A Literature Review of Semantic Web Technologies for Life Cycle Assessment in Fashion Industries

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Abstract: The fashion industry have been one of the major source of pollution in the last years with great impact on both environmental and societal aspects **[1]–[4]**. Tracking sustainability metrics has gained more and more importance: governments, institutions and customers have expressed discontent towards these unsustainable practices, and the need of adequate tools and solutions to these issues has arisen.

In this paper, we present a literature review on solutions involving Life Cycle Assessment (LCA) and semantic web technologies with the aim to discuss their possible applicability to the fashion industry. Several approaches have been considered and evidences suggest that the employment of semantic web solutions in LCA enable (1) a more robust representation of materials and products life cycle, and (2) a powerful mean for traceability, which is an essential factor in sustainability assessments.

A further contribution of this paper is about the possible use of semantic web solutions in the framework of MUSA-Next, a web application that has being developed in MUSA Spoke 5 (Multilayered Urban Sustainability Action), a NRRP project funded by the EU - NextGenerationEU.

Keywords: fashion industry; LCA; semantic web technologies; sustainability

I. INTRODUCTION

In the recent years, governments and people have been set- tling a trend towards habits and life styles with less to no impact on the ongoing climate change [5], [6]. From production to distribution, humans are daily engaged on a sort of re-education challenge with the aim at positively contributing to the reduction of the climate emergency. To this extent, there is a growing need for more information about how a product is manufactured, and how it is supposed to be treated and disposed. Industries have to meet such an expectation for more information by providing documents and tools to enforce and promote informed purchase practices from customers. Fashion industries are particularly interested on these kinds of issues, as the level of sustainability of their products are becoming a popular target of inquiries and investigations.

Life Cycle Assessment (LCA) is a procedure implemented by tools that allows to track the level of sustainability of products, by analysing the environmental impact of goods/products, and by monitoring both the whole production chain as well as the life after the purchase until the disposal [7]. For example, considering a pair of jeans, a LCA would show the raw materials, the dyes, the workers' conditions, the transportation and environmental impact of the whole production process of the jeans; furthermore, as it is purchased, LCA could keep track of its usage and maintenance; and eventually the information about its disposal and/or recycling process.

Monitoring all these stages of a product's life cycle requires a lot of data to be stored and analyzed: all the relevant pieces of information have to be listed in the so-called Life Cycle Inventory (LCI), which is the main data source for LCA and it has to be attached to the product [7]. LCI often contains data coming from different sources that are also expressed in different formats. A person involved in tracking a product's life cycle can use different notations, units of measures, and data types. This has been demonstrated to be a major problem of LCA, leading to inconsistencies in information management, and lack of collaboration and interoperability [5]–[10].

In this scenario, Semantic Web technologies represent a possible solution to mitigate the above-cited issues. Semantic Web is an extension of the original idea of the Web, in which resources have a semantic and explicit meaning and they have semantically meaningful relations with other resources. This "graph-like structure" is often referred to as an ontology, and it formally describes a specific domain of interest in terms of classes and relations with associated data formats and query languages. Semantic Web technologies thus provide many benefits, among which:

- a flexible data format to support the collaboration among employers, leading to a reduced misunderstanding and improved interoperability;
- a unified and shared model to integrate data into ontology-based knowledge representations (as much data as possible);
- less time spent on developing and learning domain-specific software for LCA [9].

With respect to the fashion industry, Semantic Web technologies seem to be a promising solution, since they can enforce the association of a semantic layer to goods, materials, and processes in a unified, seamless architecture. Relevant work in the literature is about the development of advanced search and query functionalities in fashion companies' websites [11]–[13]. Furthermore, the fashion industry requires a fine-grained approach to data extraction for LCA. For example, consider a customer interested in vegan clothing. A simple query based on "vegan clothing" as a keyword does not allow to consider whether the product's source materials are plant-based or animal-based. The association of semantic metadata to the product descriptions could improve the effectiveness of the search results, and thus the satisfaction of the customer. As a further example, consider the area for "purchase suggestions" area in a fashion retailer website. Customers could be dissatisfied if the proposed products are mostly identical to those purchased in the past. It would be attractive if the suggestions are about unusual combinations, or different clothes reminding of similar styles. With the use of an ontology as a knowledge based for product description, the kind of personalized recommendations described above could be enforced.

In this paper, we aim at collecting and analyzing literature work regarding the use of semantic web technologies and, generally speaking, ontologies in the context of LCA. The main goal is to evaluate whether and how the existing solutions can be successfully applied to the fashion industry sector. In particular, this paper aims to represent a proof of concept for the integration of fashion-oriented domain ontologies in NRRP NextGenerationEU MUSA Spoke 5 project (Multilayered Urban Sustainability Action), with specific focus on the MUSA-Next webapp as a target for testing different user functionalities, such as life cycle assessment, and semantically-enriched search. MUSA-Next has a strong focus on sustainability for the fashion and luxury sectors in the Milan urban area, and its functionalities are going to provide educational and informative content to both consumers, craftsmen, and industries.

The paper is organized as follows: Section II presents the problems with traditional LCA tools and how semantic web technologies can help solving them. Section III explains how the solution adopted by other industries could also fit the fashion industry, thus offering tools for evaluating clothing products' impact on the environment. Lastly, Section IV discusses the possible concrete application of the ideas and concepts reported in previous sections to the MUSA Spoke 5 project and related MUSA-Next app.

II. THE ROLE OF SEMANTIC WEB IN LCA

Estimating the potential environmental impacts of products or technologies is a central need in today's society. The research community have proposed tracking and analysis methods helping with the interpretation of data about industrial processes. For instance, Life Cycle Assessment (LCA) is used to identify and estimate potential environmental impacts of products or technologies. This procedure needs data from all the activities that provide materials and energy to manufacture, use and dispose of products [14], [15]. LCA not only include data about ecosystems and health impacts, but it has also been adapted to consider economic and social costs of production and consumption demand [16]. Material/Energy Flow Analysis (MEFA) helps with the understand- ing of flows and stocks of materials within a system in a certain spatial area and time period [6], [17]. Product life cycle management is another well known procedure to track knowledge about the entire product, from ideation, design, manufacture to service and disposal [9].

Although these solutions have gained wide acceptance, common and serious practical problems have arisen from their utilization [18]. Ingwersen highlights the fact that many LCA studies only show results, without making source datasets available and usable [15]. Another common problem resides in the interoperability of existing datasets: LCA practitioners need often to load data from different sources, meaning that data formats, syntactic and semantic could differ from source to source. The outcome of this lack of interoperability is the impossibility of using multiple datasets, which otherwise would have helped with having a complete picture of the analyzed situation. Another weakness of these methods is the lack of a common description of objects, which is fundamental since these assessment methods have an interdisciplinary nature. In order to formalize structures and databases, a consensus on an universal definitions need to be reached, avoiding those which are incompatible and implicit or lacking [19]. Indeed, vocabulary referring to the same entity do often change across discipline, and this worsen the interoperability problem cited above [7]. Overall, these issues are limiting both the production of system-wide and technically-detailed assessments [6], data interoperability, transparency and automated integration of external data, and this goes in the opposite direction with respect to advancements in industrial ecology and the rapid development of data [10]. Moreover, this situation gets even worse when there are multiple people working together in creating assessments in different periods of time [9].

Different approaches have been proposed to address syntactic interoperability, but this is not enough when dealing with heterogeneous data, as it is often the case in LCA [5].

Given these problems, many researchers have tried exploiting ontologies and semantic web technologies. The main idea behind Semantic Web is to provide interconnected information which can be read by both humans and machines. Data is organized such that the format has a semantically meaningful structure which can help advanced search, navigation and evaluation. Being it an extension of the World Wide Web, the Semantic Web can be expanded by users all over the world, completing and advancing the net of semantic concepts to express and represent new realities. This knowledge is read by humans and machines through ontologies and their direct translation into eXtensible Markup Language (XML) and Resource Description Framework (RDF). Reporting Ingwersen et al.'s concise theoretical background, an ontology is a conceptual map of domain and knowledge [20], which includes a vocabulary used to describe data and its properties; RDF is an architecture to relate data from diverse sources [21], and it is the format used to store data having an ontology as structure. Lastly, Web

Ontology Language (OWL) is used to describe the types and properties used in RDF data [10].

There are many benefits brought by semantic web technologies in LCA frameworks [10]:

- RDF offers a high flexible structure which helps with data management and discovery processes: indeed, the ontological schema is always available as metadata, and it can be retrieved and adapted according to varying needs. For instance, incorporating data from different domains can be simply done by adding references and links;
- one of the difficulties when it comes to merge datasets is making trade-offs concerning keywords. RDF allows the connections of datasets without imposing a single list of terms, thus making it possible the use of multiple conventions in different working groups;
- traceability and transparency are guaranteed through RDF statements and annotations when data is added or the model is changed;
- queries and inferences can be leveraged to determine data relationships in RDF's logical structure.

Overall, choosing RDF to represent LCA data and structure makes data exchange easier, allows for interoperability, and improved the processing and synthesis of non-LCA data into LCA models.

A. Literature review

In the following, we describe a few work in the literature about interoperability issues in LCA addressed through linked data and/or Semantic Web technologies.

Pauliuk et al. propose an ontology to model terms and definitions used in assessments for socioeconomic metabolism (SEM) [19]. Their goal is to provide a common, formalized description to store and retrieve interdisciplinary data on industrial systems. They do this by engaging researchers on SEM, asking them to solve inconsistencies in their disciplinary definitions of terms. Given this consensus, it is then possible to propose an ontology representing an interdisciplinary model of SEM. According to this proposal, the authors can design guidelines for semantic data annotation and database structure, which, in turn, contributes to the creation of a powerful data infrastructure for SEM. This innovation is of a great help to SEM scientists too, since it boosts research efficiency.

Janowicz et al. focus on LCA data formats [7]. The problem addressed is interoperability in LCA: the authors argue that existing solutions only address syntactic issues. Syntax-based approaches to this problem making explicit rules linking terms referring to the same concept: this solves also cases in which words are written in different formats e.g. acronyms. The authors propose the use of a conceptual model representing data: this would allow for easier translation, merge, and management of life cycle inventories. To achieve semantic interoperability, an ontology should be designed starting from use cases capturing recurring domain or cross-domain issues. This is a methodology referred to as *competency questions* [22]. Eventually, this work can act as a joint building block for semantic representation in LCA.

Ingwersen et al. argue that LCA has a "technical architecture that limits data interoperability, transparency, and automated integration of external data" [10]. This issue constraints wider use and development of data, making the creation of connections and relations between databases difficult. The authors propose the LCA Harmonization Tool (LCA-HT) having the following functionalities: (1) mapping and storing of data from different sources; (2) capturing of user-defined relationships between nomenclatures. This tool also helps with a more structured and automated incorporation of non-LCA data into LCA models.

Kuczenski et al. provide a slightly different solution including both semantic web technologies and text mining techniques to facilitate even more the integration of data from multiple and diverse sources [5]. Another common problem in LCA tools is the lack of easy-to-use search interfaces providing useful analysis based on, for instance, term co-occurrence with respect to given keywords of interest. As a contribution of this work, a consensus model based on three main classes called "Activities", "Flows", and "Flow Quantities" has been defined with the aim to provide a shared representation of possible entities to be used in queries and semantic searches over the catalogues of inventory data resources.

Germano et al.'s work is about resource efficiency and decarbonization in UK [6]. The chosen assessment method is MEFA, but the addressed problems are similar to the above ones. As claimed by the authors, there are "prohibitive barriers to the integration and use of the diverse datasets necessary for a system-wide yet technically-detailed MEFA study". This study proposes a methodology to design a domain ontology, which is guided by four use cases: (1) data integration including "system context", expressing the importance of the ability of linking resource data into a MEFA system; (2) access diverse data in a consistent and flexible structure, expressing the needs of (a) harmonizing data (e.g. with respect to unit of measurement) and of (b) having a hierarchical structure allowing for queries retrieving different levels of detail; (3) tracking the provenance and uncertainty of data to model the confidence in modelling results; (4) streamline usage of semantic web tools for domain experts, which focuses on building a tool for domain experts which are not highly familiar with semantic web technologies and, at the same time, providing a not computationally-demanding system easy to integrate with other software (e.g. Python notebooks).

Zhang et al. leverage Knowledge Based Engineering (KBE) applications for Product Lifecycle Management (PLM) and supply chain sustainability assessment [9]. The difficulties encountered in this area are about integration of knowledge at different stages and teams, which is necessary to be represented in an unified form. Many sources used by software are neither machine-readable nor human-readable, making even more difficult the process of obtaining sustainability assessments. The main output of this work is a KBE application implementing a third-party assessment ontology on supply chain sustainability. The benefits brought by this application enhance the suitability of semantic web technologies with respect to efficiency of data sharing and integration in sustainability assessments.

Ghose et al.'s aim is to provide tools and methods to enhance the use of semantic web in the field of sustainability assessments such as the Life Cycle Sustainability Assessment (LCSA) [8]. They do this by designing an ontology covering the concepts of LCSA: the authors stress the fact that the proposed solution is flexible, meaning that it can be applied both to specific information contained in LCSA and to other potentially useful data. Another key point to notice is the use of open access data, which makes the process of creating sustainability assessments affordable and reproducible. This work explicitly shows and explains the proposed BONSAI ontology, also providing query examples and use cases.

All these studies are suggesting that semantic web technologies represent a promising solution for allowing interoperability, efficiency, and management of sustainability assessment data and analysis. Ontologies are proven to be a powerful mean of complex-data representation, and there are several case studies involving varying types of industries in which the presence of linked data technology have brought many benefits [5], [7], [15], [23]–[28].

B. *Semantic web technologies in the fashion industry*

In the following, we focus on the use of the above solutions in the field of fashion industry, which could greatly benefit from sustainability assessments powered by the semantic web, especially given the problematic "fast-fashion" trends [29]–[31]. The so-called "fast-fashion" trend refers to low-cost garments imitating high-end clothing [32]. Today's fashion industry supports a fast pace of consumption by employing mass manufacturing at low prices [33]. This type of offer can sustain rapid trend turnovers through obsolescence and early disposal [34]. However, the downside to this kind of approach is the overconsumption of clothes, whose huge waste generation leads to significant impacts on the environment [35]–[37]. For instance, clothing production and disposal are processes contributing to the dispersion of coloured effluents and microplastics into the environment [38], [39]. Fast-fashion not only comes with ecological issues, but also with social implications. To maintain low prices, apparel companies outsource the production process in those countries allowing for either cheap labour or, in the worst cases, forced and child labour; this type of exploitation often happens with poor or lack of safety in the workspace [3], [4].

Given these evidences, current supply chains operations must be modified to embody sustainability [40]. In this view, production firms should find a balance on three dimensions: economics, environment, and society [41]. This philosophy is implemented in the triple bottom line (TBL) framework [42], and it aims at evaluating a company's performance not only on economic basis, but also on the impact it has on the territory and the people. This balance is more difficult to find as the production process gets more fragmented, as it is the case in the apparel industry [43]–[45]. The presence of many different actors makes it difficult to monitor compliance with codes of behaviour and to manage the production process [44]–[51]. Evidences in feasible improvements brought by digital solutions can be found in [29]: for instance, traceability and transparency of products can be supported by blockchain technologies. The work by Centobelli et al. proves that the employing blockchain allows complete traceability, thus optimising the supply chain and improving the sustainability performance [52].

Governments and organisations have started to transform sustainability needs into guidelines for industries to follow [53]. An exemplar institutional call towards a greener production are the United Nation's Sustainabilty Development Goals (SDGs), which highlight the importance of environmental sustainability, social inclusion, and economic development [54], [55]. These concerns are also shared among consumers, who are becoming more sensitive and informed about ethical issues and implications of the fast fashion business model [56]. As a result of this awareness, more and more customer choose to change their shopping habits [56], [57]. These external forces, namely SDGs, institutions, and customers, are driving fashion industries towards paying more attention to sustainability issues [58], [59]; apparel companies are expressing this intent by allocating more resources in identifying, implementing, evaluating, and reporting on their Corporate Social Responsibility (CSR) goals [60], [61]. Companies are redesigning their value chain both in terms of products, processes, and suppliers' selection and in terms of greater stakeholder engagement [30].

All these studies suggest that the use of LCA in fashion industries is a promising strategy to monitor and achieve sustainability goals. In the following, we report two attempts of ontology construction for the fashion industry.

Novalija and Leban report the lack of semantics-oriented tools, and they propose to design an ontology as well as to provide a methodology for ontology development with the aim to overcome such an issue [62]. All in all, improving information analysis and sharing throughout the whole product life-cycle is the main motivation to employ semantic web technologies in this field. The authors identify three main goals for fashion ontology development: (1) support and improve search functionalities adding semantic information; (2) monitor apparel industries' behaviour and practices; (3) define a rigorous representation of fashion entities and relationships. The proposed methodology to domain ontology development is articulated in four steps: (1) collection and definition of concept seeds; (2) mapping seeds to Wikipedia and extending the ontology with relevant related concepts; (3) definition of relationships between concepts; (4) ontology refinement. This process can be defined as semi-automatic, since it heavily relies on domain expert to declare the initial concept seeds in step (1). The mapping step is useful to collect more structured and unstructured information about the concepts provided at step (1) and to discover new related keywords. Then, having this pool of concepts, it is possible to link them through relations discovered by natural language processing (NLP) techniques leveraging dependency analysis tools [63], [64]. The last step consists of selecting appropriate concepts of the ontology, discarding those which are not mentioned enough in domain-related websites.

Roshankish and Fornara offers a new point of view about the benefits of applying semantic web technologies to fashion [65]. This work addresses the issue of providing an easy and accessible format for reading terms and conditions of websites. In particular, the presented case studies and examples are about famous brands in the fashion industry. The authors suggest developing a software to automatically process information in privacy policies, thus leveraging the representation power of semantic web technologies. The idea is to assist humans with tools for reasoning and understanding the meaning of policies. RDF reasoners can infer implicit knowledge. One example from the authors is about understanding that a Lycra blouse is made of synthetic fibre. The system understands that Lycra is a synthetic material, thus transferring this semantic information to the garment made out of Lycra. Ontologies and semantic searches are employed in [66] to help the company's sales. The idea is to manage the collected data from customers with semantic web technologies. The Imperial Data Ontology (IDO) and related visualization tools to analyse sales data are discussed. Semantic web technology have also been used to improve customers service and personalization. Zalando employs tools to (1) suggest links for further browsing; (2) implement business rules, e.g. not suggesting competing brands together; (3) leverage semantics for a precise and context-aware search, e.g. not showing leather coats when searching for vegan clothing [11]. Inspired by this latter case study, Barrasa implements semantic searches/recommendations leveraging existing ontologies, such as the Clothing Materials Ontology (http://www.nsmntx.org/2019/10/clothingMaterials) describing a hierarchy of materials commonly used in the clothing industry [67].

III. SEMANTIC WEB TECHNOLOGIES FOR RECOMMENDATION SYSTEMS

In this Section we further motivate and sustain the possibility of modeling the fashion domain with ontologies, and the effectiveness of semantic web technologies in this particular field. To this end, we present a few studies reporting successful use cases of semantic web applied to apparel recommendation systems. In particular, apparel-recommendation systems can improve the efficiency of wardrobe utilization and reduce waste throughout the whole apparel life-cycle, with focus on the use phase performed by the consumer [12].

Vogiatzis et al. focus on user model creation in the fashion domain [68]. Their approach is based on retrieving and formalizing two types of information sources: (1) generic style rules provided by fashion experts; (2) customers data collected by fashion oriented websites or social networking sites, denoting general user tendencies. All this information must be handled according to its heterogeneous nature; indeed, there are many concepts involved in the fashion industry, such as material properties, human morphology, garment styles and the occasion of wearing a garment. A knowledge base could greatly help with the collection, processing, and management of all this diverse type of information. The main contribution of Vogiatzis et al. is the creation of an ontology instilled with domain expertise and generic style advices. User instances are represented through "stereotypes", which are an abstraction of user characteristics that is easily associated with generic garments. More precisely, this latter object is an abstract representation of real garments. Social occasion is also represented through user stereotypes, thus the association also expresses appropriateness of outfits with respect to specific occasions. Interacting multiple times with the system will allow referencing to real garments, which unlocks the exploration of common purchase patterns among users. According to this framework, the user data processing in an e-commerce is articulated in three steps:

- the user provides to the system her body type, facial features and, additionally, a social occasion. This allows the system to map this user to a stereotype, thus providing initial generic advices through the reasoning mechanism of the "Servive" fashion ontology;

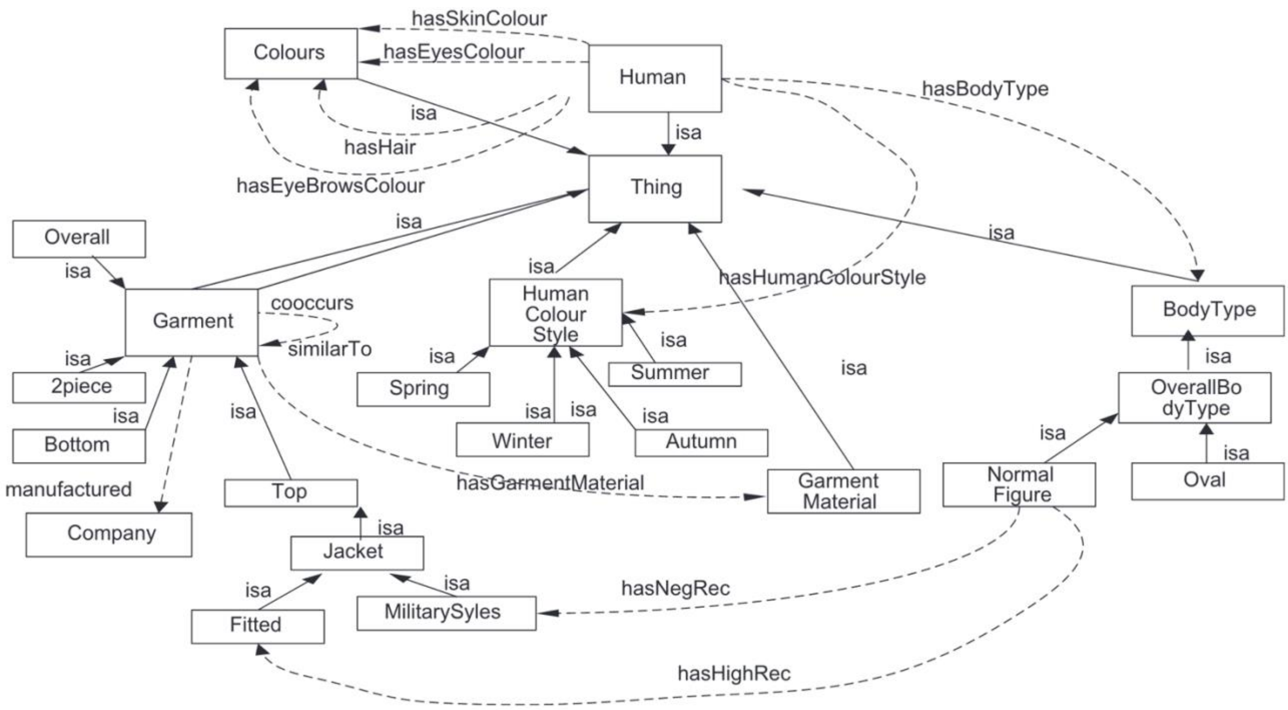

Figure 1: Top level structure of the Servive Fashion Ontology. Solid lines denote isa relations, and dashed lines denote object properties (Vogiatzis et al., 2012).

- generic garments are mapped to real ones, presenting to the user concrete advises;
- based on the purchase history, the user is assigned to a broader community, which enriches recommendations according to existing trends in that group.

Figure 1 shows a portion of the Servive Fashion Ontology, namely the top-level ontology used in Vogiatzis et al. . Classes are depicted with their first letter capitalized, relations are depicted on top of arrows. Examples of classes are: `Human`, `Garment`, `Garment Material`, `Body Type`. Examples of relations are: `hasEyesCoulour`, `hasHighRec`, `manufacturedBy`. In particular, the relations `hasHighRec`, `hasLowRec` and `hasNegRec` model recommendations, associating humans to garments. They represent high-, low-, and negative-recommended garments, respectively.

The first ontology-based advises are formalized in two types of rules: first level or attribute rules associating humans with stereotypes, and second level or style advice rules linking stereotypes to garment types or garment colours. Both of these are defined by fashion experts. The second community-based recommendations are successively formed by mapping generic garments to real ones according to the similarity. These recommendations are based on garment-centered communities, which are formed by garments that co-occur often in users' purchases. Other garments can thus be found according to trends in a specific community.

Ajmani et al. argue that the approach employed in Vogiatzis et al. is limiting the flexibility of the system [69]. To overcome this issue, Ajmani et al. propose an ontology-based recommendation system employing content-based filtering. This type of technique leverages semantic analysis of product features, specifically the visual properties encoded in the media features. The flexibility comes from a stochastic approach in knowledge representation. The authors rely on Multimedia Web Ontology Language (MOWL), which is built on a causal model of the world and encodes media properties of concepts, enabling reasoning and domain knowledge encoding [70]. This work uses the term "media property" when referring to all forms of machine-observable manifestations of concepts. The authors define "A person is said to be well-dressed, when the visual properties of the dress chosen blend well with the visual properties of her personality in context of an occasion. A

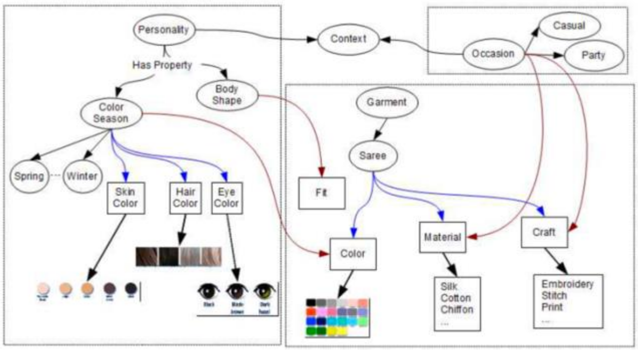

Figure 2: A portion of the ontology for Fashion Recommendation (Ajmani et al., 2013).

fashion ontology encodes the semantics of such 'blending' ".

Their fashion ontology is depicted in Figure 2. The domain concepts are shown as ellipses and their observable media properties are shown as rectangles. The brown arrows are relations defined by experts and/or shopping portals and associate garment properties with personality and occasion attributes: each link is modeled through a Conditional Probability Table (CPT). These probabilistic associations allow to model the degree of suitability of, for instance, body color seasons and garment colours. Given this ontology, the recommending system works in two stages: first, the personality is determined by observing the user's body colour from her facial and body images and mapped to the ontology concepts. Second, the recommendation is formulated leveraging the ontology and the given context of use (personality and occasion).

Dahunsi proposes a methodology for the development of an ontology-based knowledge base for apparel recommendation system [12]. The author argue that, in order to design a successful apparel recommendation system, it is necessary to integrate multiple user factors and garment features. This methodology focuses on establishing a standardized method of user-to-garment mapping through an ontology, and it defines a unified vocabulary within the fashion domain, as a side effect. Given such a kind of standardization, communications between experts and non-experts are simplified, since concepts and definitions are explicit. This work identifies a lack of flexibility in Vogiatzis et al., too: the authors argue that users may not necessarily fall within a category or grouping. To account for this limitation, the aim of this proposal is to design a methodology mapping user features to garment and ensemble features using domain expert knowledge and style rules. The procedure can be described in four steps: (1)

collection of definitions and style rules by making explicit expert knowledge references; (2) selection of those features which contributes to accuracy; (3) construction of an ontology given the defined and selected classes; (4) design, development, and evaluation of a recommendation system.

IV. THE MUSA-NEXT APP

This literature review has been performed in the context of the Multilayered Urban Sustainability Action (MUSA) project. MUSA is an ecosystem of innovation funded by the Ministry of University and Research under the National Recovery and Resilience Plan (PNRR) within the NextGenerationEU initiative (https://musascarl.it). In particular, MUSA Spoke 5 contributes by settling new and improved practices towards sustainability in fashion, design, and luxury sectors in Milan.

One of the expected deriverables of this project is a webapp called MUSA-Next, which is designed as an easy, accessible, and informative tool to sensitize the population about different sustainability facets. The app is also going to have a focus on fashion, offering solutions to some of the issues presented in Section II.A. In the following, we describe the main functionalities which are going to be implemented in MUSA-Next:

- dissemination is a key element to spread education about sustainability. For this reason, the MUSA-Next app is going to integrate a system for advertising and participating in challenges and events about sustainability in fashion. For instance, a possible challenge is to ask users to provide a creative utilization of textiles scraps. This functionality could tackle the fast fashion issue by sensitizing consumers about educational talks and activities;
- young stylists are going to be involved in a social platform to share and advertise their paper pattern for stitching clothes. Specifically, this functionality allows to frame a piece of fabric to explore which paper patterns could be applied. Supporting handmade practices is also a way to shade light on slow-fashion practices;
- educating users towards good practices in garment maintenance is essential to make the most out of a piece of clothing, elongating its life cycle. MUSA-Next is going to offer guidelines to preserve and clean garments correctly. The communication means for this functionality are going to be diverse and attractive, thus including enjoyable and educational videos;
- to support second-hand market and vintage, which are fundamental for sustainable solutions. MUSA-Next is going to provide a map allowing users to discover and report events, places, and stores for the exchange and/or selling of vintage and second-hand garments;
- gamification is an excellent strategy to further strengthen the communication and educational scopes of this project. Trivia-like quizzes are going to be offered with the aim of making users more aware about their knowledge on sustainable practices. The user responding correctly is going to be able to stitch a environmentally and socially sustainable virtual garment;

From a technical point of view, educational information is going to be coded into semantically-rich representations using ontologies. The evidences provided in Section III suggest that the use of semantic web technologies can be particularly effective for two important aspect of MUSA-Next: (1) ontologies can be used to structure clothing and material-related entities. We plan to borrow and extend the ontologies described in Vogiatzis et al. and Ajmani et al. to support the second and fourth functionalities of MUSA-Next [68], [69]. For instance, young stylists and shop owners could enrich their product descriptions by following guided instructions provided through the underlying semantic model. As a result, the users of MUSA-Next could be supported in advanced searches like “Where can I buy vegan clothing in Milan?”. As a further example, the semantic information attached to product descriptions could be used to support users in choosing an appropriate paper pattern with respect to a given piece of fabric. This way, MUSA-Next could support queries like “Which unisex garment can I stitch with a piece of blue cotton fabric?'”. A set of compatible patterns could by returned by MUSA-Next as a result. For educational purposes, further information about the sustainability of the considered fabric could be provided to improve the user awareness.

V. CONCLUSIONS

Given and increasing interest in sustainable practices in the fashion industry, new and innovative techniques have been explored in the literature. Specifically, this work focuses on solutions based on semantic web technologies for the LCA, and how they can be jointly used to strengthen sustainability performance in the fashion sector. These advancements go in the same direction as MUSA Spoke 5 scope, which focuses on supporting and sensitizing both fashion industries and customers on many sustainability themes. In this perspective, the MUSA-Next app is going to be developed. One of its aims is providing educational and informative functionalities to help with adopting good practices throughout the whole apparel's life cycle; moreover, it offers a direct connection to another important Spoke 5 deliverable for traceability of fashion and luxury products.

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