Web are discussed.

INDEX TERMS Data Integration, ISO 25964, knowledge representation, SKOS, semantic technology, semantic web, thesauri.

I. INTRODUCTION

In the library and information sciences, much effort is devoted to developing tools for organizing large collections of objects such as books or museum artifacts. These tools are known generally as ''Knowledge Organization Systems'' (KOS) or as ''controlled vocabularies''. Different families of knowledge organization systems, are widely recognized and applied in both modern and traditional information systems [1]. Thesauri are a particular type of KOS commonly used from the 1960s onwards within the library community and, in the new century, they have switched to several areas such as linguistics, business, information architecture, software engineering, artificial intelligence or the Semantic Web, etc.

Thesauri are resources that benefit communication between experts and allow knowledge of a domain or language to be shared. The implementation of a thesaurus in a search system or indexing system can be exploited in numerous ways, as set out in ISO 25964, the standard for thesauri [2]: search expansion, suggestion of alternative search terms, support of clustering or other means of refining a search, identification of common spelling mistakes, or support of automatic indexing. Whereas in the past thesauri were designed for information professionals for indexing and searching, today there is a demand for conceptual vocabularies that enable inferencing by machines.

Some thesauri are well established, consolidated KOS that depend on the consensus of wide communities (see, e.g., AGROVOC[1], GEMET[2], Getty Art & Architecture Thesaurus (AAT)[3], ERIC[4], EuroVoc[5], UNESCO[6], something difficult to achieve when it refers to agreement on what knowledge

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[1] http://aims.fao.org/standards/agrovoc/
[2] https://www.eionet.europa.eu/gemet/en/themes/
[3] https://www.getty.edu/research/tools/vocabularies/aat
[4] https://www.eric.ed.gov/
[5] https://publications.europa.eu/en/web/eu-vocabularies/th-dataset/-/resource/dataset/EuroVoc
[6]http://vocabularies.unesco.org/browser/thesaurus/en/index)

is relevant for a given community. They have been in use for many years, and are regularly updated, through the collaboration of large communities. This collaborative way of working is an important part of their success and survival for so long, because it ensures the interest of the community involved. They are supported by relevant international institutions and are the result of intense intellectual work. These thesauri have adapted to diverse technological contexts, from paper to web, through databases. All this makes them worth looking at. In our case, we look at their integration with the Semantic Web.

The development of the Semantic Web has placed the focus on a new perspective and a different approach to the use of information. This recent prospect has brought a new opportunity for thesauri. A demand has arisen for interoperability to support activities, such as web services, publishing, aggregation, and the exchange of KOS data through different media and formats, as well as ''behind-the-scenes exploitation of controlled vocabularies in navigation, filtering, and expansion of searches across networked repositories'' [3], [4]. Thesauri can be used to improve semantic interoperability [5]–[8] and concept-based searches [5], [8], [9]. The advanced ability of thesauri to manage synonymy, quasi-synonymy and subsumptions between concepts makes them optimal tools to support these searches.

In the last few years, SKOS (Simple Knowledge Organization Systems) [1], a W3C Recommendation produced in the Semantic Web, provides a way to represent controlled vocabularies by means of RDF (Resource Description Framework). Most of the prominent thesauri offer a SKOS version, and thesauri tools are evolving to support this serialization of thesauri, even to adapt to its model (in references [10], [11] some of these tools are evaluated). Moreover, Linked Data has been good for thesauri, which can now be linked with other KOS sharing similar knowledge, thus increasing their usefulness as knowledge sharing tools. But thesauri also face the challenge of proving that they contribute added value to the Semantic Web, in which ontologies play a primary role as knowledge representation tools.

ISO, the international organization in charge of thesaurus standards, updated these standards between 2011 and 2013. The ISO 25964-1:2011 Information and documentation – Thesauri and interoperability with other vocabularies – Part 1: Thesauri for information retrieval, was edited in August 2011 [2]. The second part – Part 2: Interoperability with other vocabularies [12] was published in March 2013. ISO 25964 supposes the evolution from term-based thesauri to concept-based thesauri. However, ISO 25964 appeared when SKOS was already consolidated as a standard of the Semantic Web. SKOS achieved the status of a W3C Recommendation in 2009, four years before the ISO 25964 standard was released.

Considering the above scenario, the consequences that the concept-based approach (ISO 25964) has on the integration of thesauri in the Semantic Web are analysed in this paper. The questions that motivate this study are to discover how well thesauri are aligned with Semantic Web technologies, how thesauri can profit from these technologies, what the state of the art of the integration of thesauri with Semantic Web is like, and what the challenges that the thesauri community can still tackle to improve thesauri integration with the Semantic Web are.

Elements and structures in ISO 25964 and SKOS are reviewed and compared. The comparison of ISO 25964 and SKOS considers previous studies of this issue [13]–[15][7], but here the way SKOS has been applied to some real thesauri is taken into account. Three thesauri are chosen for this aim: AGROVOC, EuroVoc and the UNESCO Thesaurus. The reason behind this choice is that all of them are well-known thesauri, with a long-standing tradition, maintained by international organizations that update them in a regular manner, and they are currently published and shared on the web.

One goal of the comparison of ISO 25964 and SKOS is to characterize alignments for which there is a solution generally accepted as valid, and those for which there is no common solution. In these latter cases, the alignment applied depends on the decisions of thesaurus editors and/or thesaurus management tools, and a range of heterogeneous solutions can be found. Studying real thesauri, such as those here taken as the object of analysis, helps to recognize these alignments that lack a common solution and the approaches taken by their designers, which in some cases differ from the proposals made with the aim of generality by some authors [14], [15]. A discussion of these heterogeneous solutions, and the consequences this situation of heterogeneity has, is included. In fact, this heterogeneity implies a challenge to the thesaurus community. Possible solutions, proposed in the past (e.g., ISO-THES), or approaches for future ones, are discussed.

It is not the main interest of this paper to return to the controversy of whether thesauri will survive in the Semantic Web context, a topic already treated in the scientific literature [17], [6], [5], [18], [4]. Furthermore, the comparison of thesauri and ontologies, which has been tackled by previous works [19]–[21], is not a main interest of this paper, but it is an issue that necessarily emerges when the coexistence of thesauri and the Semantic Web is considered. Both issues are considered in section 2.4. It should be remembered that this paper is more interested in the benefits that Semantic Web technologies offer to thesauri, how thesauri can contribute to the Semantic Web, and the advances that would help to improve their integration with the Semantic Web.

The remainder of this paper is organized as follows. Section 2 presents the background of the work and the thesauri being analysed. Section 3 studies the conceptual and terminological structures supported in thesauri, their representation possibilities in ISO 25964 and SKOS and how SKOS has been applied to representations in AGROVOC,

[7]Results from these studies include the ISO-THES ontology, which is available for download at http://purl.org/iso25964/skos-thes and https://lov.linkeddata.es/dataset/lov/vocabs/iso-thes

EuroVoc and the UNESCO Thesaurus. Section 4 presents a comparison of thesaurus integrity restrictions with SKOS restrictions. A discussion is outlined in section 5. Similarities and differences in constructs and integrity rules between thesauri and SKOS/SKOS-XL constructs, challenges for thesauri and other Semantic Web standards are addressed. Finally, Section 6 collects the main conclusions.

II. BACKGROUND

A. THESAURI AND ISO

The traditional definition by Van Slype [22] understands a thesaurus as "a structured list of concepts, intended to represent in a univocal way the content of the documents and queries within a documentation system, and to help the user in the indexation of documents and queries; the concepts are extracted from a finite list, established *a priori*; only the terms appearing in this list may be used for indexing documents and queries; the user help is provided by the semantic structure of the thesaurus: fundamentally the relations of equivalence, hierarchy and association". Likewise, the new ISO 25964 standard defines concisely a thesaurus as a "controlled and structured vocabulary in which concepts are represented by terms, organized so that relationships between concepts are made explicit, and preferred terms are accompanied by lead-in entries for synonyms or quasi-synonyms" [2].

The origin of thesauri is usually located in 1852, the year in which the Thesaurus of English Words and Phrases of Peter Mark Roget was published. However, there is agreement that in the context of information retrieval, the word "thesaurus" was first used in 1957 by Peter Luhn of IBM [23]. The next big landmark was the 1967 edition of TEST[8] with an appendix setting out the rules and conventions recognizable in today's thesaurus standards [17]. From then on, thousands of thesauri have been created[9], as Dextre Clarke claims, "consuming vast amounts of the intellectual effort needed for their construction and maintenance".

The ISO 2788 standard [24] established the constructs a thesaurus can have and the integrity restrictions that must be respected. The standard for monolingual thesauri, originally published in 1974, was revised and reedited in 1986. In addition, the ISO 5964 standard [25] established the main procedures for the treatment of several languages in the same knowledge resource, identifying the main problems related to semantic equivalence.

However, the notion of thesauri as conceptual tools resulted in the update of the ISO thesaurus standard. Between 2011 and 2013, the International Organization for Standardization (ISO) published ISO 25964 [2], [12], the thesaurus standard that supersedes ISO 2788. It is an evolution from the approach of term-based thesauri, present in ISO 2788, to concept-based thesauri [3], [26]. Concepts are represented by terms. For each concept, one term is selected as the preferred term.

A thesaurus is a tool to map and handle the fuzziness of natural language and provide reliability in knowledge sharing and information retrieval. There have been standards and guidelines for thesaurus construction from very early days[10]. Clarke [17] details the sequence of national and international standards for both monolingual and multilingual thesauri. The process of thesaurus construction is traditionally divided into three technical processes: collection of concepts and terms; formation of concepts and control of terms; and organization of concepts and terms [27]. Over the years, these principles have been developed and evolved, and these processes and recommendations have been embodied in standards.

An intrinsic feature of a thesaurus is its ability to distinguish and display the structural relationships between the concepts it contains. The literature points out that there are two broad types of relationships in a thesaurus [28]: the first is at the micro level and concerns the equivalence, hierarchical and associative relationships between concepts, and the second type is at the macro level and concerns the relationships between subject/facet groups. ISO 25964 [2] notes that groups created are sometimes called "subject categories", "themes", "domains", "groups", "subsets" or "microthesauri" (p. 108). The approach of arranging a thesaurus by disciplines or subject fields usually applies to a thesaurus covering a range of different domains; grouping concepts by subject field has the advantage of organizing concepts into groups that generally correspond to the ways of thinking of the users. In the technique of arranging a thesaurus by facets, concepts are organized into facets according to the basic categories of the concept they represent (e.g., Time, Place, Properties and Measures, Agents, Operations and Processes, Materials, and Entities). Organization by facets is particularly useful in a thesaurus devoted to a single discipline [2] (p. 76).

With the evolution from ISO 2788 to ISO 25964 standard, the thesaurus community embraces the Semantic Web approach in which thesauri are shared and reused [7], [17], [23]. Moreover, work on tools that support the collaborative edition and maintenance of thesauri and other KOS is still progressing. For example, VocBench is a tool supported by the European Commission under its research programmes[11], and a new release is expected for September 2019.

B. THESAURI ANALYSED

To study how SKOS has been applied to represent real thesauri, we have selected: AGROVOC, EuroVoc and the UNESCO Thesaurus as a representative sample. These thesauri have been in existence for many years and are supported by relevant international organizations that ensure

[8]Thesaurus of Engineering and Scientific Terms of the Engineers Joint Council.

[9]The list of vocabularies on http://www.taxonomywarehouse.com may serve as a general reference.

[10]The literature highlights the pioneering role of Eugene Wall in 1967 in the development of the *Rules and Conventions* of the TEST, while the publication *UNESCOS's Guidelines for the establishment and development of monolingual thesauri* by Derek Austin and Peter Dale later incorporates ISO 2788.

[11] https://ec.europa.eu/isa2/isa2conf18/vocbench-3_en

these controlled vocabularies are regularly updated. Furthermore, the selected thesauri deal with very large areas of knowledge. This generality makes these vocabularies very valuable to broad user communities.

Moreover, they are especially suitable for comparing the adopted solutions. Since all of them are general thesauri, it is possible to compare how the same idea (or similar ideas) has been modeled in each of them. Thus, for this work, the concept "climate", as can be found in the tables in Section III, has been chosen in the three thesauri to show most of the constructs, properties and SKOS relationships. "Climate" appears in the three thesauri. This choice makes the comparison of the SKOS representations objective; it is not conditioned by the different nature of the idea or concept, but by the decisions taken in the translation of the conceptual element to its representation in the SKOS model. Moreover, these thesauri have available alignments between them in their corresponding webs. This permitted us to check the SKOS concepts that had been aligned by their respective editors, and this can facilitate the task for interested readers when checking similar concepts in their area of interest.

Finally, we think three thesauri as the object of analysis is an appropriate number to support our discussion, while also avoiding tables that are too voluminous and thus facilitate the reading.

1) AGROVOC

AGROVOC was first published (in English, Spanish and French) at the beginning of the 1980s by the Food and Agriculture Organization (FAO) of the United Nations as an indexing tool for the FAO library and the AGRIS database (International System for Agricultural Science and Technology). It is a thesaurus covering all areas of interest of the FAO, including food, nutrition, agriculture, fisheries, forestry, environment, etc. Nowadays, it is maintained by a wide community of experts and institutions, with the coordination and technical support of the FAO. Updated content is released once a month. The current release is 3.4. AGROVOC is widely used in specialized libraries as well as digital libraries and repositories to index content and for the purpose of text mining.

In 2000, AGROVOC abandoned paper printing and went digital. In 2009 AGROVOC became a SKOS resource. Today, it is available as a SKOS-XL concept scheme, also published as a Linked Open Data set, composed of 36,000+ concepts available in up to 33 languages. It is edited using VocBench[12]. AGROVOC thesaurus is hierarchically organized under 25 top concepts. AGROVOC top concepts are very general and high level concepts, including concepts such as "activities", "entities", "locations", "products", "substances", "organisms", etc. The fact that 20,000+ concepts fall under the top concept "organisms", confirms how AGROVOC is largely oriented towards the agriculture sector [29].

[12] http://vocbench.uniroma2.it/

AGROVOC is aligned with 18 other multilingual knowledge organization systems and is accessible through a SPARQL endpoint. Two distributions are provided for download: CORE, which only includes AGROVOC concepts (RDF and NT format), and Linked Open Data (LOD) which includes AGROVOC concepts plus links to outside resources (NT and NQ format). The publication of AGROVOC on the web uses Skosmos as a search and browsing tool [30]. There is an ontology associated to this thesaurus, Agrontology[13].

2) EuroVoc

EuroVoc is a multilingual thesaurus which was originally built up specifically for processing the documentary information of the European Union (EU) institutions. In 1982 the European Parliament and the European Commission decided to construct a multilingual thesaurus covering the fields of interest to the European institutions and which would comply with the relevant international standards. The first edition of the EuroVoc thesaurus was published in 1984 in seven languages. After successive print editions, the fourth edition was disseminated on the Internet in 2002. Since Edition 4.4, it has been published and made available over the Internet in 23 EU languages [31]. The EuroVoc thesaurus is adapted continually. It is edited using VocBench. The current release, 4.9, was published in December 2018.

EuroVoc is a multi-disciplinary thesaurus covering fields which are sufficiently comprehensive to include both Community and national perspectives, with emphasis on parliamentary activities. EuroVoc is managed by the Publications Office of the EU and its users include the EU Institutions, the Publications Office of the EU, national and regional parliaments in Europe, as well as national governments and private users all around the world.

The EuroVoc thesaurus was compiled in accordance with the ISO 25964 standard. It is split into 21 domains and 127 microthesauri. Each domain is divided into a number of microthesauri. The current release has 7,222 concepts.

EuroVoc is aligned with 15 other KOS. The EuroVoc Thesaurus can be downloaded in XML, SKOS-Core, SKOS-AP-EU (rich RDF format developed by the Publications Office), Excel and Marc-XML. An SPARQL endpoint is also available. In addition, EuroVoc also has an ontology, called EuVoc[14], to extend SKOS with classes and properties specific to this thesaurus.

3) UNESCO THESAURUS

A provisional edition of the UNESCO Thesaurus was elaborated between 1973 and 1974, although the first edition in English was in 1977, with French and Spanish translations in 1983 and 1984 [32]. The second revised and restructured version was released in 1995. Today the Thesaurus is available in English, French, Russian and Spanish.

[13] http://aims.fao.org/aos/agrontology

[14] https://data.europa.eu/euodp/en/data/dataset/eurovoc/resource/eacff603-ee53-4eed-a6e3-61c5f7048a07

The UNESCO Thesaurus is primarily used for indexing and searching resources in UNESCO's repository for documents and publications in the fields of education, culture, natural sciences, social and human sciences, communication and information. It is a multidisciplinary vocabulary enriched and updated continuously.

The UNESCO Thesaurus is compliant with the ISO 25964 standard. It is composed of 4,417 concepts which are grouped into 7 domains ("Education", "Science", "Culture", "Social and Human Sciences", "Information and Communication", "Politics, law and economics", and "Countries and country groupings") and 88 microthesauri. It has been published as a SKOS dataset available according to the Linked Open Data principles, whose download is offered in the SKOS Core version and in the SKOS-XL version. The UNESCO Thesaurus is available for download[15] in different formats: PDF, RDF/XML, TURTLE and JSON-LD. In addition, it is accessible through a SPARQL endpoint. The official version of this thesaurus uses the ISO-THES ontology.

C. SEMANTIC WEB AND KOS: SKOS

By the time ISO 25964 appeared, there was already a W3C Recommendation for representing KOS in the Semantic Web: SKOS (Simple Knowledge Organization System) [1]. SKOS provides a way to represent KOS using RDF, facilitating the convergence of the Semantic Web and KOS. SKOS is available as an OWL ontology [33]. SKOS already used the concept-based approach. During the period when ISO 2788 was the available standard for thesauri, the benefits of using W3C standards such as SKOS led to several thesauri being represented with SKOS, a list to which new items are constantly being added [26], [34]. Moreover, thesaurus tools were adapted to use RDF/SKOS as the underlying language to store and share the thesauri their users created and edited.

Using SKOS, a KOS can be represented as an RDF graph, whose resources are of types predefined in the SKOS ontology. It provides with constructs and relationships that can be found in KOS, and is sufficiently flexible to accommodate a wide set of KOS, such as folksonomies, control lists, thesauri, etc. Therefore, it can be used to represent thesauri, but it is not tailored specifically for thesauri. Besides, when SKOS was stabilized, the ISO standard for thesauri was ISO 2788, which was later superseded by ISO 25964, as noted above.

SKOS understands a KOS as a set of concepts, which can be grouped in concept schemes. Each concept and concept scheme is a resource, which can be identified by a URI. A concept represents an idea and it can have several labels associated to it. These labels can be preferred or non preferred. They are literals. Only one preferred label can be associated to each concept in one language. Each concept scheme is "an aggregation of one or more SKOS concepts. Semantic relationships (links) between those concepts may also be viewed as part of a concept scheme" [1]. In general, each KOS is considered a concept scheme. Concepts from the same KOS can be related by hierarchical relationships, Broader than (BT) / Narrower than (NT), or by associative relationships, Related (RT). SKOS concept collections are "labeled and/or ordered groups of SKOS concepts. Collections are useful where a group of concepts shares something in common, and it is convenient to group them under a common label, or where some concepts can be placed in a meaningful order" [1]. Collections can be ordered or not. These are the basic types of construct that SKOS provides.

In addition, there is an extension, called SKOS-XL, in which labels are not literals, but resources that can participate in relationships. As such, each label has a URI that identifies it. No more explanation of SKOS constructs will be given here. This brief introduction is enough to have an idea of the constructs that SKOS provides and, in section 3, these will be discussed in more detail.

As it has already been noted, SKOS is a flexible proposal, prepared to accommodate more types of KOS than thesauri. This has required work on the equivalence between the ISO standards and the W3C standard (SKOS). The equivalence between thesauri constructs, as defined by ISO 2788, and SKOS constructs was first covered by guidelines provided in the SKOS Primer Guide [13]. The equivalence between ISO 25964 and SKOS is dealt with in [14]. Some mappings are direct, but there are correspondences which are more difficult to make. For example, concepts in ISO 25964 are concepts in SKOS, but relations like hasSubGroup/hasSuperGroup in ISO 25964 do not have a direct equivalence in SKOS. ISO 25964 is more complex than ISO 2788, which does complicate representing thesauri with SKOS.

Based on the W3C Recommendation [1], an extension of SKOS for thesauri according to ISO 25964, called ISO-THES[16], was proposed [15]. ISO-THES proposes new classes for types of ISO 25964 constructs and thesaurus structures that do not have a direct equivalence in SKOS, for example, concept groups and the inclusion of relationships between them. ISO-THES is in fact an ontology, which extends SKOS with classes and properties that represent the ISO 25964 constructs. However, it appeared when some thesauri had already made their transit to SKOS, so the SKOS representations of these thesauri did not follow its guidelines (that is, they do not use its classes and properties to represent thesaurus constructs). This is in fact the situation with EuroVoc and AGROVOC, two thesauri used in section 3 to exemplify how thesaurus constructs have been represented in real thesauri.

D. THESAURI AND ONTOLOGIES

When talking about the Semantic Web, it is necessary to mention ontologies. Ontologies are the powerful conceptual tools that communities use to share knowledge in the Semantic Web. There are ontologies with a general vocation, covering a wide range of fields, such as those used

[15] http://vocabularies.unesco.org/exports/thesaurus/latest/

[16] https://lov.linkeddata.es/dataset/lov/vocabs/iso-thes

by DBPedia[17], schema.org[18], etc., and ontologies more specific to a given domain, such as geographic information systems [36], [37], or to the legal domain [38]–[40]. Ontologies also provide a support for describing and linking resources based on the properties shared [41]. Given that both thesauri and ontologies are used to share knowledge, the comparison was unavoidable. The 'survival' of thesauri with the Semantic Web was questioned and the subsequent discussion was open [6]. Besides, there were various serious efforts to obtain ontologies from thesauri and other KOS [42]. There are, however, relevant differences between ontologies and thesauri [20].

These differences are enough to justify the existence of a Semantic Web standard, SKOS, specifically designed to represent KOS in the Semantic Web context [7]. One relevant difference, sufficient to support this argument, is provided by the ISO 25964 standard (Part II, chapter 21) [12]: ontologies deal with classes, which have instances (individuals). Reasoning benefits from this, meaning that all individuals or instances inherit the properties of the classes they belong to. However, thesauri only deal with concepts. For example, in an ontology, 'Earth' is an instance of the 'Planet' class and inherits the properties of a planet, while in a thesaurus both, 'Earth' and 'Planet', are concepts. It is not in the interest of this paper to get into the analysis of ontologies and thesauri similarities and differences, for which readers are forwarded to the references mentioned above. However, these differences prove that specific work about thesauri is of interest.

Ontologies and thesauri have been successfully used as complementary resources in [43], [44]. The approach taken in these works is to use thesauri and other terminological resources to enrich ontologies with terminological information about an ontology's elements. This approach is, in fact, opposite to the approach of SKOS: thesauri enrich ontologies, while with SKOS, ontologies benefit thesauri by facilitating their integration with the Semantic Web.

Moreover, the use of ontologies is compatible with maintaining thesauri. For example, the use of legal ontologies, such as the one developed by the Publications Office of the European Union [39], is not in conflict with the use by this institution of long-standing thesauri such as EuroVoc in its information systems. In fact, EuroVoc is one of the three thesauri used in this article. Besides, thesauri have not only been represented with SKOS: specific ontologies have been created to accompany them, extending the SKOS ontology with ad-hoc classes and properties that provide the specific semantics used in each thesaurus that is not available in SKOS. In some cases, these extensions represent similar semantics with different properties (an example will be shown in section 3, with the manner of representing concept groups nesting in ISO-THES and the EuroVoc ontology). In other cases, the semantic is really specific to each thesaurus, as happens with the AGROVOC ontology, for instance, Influence, Is component of, and Is influenced by or Depends on, are properties that represent a semantic specific to the AGROVOC thesaurus.

E. THESAURI AND LINKED DATA

Thesauri are increasingly being represented in the Semantic Web, but for vocabularies to be reused in this new ecosystem they need to be published as Linked Open Data. Linked data are therefore essential ingredients of the Semantic Web, where representing information entities via URIs makes them machine processable [45]. The main principles of Linked Data are: entities should be named via unique URIs; these URIs should be HTTP URIs and be resolved using standard web protocols; when these URIs are resolved, they should return useful information about the resource; they should contain links to other URIs so people can discover related resources.

There are many initiatives and research groups focused on work related to the development of vocabularies and terminologies published as open data. For example, in the legal field, Poblet *et al.* [46] discuss how to use Linked Data and Open Data in the construction of a model of "linked democracy". Meanwhile, Cimiano *et al.* [47] address the advantages of applying Linked Data principles to terminologies and present a model for representing terminologies in RDF.

In Montiel-Ponsoda *et al.* [48], the European project Lynx[19] is presented. The project relies on public open data, on the one hand, and on the technologies provided by the Linked Data paradigm, on the other. Lynx, based on a legal knowledge graph, which uses terminologies and thesauri, including the Unesco Thesaurus, shows how to contribute to the construction of advanced services, for example, to annotate documents in the area of Law, to provide definitions of the terms used in them, to classify texts, to identify subjects, and so on.

Moreover, Bosque-Gil *et al.* [49], introduce *Terminoteca RDF*, a prototype that aims to lay the foundations of a repository of linked multilingual terminologies of official languages in Spain. This project aims to integrate different terminologies into a single unified graph and constitute a single entry point to them. Thus, information coming from different sources and developed in isolation can now be traversed and searched in an easy way by following Semantic Web standards. The core data has been modelled using the Lemon-Ontolex model.

F. RELATED WORK

There are works that test the quality of KOS represented with SKOS [50]. In these works, the goal is to analyze the quality of the SKOS representation of controlled vocabularies (which include other KOS than thesauri) and to provide suggestions to correct the problems detected. In this paper, we focus

[17] https://wiki.dbpedia.org/
[18] https://schema.org/
[19] Lynx: Building the Legal Knowledge Graph for Smart Compliance Services in Multilingual Europe. http://www.lynx-project.eu/

on thesauri and their representation with SKOS. More than suggesting manners of correcting problems detected, we are interested in identifying the issues that lack general solutions, and suggesting approaches for future work that overcomes these difficulties.

Mastora *et al.* [8] compare 'the ontological substance of KOS concepts' with the results (concepts) of applying Natural Language Processing (NLP) techniques to the lexical representations (RDF literals) of SKOS concepts. This same team [21] investigates the potential of various types of KOS (thesauri, subject heading systems, and classifications) to be represented on the Semantic Web. As in our work, the integration of thesauri with the Semantic Web is evaluated, but the perspective is from the comparison of Functional Requirements for Subject Authority Data (FRSAD) and the Simple Knowledge Organization System (SKOS), supported with natural language processing techniques. Our approach is different: we focus on thesauri and compare the solutions that have been used to represent them with SKOS, looking for commonly used solutions, which therefore seem to be the most solid, and the weakest points, where there are opportunities to continue moving towards shared solutions. We are also interested in how thesauri are benefiting, and could benefit in the future, from Semantic Web proposals.

Likewise, Alexiev *et al.* [51] pose the elaboration based on logical conditions and restrictions of semantic relationships in KOS, especially concerning the part-whole relationship: broader generic (BTG), broader partitive (BTP), and broader instantial (BTI) formalized in ISO 25964. They define extended properties (BTGE, BTPE, BTIE) that have the same semantic precision in their representation in SKOS. A first step towards an agreement on formal semantics for these relationships are presented. However, it is still too soon to know if it will become a standard solution.

III. CONCEPTUAL AND TERMINOLOGICAL STRUCTURES SUPPORTED: THESAURUS CONSTRUCTS

The main construct types that can be used in a thesaurus are presented in this section. For each of them, besides their main characteristics, the possibilities of representing them with SKOS are introduced. Table 1 summarizes this. The first column lists the types of constructs according to ISO 25964 and the second presents the SKOS construct or constructs that represent a similar idea, that is, those which can be used to represent it (if there is no SKOS construct with similarities, this will be referred to in tables as 'No equivalent in SKOS'). Table 1 has been filled using the guidelines in [14] as a main guide[20]. However, other variations found in the thesauri examined are included. As we will discuss along this section, the guidelines in [14] are not always followed.

[20]The prefixes used in this table and the following are listed in the Appendix. For the SKOS vocabulary, the prefixes used, skos: and skosxl:, are the same as those used in the SKOS Recommendation. Other variations can be found in some implementations and examples used in this paper. However, it is easy to recognize that they refer to the same entity. The RDF statements included as examples in tables, have been normalized and serialized according to the RDF Turtle syntax.

TABLE 1. Constructs in ISO 25964 and SKOS.

ISO 25964 construct	SKOS construct
Thesaurus	skos:ConceptScheme
ThesaurusConcept	skos:Concept
ThesaurusTerm	skosxl:Label
ConceptGroup (subject category, domain, microthesaurus, theme)	(Subclass of) skos:Collection, skos:ConceptScheme
Note	skos:note
ThesaurusArray	(subclass of) skos:Collection
CompoundEquivalence	No equivalent in SKOS

ISO 25964 constructs are grouped in sets for their detailed examination in the rest of this section. For each group, the possible representations with SKOS are discussed. This discussion is built on the examination of three thesauri represented with SKOS, presented in section 2.2: AGROVOC, EuroVoc, and the UNESCO thesaurus. Examples are shown for each of these thesauri. These examples include the serialization of the relationships that can be established between them. However, when relations deserve a separate section due to their special relevance in the construction of a thesaurus, a specific section has been devoted to them. This is the case, for example, of hierarchical and associative relations, crucial for providing the structure of a thesaurus.

A. TESAURI, CONCEPTS AND TERMS

A thesaurus is a controlled and structured vocabulary. ISO 25964 uses the concept-based approach, i.e., the main constructs of thesauri are Concepts, units of thought. The relationships that provide structure to a thesaurus are established between concepts, that is, concepts are fundamental constructs of thesauri. Concepts are represented by terms. These terms can be PreferredLabels, of which each concept can have only one per language, or NonPreferredLabels, of which each concept can have more than one for each language. Consequently, ISO 25964 distinguishes between preferred and non-preferred terms. The relationships provided for this aim in ISO are isPreferredLabelFor/hasPreferredLabel[21] for preferred labels. For non preferred labels they are isNonPreferredLabelFor/hasNonPreferredLabel. The membership of a concept to a thesaurus is modeled with isPartOf/contains relationships.

ISO 25964 provides the possibility of establishing an equivalence relationship between two terms in a thesaurus representing the same concept in the same natural language. The equivalence relationships are USE (for the preferred term), and UF (for the non-preferred term). These relationships are maintained for compatibility with ISO 2788, its predecessor standard. In fact, they represent the same meaning that is already represented with the preferred/non preferred label relationships of each concept with its labels.

When mapping to SKOS, skos:ConceptScheme is used to represent a thesaurus, a structure that compiles and organizes a set of concepts, and each concept is represented

[21]They are reciprocal relationships.

TABLE 2. Constructs in ISO 25964 and SKOS: Thesauri, concepts and terms.

ISO 25964 construct	SKOS construct
Thesaurus	**skos:ConceptScheme**
SKOS AGROVOC	**AGROVOC example**
skos:ConceptScheme	*Agrovoc is a Thesaurus:* <http://aims.fao.org/aos/agrovoc> rdf:type skos:ConceptScheme.
SKOS EuroVoc	**EuroVoc example**
skos:ConceptScheme eu:Thesaurus	*EuroVoc is a Thesaurus:* <http://eurovoc.europa.eu/100141> rdf:type skos:ConceptScheme, eu:Thesaurus.
SKOS Unesco	**Unesco example**
skos:ConceptScheme	*Unesco is a Thesaurus:* <http://vocabularies.unesco.org/thesaurus> rdf:type skos:ConceptScheme.
ThesaurusConcept	**skos:Concept**
SKOS AGROVOC	**AGROVOC example**
skos:Concept	*Climate is a ThesaurusConcept:* agrovoc:c_1665 rdf:type skos:Concept.
SKOS EuroVoc	**EuroVoc example**
skos:Concept eu:ThesaurusConcept	*Climate is a ThesaurusConcept:* eurovoc:6011 rdf:type skos:Concept, eu:ThesaurusConcept.
SKOS Unesco	**Unesco example**
skos:Concept	*Climate is a ThesaurusConcept:* thesaurus:concept5434 rdf:type skos:Concept.
ThesaurusTerm	**skosxl:Label**
SKOS AGROVOC	**AGROVOC example**
skosxl:Label skos-xl:literalForm	*'Climate' is a ThesaurusTerm:* agrovoc:xl_en_1299512695556 rdf:type skosxl:Label; skosxl:literalForm "climate"@en .
SKOS EuroVoc	**EuroVoc example**
skosxl:Label eu:SimplePreferredTerm	*'Climate' is a ThesaurusTerm:* eurovoc:218442 rdf:type eu:SimplePreferredTerm, skosxl:Label.
SKOS Unesco	**Unesco example**
skosxl:Label	*'Climate' is a ThesaurusTerm:* thesaurus:concept5434-xl-d1e27930 rdf:type skosxl:Label.

with skos:Concept, each of them in turn identified with a URI. Labels can be preferred (skos:prefLabel), alternative (skos:altLabel), or hidden (skos:hiddenLabel). The relationships between a thesaurus concept and the thesaurus it is in, can be represented with the skos:inScheme property. There is another property in SKOS, skos:topConceptOf, which is a subproperty of skos:inScheme. As this implies that a concept related with a concept scheme by a skos:topConceptOf is also related by a skos:inScheme property, it could have been included in table 2. However, Top Concepts will be dealt with in detail later in this article, where the use of skos:topConceptOf property and its implications will be examined.

The idea of Terms in ISO 25964 matches the SKOS-XL extension [35], where terms are raised to the category of objects that can be related with other objects, something which is not possible for labels. The skos-xl:label is used in this case.

For example, the concept represented with the preferred label "climate"@en in EuroVoc has twelve non preferred labels, "clima continentale"@it, "microclima"@it, etc., which can be used to represent the same idea. ISO 25964 hasPreferredLabel and hasNonPreferredLabel properties link the concept to its labels. The mapping to SKOS is direct: this concept is identified with the URI http://eurovoc.europa.eu/6011, classified as a resource of type skos:Concept, and its labels are referred to either with the skos:prefLabel, skos:altLabel properties in the SKOS Core version, or with the skosxl:prefLabel, skosxl:altLabel properties in the SKOS-XL version (see Table 3). The URIs of terms used as PreferredLabels and NonPreferredLabels with SKOS-XL are http://eurovoc.europa.eu/218442 http://eurovoc.europa.eu/256442, etc. The equivalence relationship between preferred and non-preferred labels is shown on the web page in EuroVoc by the abbreviations 'UF' (used for), in front of the SimpleNonPreferredTerm and 'USE', in front of the PreferredTerm. 'Climate' has also been selected as the example concept in AGROVOC and Unesco Thesaurus. Table 2 shows examples from the three thesauri. Relationships between thesauri, concepts, and terms, are exemplified in table 3.

The examples of the tables have been extracted from the RDF files downloaded from the official websites of each of the thesauri. As for the cells, each one contains the statement in natural language in italics, followed by its expression in RDF (when there are two possibilities, with SKOS and SKOS-XL, both are indicated).

B. CONCEPT GROUPS

Thesauri have usually been organized in groups based on thematic fields or disciplines, called 'themes', 'domains', 'subject categories' or 'microthesauri'. ISO 25964 introduces a new construct for them: concept groups. Concept groups can have their own labels, called ConceptGroupLabels in this case, one for each language.

Even if not common, thesauri can have multiple concept group levels, that is, concept group nesting is possible in thesauri. For instance, the EuroVoc thesaurus has 21 thematic fields and 127 microthesauri. Thus, the domain 'Environment' is divided into 3 microthesauri: '5206 environmental policy, '5211 natural environment' and '5216 deterioration of the environment'; the UNESCO Thesaurus has 7 domains and 88 microthesauri, for example 'Science' is a domain split into 17 microhesauri, some of which are 'Environmental sciences and engineering' or 'Meteorology'. In the case of AGROVOC, this vocabulary is not organized in concept groups, it is organized under 25 top concepts, for example 'phenomena', a top concept divided into 27 concepts like 'biological phenomena', 'chemical phenomena', 'damage', 'deficiencies', 'deterioration', etc.

TABLE 3. Relationships for thesauri, concepts and terms in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS property
isPreferredLabelFor / hasPreferredLabel (relates PreferredTerm, ThesaurusConcept)	**skos:prefLabel / skosxl:prefLabel**
SKOS AGROVOC	**AGROVOC example**
skos:prefLabel / skosxl:prefLabel	*Climate hasPreferredLabel "climate"@en:* In SKOS-CORE: agrovoc:c_1665 skos:prefLabel “climate”@en. In SKOS-XL: agrovoc:c_1665 skosxl:prefLabel agrovoc:xl_en_1299512695556.
SKOS EuroVoc	**EuroVoc example**
skos:prefLabel / skosxl:prefLabel	*Climate hasPreferredLabel "climate"@en:* In SKOS-CORE: eurovoc:6011 skos:prefLabel "climate"@en. In SKOS-XL: eurovoc:6011 skosxl:prefLabel eurovoc:218442.
SKOS Unesco	**Unesco example**
skos:prefLabel / skosxl:prefLabel	*Climate hasPreferredLabel "climate"@en:* In SKOS-CORE: thesaurus:concept5434 skos:prefLabel "Climate"@en. In SKOS-XL: thesaurus:concept5434 skosxl:prefLabel thesaurus:concept5434-xl-d1e27930.
isNonPreferredLabelFor / hasNonPreferredLabel (relates NonPreferredTerm, ThesaurusConcept)	**skos:altLabel / skosxl:altLabel**
SKOS AGROVOC	**AGROVOC example**
skos:prefLabel / skosxl:prefLabel	*Climate hasNonPreferredLabel "natural climate"@en:* In SKOS-CORE: agrovoc:c_1665 skos:altLabel “natural climate”@en. In SKOS-XL: agrovoc:c_1665 skosxl:altLabel agrovoc: xl_en_1299512700086. agrovoc:xl_en_1299512700086 skosxl:literalForm "natural climate"@en.
SKOS EuroVoc	**EuroVoc example**
skos:altLabel / skosxl:altLabel	*Climate hasNonPreferredLabel "microclima"@it:* In SKOS-CORE: eurovoc:6011 skos:altLabel "microclima"@it; In SKOS-XL: eurovoc:6011 skosxl:altLabel eurovoc:256442.
SKOS Unesco	**Unesco example**
skos:altLabel / skosxl:altLabel	*Abandoned children hasNonPreferredLabel “Deserted children”@en* In SKOS-CORE: thesaurus:concept977 skos:altLabel "Deserted children"@en. In SKOS-XL: thesaurus:concept977 skosxl:altLabel thesaurus: concept977-xl-d1e1789.

TABLE 3. *(Continued.)* Relationships for thesauri, concepts and terms in ISO 25964 and SKOS.

isPartOf / contains (relates ThesaurusConcept, Thesaurus)	**skos:inScheme**
SKOS AGROVOC	**AGROVOC example**
skos:inScheme	*Climate isPartOf Agrovoc:* agrovoc:c_1665 skos:inScheme <http://aims.fao.org/aos/agrovoc>.
SKOS EuroVoc	**EuroVoc example**
skos:inScheme	*Climate isPartOf EuroVoc:* eurovoc:6011 skos:inScheme eurovoc:100141.
SKOS Unesco	**Unesco example**
Skos:inScheme	*Climate isPartOf Unesco Thesaurus:* thesaurus:concept5434 skos:inScheme <http://vocabularies.unesco.org/thesaurus>.

ISO 25964 Concept groups are considered a subclass of skos:Collection by Isaac in [14]. A SKOS Collections is a labeled and/or ordered group of concepts which do not need to be related by hierarchical relationships [13]. ISO-THES provides the iso-thes:ConceptGroup class for concept groups. However, as we have already mentioned, while ISO 25964 was not yet available, term-based thesauri started to be represented with SKOS, and in some of them skos:ConceptSchemes were used to represent constructs that ISO 25964 names concept group. As defined by the SKOS Recommendation, a SKOS concept scheme can be an aggregation of two or more different concepts. Both definitions can be applied to the idea of concept group present in ISO 25964, and this is what has happened.

An interesting example is found in EuroVoc, which uses two different types of SKOS constructs for its domains and its microthesauri. This is the solution that this thesaurus has for the fact that SKOS does not anticipate the possibility to define a hierarchy of concept schemes. The EuroVoc ontology provides two different classes for domains and microthesauri (eu:Domain, eu:MicroThesaurus) and a specific property for relating them (eu:domain). See in table 4, the ‘Natural environment’ microthesaurus, and the ‘Environment’ domain. It is, in fact, in this ontology where the idea of domains and microthesauri, historically used in EuroVoc, has been reflected in its purest form. With SKOS constructs, domains are mapped to skos:Concepts, while microthesauri are mapped to skos:ConceptSchemes. AGROVOC is a peculiar thesaurus: it only uses skos:Concept and one single skos:ConceptScheme (for the thesaurus itself). On the other hand, the UNESCO thesaurus uses ISO-THES, which follows the guidelines outlined in [14], so that domains and microthesauri are both subclasses of skos:Collection. As a consequence, concept groups from ISO 25964 have been

TABLE 4. Concept groups (domains, microthesauri…) in ISO 25964 and SKOS.

ISO 25964 construct	SKOS construct
ConceptGroup	**(subclass of) skos:Collection, skos:ConceptScheme**
SKOS AGROVOC	**AGROVOC example**
----	----
SKOS EuroVoc	**EuroVoc example**
skos:ConceptScheme, eu:MicroThesaurus, skos:Concept, eu:Domain	*Natural environment is a Microthesaurus:* eurovoc:100243 rdf:type skos:ConceptScheme, eu:MicroThesaurus. *Environment is a Domain:* eurovoc:100155 rdf:type skos:Concept, eu:Domain.
SKOS Unesco	**Unesco example**
isothes:ConceptGroup, unes:MicroThesaurus, unes:Domain, skos:Collection	*Meteorology is a Microthesaurus:* thesaurus:mt2.45 rdf:type isothes:ConceptGroup, unes:MicroThesaurus, skos:Collection. *Science is a Domain:* thesaurus:domain2 rdf:type isothes:ConceptGroup, unes:Domain, skos:Collection.

presented in three different ways: with skos:Concept, with skos:ConceptScheme and with skos:Collection.

The possibility of nesting between groups of concepts, is indeed the cause of one of the more interesting sources of heterogeneous solutions when representing thesauri with SKOS. This situation not having a solution in SKOS similar to concept group nesting in thesauri, impacts the representation of concept groups with SKOS, as heterogeneity may occur. AGROVOC does not have concept groups. So, there is no concept group nesting in this thesaurus. The cells for this thesaurus are left empty in tables 4 and 5. EuroVoc uses an ad-hoc property, eu:domain, to represent concept group nesting, while the UNESCO thesaurus uses the ISO-THES property for this purpose, isothes:SuperGroup. The closest SKOS property for the ISO 25964 hasSubGroup/hasSuperGroup property would be the skos:member property, which can be used to nest collections. This is the one shown in table 5. However, it should be remembered that this property cannot be used when SKOS concept schemes are used to represent concept groups. Besides, the belonging of a concept group to a thesaurus can be expressed in various manners. The skos:inScheme property can be used for this aim [14], independent of how a concept group has been represented with SKOS. The UNESCO example in table 5 uses this. However, EuroVoc shows a different solution. The 'Natural environment' microthesaurus is related to the EuroVoc thesaurus by the Dublin Core property isPartOf, while the 'Environment' domain is not explicitly related to EuroVoc (see table 5).

TABLE 5. Relationships for concept groups in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS property
isConceptGroupLabelOf / hasConceptGroupLabel (relates ConceptGroupLabel, ConceptGroup)	**skos:prefLabel / skosxl:prefLabel**
SKOS AGROVOC	**AGROVOC example**
----	----
SKOS EuroVoc	**EuroVoc example**
skos:prefLabel, skosxl:prefLabel	*Natural environment hasConceptGroupLabel "5211 natural environment"@en* In SKOS-CORE: eurovoc:100243 skos:prefLabel "5211 natural environment"@en. In SKOS-XL: eurovoc:100243 skosxl:prefLabel eurovoc:1001155.
SKOS Unesco	**Unesco example**
skos:prefLabel, skosxl:prefLabel	*Meteorology hasConceptGroupLabel "Meteorology"@en* In SKOS-CORE: thesaurus:mt2.45 skos:prefLabel "Meteorology"@en.
isPartOf / contains (relates ConceptGroup, Thesaurus)	**skos:inScheme**
SKOS AGROVOC	**AGROVOC example**
----	----
SKOS EuroVoc	**EuroVoc example**
dct:isPartOf	*Natural environment isPartOf EuroVoc:* eurovoc:100243 dct:isPartOf eurovoc:100141.
SKOS Unesco	**Unesco example**
skos:inScheme	*Meteorology isPartOf Unesco Thesaurus:* thesaurus:mt2.45 skos:inScheme <http://vocabularies.unesco.org/thesaurus>.
hasSubGroup / hasSuperGroup (relates ConceptGroup, ConceptGroup).	**skos:member**
SKOS AGROVOC	**AGROVOC example**
----	----
SKOS EuroVoc	**EuroVoc example**
eu:domain	*Natural environment hasSuperGroup Environment:* eurovoc:100243 eu:domain eurovoc:100155.
SKOS Unesco	**Unesco example**
isothes:superGroup	*Meteorology hasSuperGroup Science:* thesaurus:mt2.45 isothes:superGroup thesaurus:domain2.
isMemberOfGroup / hasAsMember (relates ThesaurusConcept, ConceptGroup).	**skos:member, skos:inScheme**
SKOS AGROVOC	**AGROVOC example**
----	----
SKOS EuroVoc	**EuroVoc example**
skos:inScheme	*Climate isMemberOfGroup Natural environment:* eurovoc:6011 skos:inScheme eurovoc:100243. *Climatic zone isMemberOfGroup Natural Environment:* eurovoc:4786 skos:inScheme eurovoc:100243.
SKOS Unesco	**Unesco example**
skos:member	*Climate isMemberofGroup Meteorology:* thesaurus:mt2.45 skos:member thesaurus:concept5434.

C. HIERARCHICAL RELATIONSHIPS

These relationships provide the hierarchical structure that organizes a thesaurus. They relate a pair of concepts of which one has a scope falling completely within the scope of the other. They are broader term (BT) and narrower term (NT), which are reciprocal. ISO 25964 maintains these traditional symbols, but they should be understood as "broader concept and "narrower concept", respectively. For example, in AGROVOC, the concept 'climate' has 22 narrower concepts: 'arid climate', 'coastal climate', 'continental climate', 'dry subhumid climate', 'humid climate', 'macroclimate', etc. In EuroVoc, the concept described as 'climate' has 2 narrower concepts: 'atmospheric conditions' and 'climatic zone'. Lastly, in the case of the UNESCO Thesaurus, the concept 'climate' has 2 narrower concepts: 'climatic data' and 'climatic maps'. Some are shown in table 6. These relationships have a direct mapping in SKOS: skos:broader and skos:narrower.

TABLE 6. Hierarchical relationships in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS property
BT/NT (relates ThesaurusConcept, ThesaurusConcept): **a) Without type** **b) Type = "kind of"** **c) Type = "part of"** **d) Type = "instance of"**	**skos:broader / skos:narrower**
SKOS AGROVOC	**AGROVOC example**
skos:broader, skos:narrower	*Microclimate BT Climate:* agrovoc:c_4802 skos:broader agrovoc:c_1665. *Climate NT Microclimate:* agrovoc:c_1665 skos:narrower agrovoc:c_4802.
SKOS EuroVoc	**EuroVoc example**
skos:broader, skos:narrower	*climatic zone BT climate:* eurovoc:4786 skos:broader eurovoc:6011.
SKOS Unesco	**Unesco example**
skos:broader, skos:narrower	*Climate BT Climatology:* thesaurus:concept5434 skos:broader thesaurus:concept183.

A novelty in ISO 25964 is that it introduces the possibility of distinguishing between three types of hierarchical relationships: generic (kind of, BTG), partitive (part of, BTP) and instantial (instance of, BTI). This has several effects [16]. In addition, this distinction between the three types of hierarchical relationships, as yet, has no mapping in SKOS[22]. Indeed, a solution provided by ISO-THES was explained in [51] and used with the Getty Vocabularies[23]. Its essence is to define extended properties (BTGE, BTPE, BTIE). However, we did not find any example of typed hierarchical relationships in the SKOS representation of the thesauri used in this article. Some considerations concerning this issue are included in the Discussion (section 5).

Even if not common, hierarchical relationships can be combined in a thesaurus to obtain polyhierarchical structures. Polyhierarchical structures are defined by ISO 25964-1:2011 as a "hierarchical arrangement of concepts in a thesaurus or classification scheme in which each concept can have more than one broader concept". Polyhierarchy is not a different type of relationships, but the situation produced when concepts participate in multiple hierarchical relationships. In such situations, the concept that has several BT concepts "has the same attributes, narrower and related concepts wherever it occurs" [2]. This introduces a degree of flexibility in a thesaurus structure that requires careful manipulation during the processes of thesaurus editing and management. In fact, its use is not extended and, in some thesauri, it is explicitly modeled with specific attributes, so that it can be better controlled. In EuroVoc, a dedicated attribute, eu:hasPolyHierarchy, is used to distinguish microthesauri that support polyhierarchy[24].

An AGROVOC example of polyhierarchy is: 'renewable energy' is NT of 'energy'; 'renewable energy' is NT of 'renewable resources' (http://aims.fao.org/aos/agrovoc/c_25719). In EuroVoc an example of polyhierarchy is: 'Spain' is NT of 'NATO countries'; 'Spain' is NT of 'Southern Europe' (http://eurovoc.europa.eu/863).

D. TOP CONCEPTS

Top concepts are concepts that have no broader concepts. ISO 25964 has special properties, hasTopConcept/isTopConceptOf, for representing the relationship between a top concept and the concept group in which it is a top concept. In SKOS, it is possible to state that a concept is a top concept of a concept scheme by using the skos:topConceptOf property. It is worth paying attention to the fact that the skos:topConceptOf property can only be used with skos:ConceptSchemes. Thus, if skos:Collections are used to represent concept groups, as suggested in [14], this property cannot be used to map the ISO property. In this way, the heterogeneity found in mapping concept groups to SKOS constructs is transmitted to the manner of representing top concepts. In fact, [14] proposes to infer that a concept is a top concept from the NarrowerTransitive/BroaderTransitive relationships in SKOS.

In conclusion, if skos:Collections are used for concept groups, there is no similar property or attribute in SKOS for top concepts. However, when skos:ConceptSchemes have been used to represent concept groups, the skos:topConceptOf relationship can be used. From the

[22]A W3C draft, which did not evolve to a W3C Recommendation, raised the possibility of a SKOS Extension to support some common features of KOS, especially thesauri. In particular, it introduced generic, partitive and instantial relationships. A. Miles, D. Brickley, SKOS Extensions Vocabulary Specification, World Wide Web Consortium, 2004. https://www.w3.org/2004/02/skos/extensions/spec/2004-10-18.htmlW3C

[23]Art & Architecture Thesaurus (AAT), Getty Thesaurus of Geographic Names (TGN), and Union List of Artist Names (ULAN). http://vocab.getty.edu/. Detailed explanation is available at: Alexiev, V., Cobb, J., Garcia, G., and Harpring, P. *Getty Vocabularies: Linked Open Data. Semantic Representation*. Version 3.4, 13 June 2017. http://vocab.getty.edu/doc/#Hierarchical_Relations_Inference.

[24]The EuroVoc documentation underlines the fact that the grouping of descriptors into fields is, to a certain extent, arbitrary. One of EuroVoc's distinctive features is the limitation of polyhierarchy. Concepts which could fit into two or more subject fields are thus generally assigned only to the field which seems the most natural for users, in order to facilitate the management of the thesaurus and limit its volume.

example thesauri, only EuroVoc considers top concepts in its microthesauri. The example in table 7 is a top concept of the 'Natural environment' microthesaurus in EuroVoc. We saw that EuroVoc uses skos:ConceptScheme for its microthesauri. The concept 'climate' in EuroVoc is a Top Concept of the 'natural environment' microthesaurus. This is asserted in its RDF representation with the skos:topConceptOf and skos:hasTopConcept properties. However, the three thesauri have statements to assert which are top concepts within the thesaurus. These last types of statement are the examples taken from AGROVOC and the Unesco Thesaurus.

TABLE 7. Relationships for top concepts in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS property
hasTopConcept/isTopConcept Of (relates ThesaurusConcept, ConceptGroup)	**skos:topConceptOf / skos:hasTopConcept**
SKOS AGROVOC	**AGROVOC example**
skos:topConceptOf	*Activities isTopConceptOf Agrovoc:* agrovoc:c_330834 skos:topConceptOf <http://aims.fao.org/aos/agrovoc>.
SKOS EuroVoc	**EuroVoc example**
skos:hasTopconcept	*climate isTopConceptOf natural environment:* eurovoc:6011 skos:topConceptOf eurovoc:100243.
SKOS Unesco	**Unesco example**
skos:topConceptOf	Climatology isTopConceptOf UNESCOThesaurus: thesaurus:concept183 skos:topConceptOf <http://vocabularies.unesco.org/thesaurus>.

E. ASSOCIATIVE RELATIONSHIPS

An associative relationship relates two concepts that are not in the same hierarchical structure, but are semantically similar. The symbol used is RT (Related Term) and there is a direct mapping in SKOS by means of the skos:related property. ISO 25964 offers the possibility, which was not available in ISO 2788, to comment on the nature of these relationships, something which brings the thesaurus ISO standard closer to the ability of ontologies to model semantics in relationships. Following the same previous example, the concept described as 'climate' has a related concept (RT), 'bioclimatology' in EuroVoc, 'climatic zones' in Unesco. The skos:related property provides this meaning. Table 8 shows the examples.

F. NOTES

These serve to clarify the meaning and application of a concept, in relation to other terms or concepts in the same thesaurus. Notes can be divided into scope notes, historical notes, editor notes, usage notes, etc. SKOS also supports notes. Thesauri editors can add as many notes as they want, or none. Notes do not change the essence of a thesaurus, so no more space will be devoted to them. Table 9 shows examples taken from the three thesauri.

TABLE 8. Associative relationships in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS relationship
RT (relates ThesaurusConcept, ThesaurusConcept)	**skos:related**
SKOS AGROVOC	**AGROVOC example**
skos:related	*Climate RT Phenology:* agrovoc:c_1665 skos:related agrovoc:c_5774.
SKOS EuroVoc	**EuroVoc example**
skos:related	*climate RT bioclimatology:* eurovoc:6011 skos:related eurovoc:6385.
SKOS Unesco	**Unesco example**
skos:related	*Climate RT Climatic zones:* thesaurus:concept5434 skos:related thesaurus:concept182.

TABLE 9. Notes in ISO 25964 and SKOS.

ISO 25964	SKOS
SN	**skos:scopeNote**
SKOS AGROVOC	**AGROVOC example**
skos:scopeNote	*Climate SN Average course or conditions of the weather at a place over a period of years; for areas having similar climates use <1669> (en):* agrovoc:c_1665 skos:scopeNote "Average course or conditions of the weather at a place over a period of years; for areas having similar climates use <1669>"@en.
SKOS EuroVoc	**EuroVoc example**
skos:scopeNote	*Ecology SN Study of relations with the environment, mainly physical or geographical:* eurovoc:632 skos:scopeNote "Study of relations with the environment, mainly physical or geographical"@en.
SKOS Unesco	**Unesco example**
skos:scopeNote	*Global commons SN Resources or zones that are shared as common property by all nations:* thesaurus:concept4015 skos:scopeNote "Resources or zones that are shared as common property by all nations"@en.

G. ARRAYS

Arrays are groups of sibling concepts. There is no specific construct for arrays in SKOS. In [14], the proposition is to represent them with iso-thes:ThesaurusArray, a subclass of skos:Collection. That is, the SKOS collections can be used to represent domains and arrays.

We have not found an example of an array in the three thesauri examined[25]. Thus, table 10 only shows the

[25] Arrays are used by the Getty thesauri. The interested reader can find examples in these thesauri: http://vocab.getty.edu/.

TABLE 10. Relationships for arrays in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS relationship
hasMemberConcept / isMemberOfArray (relates ThesaurusConcept, ThesaurusArray)	(subclass of) skos:Collection

TABLE 11. Relationships for compound equivalence in ISO 25964 and SKOS.

ISO 25964 relationship	SKOS property
CompoundEquivalence	No equivalent in SKOS

equivalence proposed in [14] for SKOS collections. However, for the aim of providing an example here, an array could be made with the set of sibling concepts 'agricultural vehicle, air-cushion vehicle, camping vehicle, electric vehicle, large vehicle, motor vehicle'. All of them have a common parent concept, 'vehicle', and this set could be labeled with the characteristic 'type of vehicle'.

H. COMPOUND EQUIVALENCE

USE+ and UF+ relationships are used to represent compound concepts that do not exist in a thesaurus, which can be expressed as a combination of two or more simpler concepts. ISO 25964 defines it as a 'multi-word term deemed to be unsuitable as a preferred term, but that may be sought by some users'. In some cases, the new concept is the union of subconcepts (e.g., in EuroVoc 'fossil fuel' could be considered the union of 'coal', 'natural gas', and 'petroleum'). For these situations, [16] recommends using hierarchical relationships instead of compound equivalence, that is, introducing the compound concept as one more thesaurus concept, which is related by hierarchical relationships with its components.

There is no standard solution yet to represent this with SKOS. ISO-THES proposes a specific class for this construct, iso-thes:CompoundEquivalence [14]. It is not represented in SKOS or SKOS-XL, but it is related with split non-preferred terms, which are themselves represented with SKOS-XL labels. EuroVoc has included in its ontology specific classes and properties to model compound equivalence, eu:CompoundEquivalence, eu:compoundNonPreferredTerm, eu:preferredTermComponent. However, we have not found examples in the rdf file downloaded. Nevertheless, the 'fossil fuel' example has been modeled in EuroVoc as a concept, which is related with three other concepts ('coal', 'natural gas', and 'petroleum') by RT relationships. This is not the solution proposed by [16] (RT relationships have been used in EuroVoc instead of hierarchical relationships), but it is closer to its approach than the compound equivalence of ISO 25964. We have not found compound equivalence in either AGROVOC or the UNESCO thesaurus.

IV. THESAURUS INTEGRITY

ISO 25964 establishes a set of integrity restrictions for thesauri, for example, no more than one preferred term for each language can be associated to a concept, or a concept cannot be narrower and broader of the same concept simultaneously. On the other hand, SKOS has its own integrity constraints for KOS, some of which it shares with ISO 25964. Restrictions common to both standards will be more easily ensured by any system that supports SKOS. However, there are restrictions specific to thesauri which will have to be ensured by some additional means. In the following, integrity restrictions for both standards are presented first. Then, their similarities and differences are analysed.

A. THESAURUS INTEGRITY

The integrity conditions for thesauri can be derived from the ISO standard.

1. Uniqueness: there cannot be duplicated elements in a thesaurus. This means:
   a) Each concept or idea has a single term that represents it in each language. There must be only one Preferred Label for each concept in each language.
   b) Concept groups cannot be repeated. Two concept groups do not share the same preferred label.
   c) Concepts cannot be repeated. Two concepts do not share the same preferred label.
   d) Concepts, concept groups, and arrays, are disjoint, i.e., a concept cannot also be a concept group or an array.
   e) Preferred terms cannot be used as non-preferred terms. In other words, preferred terms and non-preferred terms are disjoint sets.
2. Only concepts can participate in hierarchical and associative relationships. This means that, e.g., a term cannot participate in these relationships.
3. Some relationships are *incompatible*: BT and NT relationships are not compatible with RT relationships. Two concepts already related by a BT or NT relationship cannot be related by an RT relationship.
4. Cycles involving hierarchical relationships are forbidden. For example, if *A BT B* is true, *B BT A* is forbidden. This also holds when hierarchical and associative relationships are involved in the cycle. In addition, a top concept cannot be narrower than another one.
5. Some relationships require the existence of a reciprocal relationship. For example, if *A NT B*, then *B BT A* should be inferred.
6. When a concept is deleted, all the relationships it participates in, should also be deleted.

B. SKOS INTEGRITY

SKOS establishes its own integrity conditions, expressed in the SKOS Recommendation [1] by a set of axioms. The ones relevant for this work are included[26]:

> **S9** - *skos:ConceptScheme is disjoint with skos:Concept.*
> **S13**- *skos:prefLabel, skos:altLabel and skos:hiddenLabel are pairwise disjoint properties.*

[26]We have considered all those rules that can be used to validate the correction of the data according to the data model, even though they are not listed in the SKOS Recommendation as "Integrity Conditions".

S14 - *A resource has no more than one value of skos:prefLabel per language tag.*
S19 - *The rdfs:domain of skos:semanticRelation is the class skos:Concept.*
S20 - *The rdfs:range of skos:semanticRelation is the class skos:Concept.*
S27 - *skos:related is disjoint with the property skos:broaderTransitive.*
S37 - *skos:Collection is disjoint with each of skos:Concept and skos:ConceptScheme.*

C. COMPARISON OF THESAURUS INTEGRITY RESTRICTIONS WITH SKOS RESTRICTIONS

Table 12 summarizes the set of similarities and differences between SKOS and the ISO standard concerning integrity. They have been obtained by comparing both sets of restrictions, bearing in mind the correspondences between the types of constructs of ISO 25964 and SKOS commented in section 3. There are no equivalent restrictions in SKOS for thesauri conditions 1b, 1c, 4, and 5. The reasons are explained below.

TABLE 12. **Integrity in thesauri and SKOS: Comparison.**

ISO restriction	SKOS equivalence
Condition 1a: Only one Preferred Term for each concept	SKOS axiom S14
Condition 1b: Concept groups cannot be repeated	Not in SKOS
Condition 1c: Concepts cannot be repeated	Not in SKOS
Condition 1d: Concepts and concept groups are disjoint sets	SKOS axioms S9 and S37
Condition 1e: PreferredTerms, Non-PreferredTerms, ... disjoint sets	SKOS axiom S13
Condition 2: Only concepts participate in hierarchical and associative relationships	SKOS axioms S19 and S20
Condition 3: Incompatible semantic relationships	SKOS axiom S27
Condition 4: Forbidden cycles	Not in SKOS
Cond. 5: Inverse relationships	Not in SKOS

Condition 1a: SKOS axiom S14 guarantees that there is no more than one preferred term (property hasPreferredLabel in ISO 25964) for each concept, that is, it guarantees condition 1a.

Conditions 1b and 1c: in SKOS, the repetition of labels does not imply a duplicity of concepts; hence, even if not recommended, duplicity is not restricted [13]. For example, if two SKOS concepts share the same Preferred label, it is not inconsistent in SKOS. However, two concepts sharing a Preferred label should not be possible in a thesaurus. Consequently, conditions 1b and 1c do not have an equivalent restriction in SKOS. Even if some works on SKOS validation have considered this possibility as an improvement in quality checking of KOS, of which their editors are warned [50], [52], this is not the same as a restriction in the sense these conditions operate for thesauri.

Condition 1d: SKOS axioms S9 and S37 guarantee that a concept cannot be, at the same time, a microthesaurus/group of concepts (condition 1d). This is true both with thesauri in which microthesauri have been represented with skos:ConceptScheme, e.g., the EuroVoc thesaurus, and with thesauri in which skos:Collection has been used for this aim, which is the proposal made in [14] and has been used in the Unesco thesaurus.

Condition 1e: Axiom S13 guarantees that terms used as preferred labels are not also used as non-preferred labels.

Condition 2: Axioms S19 and S20 guarantee that only concepts participate in semantic relationships (hierarchical and associative), therefore it is not possible to relate labels.

Condition 3: Axiom S27 ensures the incompatibility of basic relationships.

Condition 4: in SKOS, cycles in hierarchical relationships are possible, in opposition to condition 4 of thesauri. For example, A skos:broader B and B skos:broader A is consistent in SKOS (see section 8.6.8 of [1]), something that would be inconsistent in an ISO valid thesaurus. The restriction for top concepts (a top concept cannot be narrower than another concept in the same group), included in condition 4, has no equivalent axiom in SKOS. This is due to the different ways of representing concept groups, as collections and as concept schemes. SKOS concept schemes have top concepts, but there are no top concepts in SKOS collections. However, even when concept schemes are used and top concepts are tagged with skos:topConceptOf/skos:hasTopConcept properties, the SKOS Recommendation states that "there are no integrity conditions enforcing this convention" [1].

Condition 5: in SKOS, there is no integrity condition associated to the fact that skos:narrower and skos:broader are reciprocal relationships. There are only logical dependencies that permit the presence of a statement such as A skos:narrower B entails B skos:broader A to be inferred (see section 1.5 of [1]). However, the presence of only one of them is consistent with the SKOS data model, which was designed with flexibility as one of its guidelines. That is, the integrity condition 5 is not required by the SKOS recommendation.

V. DISCUSSION

The convergence of thesauri and the Semantic Web is not as immediate as it could seem at a first glance. The restrictive approach that guides the definition of thesauri standards (if something does not comply with the established rules, it is not a thesaurus) diverges with the open approach of Semantic Web standards. These standards have a vocation to accept a wider set of KOS, classifications, folksonomies, glossaries, lists of subject headings, taxonomies..., even those that, being 'incomplete' (e.g., because not every reciprocal relationship is asserted) comply with a set of minimal integrity rules which make them recognizable as the type of KOS they assert to be, so that they can be completed by applying some inference.

This discussion starts with the analysis of similarities and differences between ISO 25964 and SKOS. First, comparing constructs. Some types of thesaurus constructs do not have a direct correspondence in SKOS constructs. Then, there is the comparison on the integrity issue. Integrity is more restrictive in thesauri than SKOS integrity. It is followed by the analysis of how SKOS-XL and ontologies that extend SKOS have been used to solve some of the difficulties found when thesauri are represented with RDF/SKOS. However, there are still challenges. These are presented next. How can ontologies help to meet them is the next issue we include in this discussion. Finally, some considerations concerning the adequate integration of thesauri with Linked Data close the Discussion.

A. SIMILARITIES AND DIFFERENCES BETWEEN THESAURI CONSTRUCTS AND SKOS CONSTRUCTS

There are similarities between thesauri and SKOS that facilitate the mapping of some thesaurus constructs to SKOS constructs. A thesaurus is represented as a SKOS concept scheme, concepts are defined in a similar manner in both standards. In both they have preferred and non-preferred labels, notes, and they can be related by hierarchical (NT/BT) and associative (RT) relationships. Besides, terms in ISO 25964 can be represented with SKOS-XL labels, and in both standards it is possible to have relationships between them.

Difficulties appear when some ISO 25964 constructs do not have an equivalent construct in SKOS. Some types of thesaurus constructs do not have a direct correspondence in SKOS constructs. There is no unique possibility for representing concept groups in SKOS. Thesauri arrays do not have a direct correspondence to a SKOS construct. Compound equivalence is specific to thesauri. The possibility of introducing types in hierarchical relationships, and polyhierarchy, are other characteristics of thesauri which do not have an equivalent in SKOS. This adds a level of complexity that complicates thesauri representation with Semantic Web standards.

1) CONCEPT GROUPS

Representing concept groups with SKOS has been solved with heterogeneous solutions. The types of SKOS constructs that can be used for this are concept schemes and collections, but none of them exactly represent the nature that concept groups have in ISO 25964. As a result, ontologies that extend SKOS propose new classes for concept groups, even distinguishing between domains and microthesauri. This is the way to preserve their nature: these classes represent exactly that type of construct. An interesting example is EuroVoc, in which domains have been tagged as members of the *skos:Concept* and *eu:Domain* classes. If we pay attention to the first statement (domains are represented with skos:concepts) it seems a bit surprising that a concept group has "evolved" to a concept because it is represented with SKOS. It is the second statement (domains are of type *eu:Domain*) which gives us information about its real nature. This is a really interesting issue, which shows a desire to preserve the nature of these thesaurus constructs, and that the manner of doing so is with ad-hoc ontologies able to provide the semantics not found in SKOS.

2) CONCEPT GROUP NESTING

Despite the fact that the nesting between concept groups has received a dedicated relationship in ISO 25964, hasSubGroup/hasSuperGroup, there is no equivalence in SKOS [14]. The solutions for concept group nesting used in the thesauri examined and ISO-THES consist in creating new properties to relate concept groups. Each ontology proposes its own properties for this aim. ISO-THES proposes adding a 'sub group/super group' relationship. However, other thesauri, such as EuroVoc, propose their own properties for this aim. In our opinion, this is a consequence of the fact that the SKOS representation of these thesauri was tackled prior to the proposals made in [14], and given that there was no 'official' foreseeable expected equivalence (the SKOS Primer Recommendation did not include it), thesauri editors looked for their own solutions.

Moreover, this has to do with the lack of a clear equivalence for concept groups in SKOS. SKOS collections can be nested, but there is no property that relates two concept groups in SKOS, which would seem the ideal candidate for concept group nesting. Thus, there are various approaches to solve the problem of representing with SKOS the existence of several levels of concept groups in thesauri, and their nesting.

3) TOP CONCEPTS

The different ways to represent concept groups with SKOS also result in differences when dealing with top concepts. Thesauri using concept schemes to represent microthesauri, such as EuroVoc, use the skos:hasTopConcept property for this aim. However, as commented in section 3, when collections are used to represent microthesauri, as ISO-THES does, it is not possible to use this SKOS property. In this situation, the fact that a concept is a top concept cannot be explicitly expressed with a statement. So, stating that a thesaurus concept is a top concept of some microthesauri (see, e.g., the examples in section 3 with EuroVoc), cannot be represented with the skos:topConceptOf property, which seems the first approach a designer would try. This has been left to inference in [14]. Despite being absolutely correct from a technical perspective, it is true that relying on inference increases the dependence on software in charge of inference (reasoners), and that the information that a concept is a top concept is not explicitly shared. Once it is known that a concept is a top concept, it would be nice to be able to share this knowledge, thus avoiding having to infer it again. Because of this, we find it worthwhile to have a means to share this knowledge, even if it is with ad-hoc properties created specifically for this aim.

4) EFFECTS OF HAVING VARIOUS TYPES OF NT/BT RELATIONSHIPS

Regarding the implications that the introduction of types of BT/NT relationships has, it is worth taking into account the fact that the manner of representing the diversity of hierarchies associated to types of BT/NT relationships in

SKOS has no definitive solution yet (see the proposals made in [14], [51]). Besides, the introduction of types impacts on transitivity. Transitivity applies when the hierarchical relationships used for reasoning are all generic (kind of), but not if they are mixed with partitive (part of) relationships.

5) EFFECT OF POLYHIERARCHY

Polyhierarchy is not a type of construct, but a situation in which the hierarchical structure of a thesaurus becomes more complex than a tree. Modeling, and reasoning, is easier and more robust when the resulting hierarchy is a tree (the chances of obtaining inconsistent conclusions are lower than with other graphs). This is why it is recommended to control polyhierarchy. If there is polyhierarchy in a thesaurus, this can be represented with SKOS, because SKOS does not restrict the use of polyhierarchy. However, it does not have specific means to represent and control polyhierarchy. Thus, polyhierarchy is in fact another specific characteristic of thesauri that is controlled by means of ad-hoc solutions, as the one found in EuroVoc.

B. SIMILARITIES AND DIFFERENCES IN INTEGRITY RULES BETWEEN ISO 25964 AND SKOS: THESAURI ARE MORE RESTRICTIVE THAN SKOS

1) INTEGRITY IN ISO 25964 vs SKOS

As for the integrity issue, a positive conclusion from the comparison of ISO 25964 and SKOS is that there are situations in which the integrity axioms of the SKOS Recommendation guarantee a good set of integrity restrictions. Restrictions about the number of preferred terms for each concept, disjointness of concepts with other constructs used to group them, the restriction that only concepts can participate in semantic relationships (NT/BT, RT), or that hierarchical relationships are incompatible with RT relationships are found in both ISO 25964 and SKOS.

However, rules for thesaurus integrity are more restrictive than SKOS restrictions. The lack of a direct correspondence between concept groups and SKOS constructs has resulted in heterogeneous solutions for representing concept groups with SKOS. This means that the SKOS axioms that apply depends on the SKOS construct used, which in the very end means that it is not possible to fix a direct equivalence of some thesauri integrity rules with SKOS axioms. This is what happens, for example, when the restriction which guarantees that a construct cannot be simultaneously a concept group and a concept (condition with number 1.d in section 4) has to be mapped to SKOS. Axioms S9 and S37 express similar restrictions, but for SKOS constructs. As we have seen in section 4, in some cases, such as EuroVoc, different SKOS classes have been used for domains and microthesauri, which are groups of concepts. In the case of EuroVoc the SKOS class assigned to each domain is skos:Concept, while each microthesaurus has been represented as a skos:conceptScheme. In cases like this, the axioms S9 and S37 do not guarantee condition 1.d.

There are also differences in restrictions for cycles, and in reciprocal relationships. Cycles involving hierarchical relationships are forbidden in thesauri. Something similar happens with top concepts. There is no SKOS axiom expressing a restriction similar to condition 4. It should be pointed out in this respect that SKOS is conceived for a wider set of KOS than thesauri. As a consequence, the restrictions that are exclusive for thesauri have to be ensured by thesauri editors in addition to the integrity provided by SKOS.

Reciprocal relationships are required in ISO 25964. If a concept A is related to a concept B in some thesauri by a relationship such as NT, BT or RT, the reciprocal relationships also exists. Therefore, both statements should be present in the RDF representation of the thesaurus. However, SKOS does not require the existence of reciprocal relationships, they can be there or not (thus allowing the possibility to economize the number of RDF triples stored). This is a flexibility of SKOS that it does not share with thesauri.

C. SKOS-XL AND ONTOLOGIES THAT EXTEND SKOS

Constructs of ISO 25964 have been represented in the thesauri examined using SKOS, SKOS-XL for Terms, and with ad-hoc solutions for situations whose mapping from ISO 25964 to SKOS was not direct. The thesauri examined use ontologies that extend the SKOS ontology with additional semantics for these situations. This is what happens with concept groups and concept group nesting, or with specific semantics such as the enriched relationships of AGROVOC. This would also be the situation with typed hierarchical relationships (kind of, instance of, part of); however, we have not found examples in the three thesauri used in this article, and no reference in their specific ontologies neither. A similar situation would be the one with compound equivalence. In this case, some thesauri (EuroVoc) preview them (their documentation about how EuroVoc has been represented with SKOS talks about them), even if we have not found examples in the current version examined.

ISO-THES is a general ontology that extends SKOS with classes and properties of ISO 25964 that do not have a direct representation in SKOS. Its main difference with the ontologies that have been created for each thesaurus, is that it is not associated to a specific thesaurus, so it does not provide classes and/or properties for semantics specific to a thesaurus. It provides extensions for what is in ISO 25964 but not in SKOS.

It has specific classes for concept groups (isothes: ConceptGroup), domains (isothes:Domain) and microthesauri (isothes:MicroThesaurus). All of them are subclasses of skos:Collection, and isothes:ConceptGroup is itself a superclass of isothes:domain and isothes:microthesaurus.

An advantage of using skos:Collections for concept groups is that SKOS has properties that can be used for collection nesting. skos:member relates two collections, while SKOS does not have a property that relates two concept schemes. Therefore, the use of collections rather than concept schemes would seem to be better aligned with concept group nesting.

The drawback is that collections cannot have top concepts in SKOS. The property skos:topConceptOf relates a concept and a concept scheme, never a collection.

We have examined three thesauri, EuroVoc, Unesco, AGROVOC. Only Unesco actively uses ISO-THES classes. Examples showing how its classes have been used for the Unesco thesaurus can be found in tables 2 to 9. There are statements in this RDF thesaurus representation stating that a construct is of a type from one of its classes. In the other two, there are no such statements. ISO-THES is also used with the Getty thesauri, where some constructs not used with the Unesco thesaurus can be found, for example, Arrays. Despite being a general proposal, ISO-THES is not used in a general manner.

D. CHALLENGES

Ontologies have been used to extend SKOS with semantics specific to thesauri that is not available in the SKOS ontology. This is what has been found in the three thesauri used as examples in this article. This is also what the ISO-THES ontology does. There are still several challenges for thesauri in the Semantic Web.

The first one is being able to find a common way of representing groups of concepts. By now, there are several proposals to extend SKOS with classes specific for them. It would be a step forward to find a common solution, or at least, being able to express the equivalence between the different solutions available.

A second challenge comes from the diversity in types of hierarchical relationships that ISO 25964 introduces. There is no standard solution for this yet, despite there being some valuable proposals [51]. But what is clear is that SKOS does not preview types in hierarchical relationships. The consequences of using types in hierarchical relationships go farther than extending SKOS with new classes and properties. It affects inference (see section 5.1). It is true that SKOS does not associate transitiveness to the skos:broader and skos:narrower properties, but to skos:transitivenarrower and skos:transitivebroader relationships, so that reasoning on transitiveness will only be done if these last properties are present. But some means to limit inference to the situations in which it can be done should be provided anyway.

The last challenge is to find a means to express, and share, restrictions specific to thesauri, which are not in SKOS, such as those presented for cycles and reciprocal relationships. While this knowledge is not shared somehow, thesauri tools are in charge of implementing them as extra functionality. However, if they can be shared, they could be reused by any tool able to understand this knowledge.

E. HOW CAN ONTOLOGIES AND SEMANTIC WEB STANDARDS HELP TO MEET THESE CHALLENGES

Ontologies can help to fill the gap between thesauri and SKOS, extending SKOS with classes, properties and restrictions specific to thesauri, which are not offered by SKOS. This is what has been done by ontologies such as ISO-THES and the ontologies associated to the thesauri used as examples in this article.

The Semantic Web provides means to express the equivalence between classes from different ontologies. This could be helpful, because software could recognize them as equivalent and apply treatments based on this. Such knowledge could be used in other treatments not so typical of thesauri, for example, to compare the way in which different communities organize their knowledge in domains or thematic fields. We have not found such an application, but in the era of social analysis, this is one more possibility to compare and know communities better. So, being able to express, and share, these equivalences would contribute to a better exploitation of relationships between thesauri. This could also help to express the equivalence between the different classes and/or properties used with each thesaurus to represent concept groups and concept group nesting. However, for this specific issue, we believe this would be a first step. A common ontology would be a better solution to this issue. It could be understood and managed by any thesaurus tool, therefore providing thesaurus designers with a direct solution for concept groups. ISO-THES could be the base for such an ontology, but some changes would be needed to overcome the current limitation it has with top concepts, which was commented in section 5.3.

The answer to the question of sharing semantics between ontologies associated to different thesauri comes from the ontology area itself. Ontology alignment is a topic which condenses serious and diverse efforts [53]. A first issue is that these alignments should be available to tools, which themselves should be able to process them. OWL provides the bricks to express alignments, e.g., the owl:same property is used to express equivalences between ontology classes. Another issue is how these alignments can be produced. There are two possibilities. The first is to do it manually. This could be an affordable task for a limited set of thesauri, given that the classes and properties to align are not too numerous. The second possibility is to discover these alignments with automatic processes, but this leads to the ontology alignment problem.

It is worth remembering that ontology alignment can be a hard problem, in which obtaining a good percentage of credible alignments can be difficult.[27] It may not always be the best choice in terms of results. In our opinion, it would be helpful to have some general ontology, not specific to a given thesaurus, which would ideally emerge from a consensus by the thesaurus community and could be used as reference for the alignments. Such an effort would require the collaboration of thesaurus management tool developers to provide support

[27]The Ontology Alignment Initiative proposes every year a challenge. A set of ontologies is published and participants have to find alignments between them. Participants present the results of their ontology matchers. This contest is renewed every year with new challenges. The most recent at the moment of writing this article can be found at http://oaei.ontologymatching.org/2019/.

for such an ontology by default in their tools. ISO-THES or similar ontologies could play such a role.

Another challenge is being able to express thesauri restrictions and share them. Being able to express constraints is another issue closely related to ontologies in the Semantic Web. There are several languages in the Semantic Web context which have been created to express this type of knowledge. OWL offers some possibilities to express constraints, but there are also other proposals made in this regard, e.g., SHACL, a language for validating RDF graphs against a set of conditions[28].

F. THESAURI, SPARQL, AND LINKED DATA

Thesauri have profited from Semantic Web technologies in several ways. RDF has been adopted by thesaurus management tools to store, distribute, and share thesauri. Semantic repositories are used to store the RDF representations of thesauri (for example, VocBench and Synaptica use Ontotext GraphDB, PoolParty uses RDF4J, and the TopQuadrant Enterprise Vocabulary Network uses Jena). The thesauri RDF files are available for download (for example, the thesauri mentioned in this paper can be downloaded from the URLs shown in the footnotes 1 to 6 that accompany their mention). These files can be inserted in any RDF store and used for specific applications, and they can also be queried through SPARQL endpoints. The three thesauri examined offer SPARQL endpoints that can be used to query them. This is a strong step forward for the possibilities of getting access to their content. Queries are a means to obtain the desired information without being forced to browse through the thesauri. Querying thesauri is now easier than it has ever been before. SPARQL endpoints are accessed using standard interfaces, and queries are built using SPARQL, a standard query language. A person proficient in SPARQL is someone proficient in querying any thesaurus.

Finally, it seems clear that thesauri have enthusiastically incorporated the possibility of using SKOS properties (skos:exactMatch, skos:aproxMatch, etc) to align concepts from different thesauri. The thesauri used in this article offer their alignments with several other thesauri, which can be downloaded in RDF[29]. Thus, a network of linked concepts is created, which moreover implies that any data linked with these concepts (for example, because the concepts have been used to 'tag' them) are themselves linked. This fits really well with Linked Data principles, and it is promising as a means for thesauri to contribute to knowledge organization on the web of data.

VI. CONCLUSION

We have compared the constructs and integrity rules of ISO 25964, the current ISO standard for thesauri, and SKOS, the W3C standard for representing KOS with RDF. For this comparison we have checked how the thesaurus constructs have been represented with SKOS in three thesauri (AGROVOC, EuroVoc and Unesco) and we have contrasted the integrity rules of thesauri with the SKOS axioms. We have found that the way thesaurus constructs are represented with SKOS impacts on the correspondences that can be established between the integrity rules in both standards.

We have also examined how ontologies are effectively used to provide the level of semantic precision that a given thesaurus may require and SKOS, given its general scope, cannot provide. Our proposal is to advance in the alignment between these ontologies, which, in our opinion, will facilitate collaboration between different thesauri. This has been discussed in section 5.5.

From the results of the observations made in this study, we have the impression that thesauri do not seem to be in decline, but rather in full process of integration into the Semantic Web. Thesauri and Linked Data have found good mutual accommodation. Thesauri take advantage of Linked Data technologies to show the alignment between them, and Linked Data has found in thesauri a great use case to demonstrate its potential.

We think that the future requires advancing the work with integrity rules, how to express them and how to share them, and for this, the path, once more, certainly passes through the Semantic Web and its advances in this line. Some ideas about the possibilities that the Semantic Web offers to express (thesauri) restrictions have been commented in section 5.5. To be able to share restrictions means being able to simplify the development of thesaurus management tools and therefore make thesauri more capable of being offered as open data in the web of data.

APPENDIX: PREFIXES

agrovoc: <http://aims.fao.org/aos/agrovoc/>
dct: < http://purl.org/dc/terms/>
eu: <http://EuroVoc.europa.eu/schema#>
eurovoc: <http://eurovoc.europa.eu/>
isothes: <http://purl.org/iso25964/skos-thes#>
ns3: <http://EuroVoc.europa.eu/schema#>
rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
skos: <http://www.w3.org/2004/02/skos/core#>
skosxl: <http://www.w3.org/2008/05/skos-xl#>
thesaurus: <http://vocabularies.unesco.org/thesaurus/>
unes: <http://vocabularies.unesco.org/ontology#>

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[28] https://www.w3.org/TR/shacl/

[29] AGROVOC: http://aims.fao.org/agrovoc/releases.
EuroVoc: https://data.europa.eu/euodp/en/data/dataset/eurovoc.
Unesco Thesaurus: http://vocabularies.unesco.org/exports/thesaurus/latest/

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