Ontology and Vocabularies for Olfactory Information

Deliverable D4.1

Version FINAL

NEGOTIATING OLFACTORY AND SENSORY EXPERIENCES IN CULTURAL HERITAGE PRACTICE AND RESEARCH

The Odeuropa project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004469. This document has been produced by the Odeuropa project. The content in this document represents the views of the authors, and the European Commission has no liability in respect of the content.

Grant Agreement No.	101004469
Project Acronym	ODEUROPA
Project full title	Negotiating Olfactory and Sensory Experiences in Cultural Heritage Practice and Research
Funding Scheme	H2020-SC6-TRANSFORMATIONS-2020
Project website	http://odeuropa.eu/
Project Coordinator	Prof. Dr. Inger Leemans KNAW Humanities Cluster Email: inger.leemans@huc.knaw.nl
Document Number	Deliverable D4.1
Status & version	FINAL
Contractual date of delivery	December 2021
Date of delivery	December 2021
Type	Report
Security (distribution level)	Public
Number of pages	16
WP contributing to the deliverable	WP4
WP responsible	WP4
EC Project Officer	Hinano Spreafico
Authors: Pasquale Lisena,[1] Daniel Schwabe,[2] Marieke van Erp,[3] Raphael Troncy,[1] William Tullett,[4] Inger Leemans,[3] Lizzie Marx,[3] Sofia Colette Ehrich[3]	
Internal reviewers: Mathias Zinnen,[5] Sara Tonelli[6]	
Affiliations: (1) EUR, (2) JSI, (3) KNAW, (4) ARU, (5) FAU, (6) FBK	
Keywords: ontology, vocabulary, semantic web, data model	
Abstract: This document describes the Odeuropa data model and the olfactory vocabularies developed as part of WP4. We describe our methodology for designing the ontology and provide a number of examples of how to use it. Finally, we show how this model can be evaluated using competency questions.	

Table of Revisions

Version	Date	Description and reason	By	Affected sections
0.1	12 December 2021	First Draft	Pasquale Lisena	All
0.2	17 December 2021	Update after internal review	Pasquale Lisena	All
0.3	23 December 2021	Final proof reading	Raphael Troncy	All
1.0	27 December	Final check and approval by project manager	Marieke van Erp	-

Executive Summary

This deliverable introduces the Odeuropa data model, an olfactory extension of the CIDOC-CRM ontology which makes use of other ontologies such as PROV and CRMsci. The model can represent smell-related information. In particular, it enables to describe the emission, use and experience of a given odour. The data model has been designed and evaluated using a set of competency questions provided by cultural heritage scholars and historians, followed by several iterations of refinement until each question was successfully converted into a SPARQL query. This document not only describes the model itself, but also the methodology followed by the different project partners, as well as an example of its usage.

The data model come with a set of multilingual controlled vocabularies for disambiguating crucial olfactory information elements, namely olfactory objects, olfactory gestures and fragrant spaces, as well as widely adopted odour classifications such as Michael Edwards' scent wheel and Flavornet odour space.

The resulting ontology has been published at http://data.odeuropa.eu/ontology/ and the vocabularies can be browsed at http://vocab.odeuropa.eu/.

List of Acronyms

API. Application Programming Interface
CQ. Competency Questions
EOKG. European Olfactory Knowledge Graph
HTTP. HyperText Transfer Protocol
RDF. Resource Description Framework
SKOS. Simple Knowledge Organization System
SPARQL. SPARQL Protocol and RDF Query Language

Contents

1 Introduction

Senses such as vision and hearing are largely studied in signal processing and computer science, while others – such as olfaction – are underrepresented in scientific research. Cultural heritage data collections pose both an opportunity and a challenge. Up to now, most effort in olfactory mining has been put into mapping and classifying fragrances and malodours (specifically in the perfume and odor industries) and in computing the nose – the act of smelling and its effect on the body. Smells are notoriously hard to predict. Thus far, olfactory informatics has been focused on computing what a molecule smells like based on its chemical structure [Sanchez-Lengeling et al., 2019, Wu et al., 2019, Licon et al., 2019]. Cultural Heritage texts and images, however, provide a different type of information. They offer rich data about odour perception and valuation, about the cultural experience of smelling, including subjective interpretations of the perceived odours. To capture this information, different computer science technologies are required, such as image recognition, text mining, and semantic web technologies.

In order to represent olfactory information, we developed the Odeuropa data model for representing odours and their experiences from a cultural heritage perspective. The data model re-uses and extends established ontologies such as CIDOC-CRM [Doerr, 2003], in order to represent the relevant information as a set of interconnected events. The model is completed by a set of controlled vocabularies for representing some crucial elements such as olfactory objects and gestures. This ontology is the backbone structure for realising the European Olfactory Knowledge Graph (EOKG) described in the Deliverable D4.2.

2 Design Methodology and Model Requirements

As there is a large gap between the everyday practices of computer science and humanities researchers in which this model is to fit, we opted for a user-centred design methodology, in which 4 scholars (olfactory and art historian experts) from the Odeuropa consortium were closely involved. In a series of (mostly online) meetings and hands-on exercises, the requirements of the model were elicited whereby the overall Odeuropa project goals were kept in mind as the end-goal to work towards.[1] A core instrument in this process was the formulation of 74 competency questions for the model to answer.[2] These questions have been chosen because they are representative of the main goals of the project.

With each step, the intermediate results were shared and progress on the design was measured according to the competency questions formulated and results of these were used to steer the next development iteration. A visual overview of our method is provided in Figure 1

[1] https://odeuropa.eu/objectives-timeline/
[2] https://bit.ly/odeuropa-cq

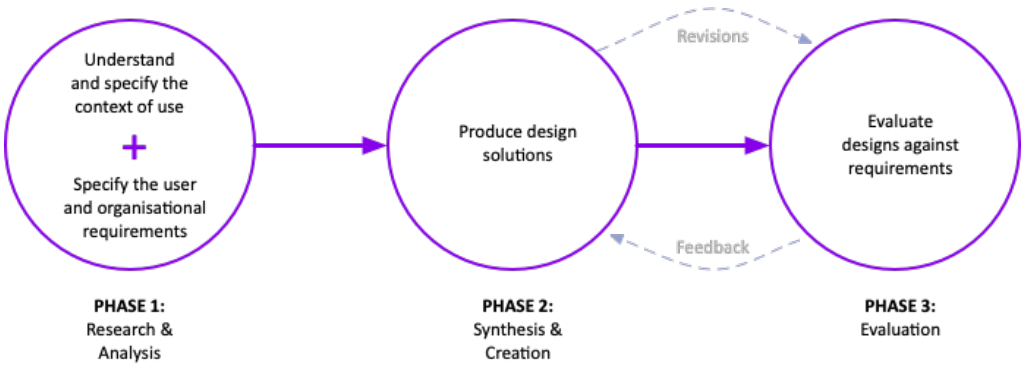

Figure 1: User-centred design

The desired ontology will enable to represent and store olfactory information coming from structured resources, as well as information extracted from texts and images. Furthermore, the resulting knowledge graph will be used to research smells through time and related to places. Historians are particularly interested in what people did with smells, how they created smells, and what emotions these evoked. These requirements led to the following 7 categories of competency questions (reported with 2 examples for each category):

Smells: About core properties of smell (source, carrier).
- *What are the most frequent smell sources in London in the 18th century?*
- *Which smells were perceived during spring?*

Noses and Gestures: Involving the actors perceiving the odours.
- *Which professions are more present in smelling experience descriptions?*
- *Which smelling gestures are described more frequently in tea-merchants' experiences?*

Identities: About the meaning of smells and their capability of being representative of something/someone.
- *Which flavours are associated with femininity in Asia?*
- *What are the odours most associated with Ashkenazi Jewish practices?*

Emotions: Focusing on the interaction between olfaction and feelings.
- *What odours disgusted high-class Europeans most?*
- *Which smell triggers memories of childhood?*

Practices: About smell-producing practices.
- *What types of cooking produce a bad smell?*
- *Which practice can reduce a smell intensity?*

Sites and contexts: About the presence of odours in particular places.
- *Which smells are associated with ships?*
- *Which smell could be perceived during the Crimean War?*

Texts and images: About how smells are represented in texts and images.
- *What are the adjectives used for orange aroma in the 15th century?*
- *Which smells can be found in paintings of the Rijksmuseum?*

All questions can be further modified for focusing on a specific time and space, e.g. Which smells were perceived during Spring *in 17th century*?

3 The Odeuropa Data Model

This section describes the olfactory data model, highlighting our core modelling decisions and the main structure of the resulting ontology.

3.1 Extending established ontologies

Following best practices in ontology development [Carriero et al., 2020], we aim to re-use existing data models – serving as base for our own – and extend them to represent domain-specific classes and properties. Given the lack of sensory-centered ontology, we chose **CIDOC-CRM** [Doerr, 2003] as our core ontology for the following reasons:

- **It is a bridge to other cultural and heritage objects:** CIDOC-CRM can be used to describe objects in museums and creative works [Lisena and Troncy, 2020], including paintings and textual resources. This makes it more natural to describe the relations between olfactory information and those elements;

- **It is already familiar to museums and digital libraries:** This can be an advantage when creating interlinks with existing collections and for eventual adoption by these institutions;
- **It is event-based:** Due to the intangible nature of smells and the inevitable subjectivity in their usual descriptions, we decided to focus on the representation of olfactory events rather than on odours themselves. An event can be described in relation to time, space, and involved participants can be linked to other events, including sub-events such as actions and gestures. This is also compliant with text annotation, which are carried out following an event-based approach (see the Deliverable D3.1);
- **It is expressive and flexible:** The information to be represented may vary significantly, ranging from highly detailed olfactory experiences to brief mentions of a particular smell. The modularity of CIDOC-CRM – itself made of interconnected events – provides the required flexibility in the representation. In particular, it allows to independently represent the event which generated (or transformed) the smell and the olfactory experience(s), allowing to describe both or only one of them.

CIDOC-CRM is completed by **CRMsci** [Doerr et al., 2015], which adds properties about the scientific observation and description of natural phenomena. Here, the *observation* concept has to be understood in the broad sense of *experiencing something*, such that it can also be applied to sensory experiences beyond sight.

As a derivation of CIDOC-CRM, the Odeuropa model follows the naming convention to prefix classes and property names with a number and a letter: CIDOC-CRM uses E (for classes) and P (for properties); CRMSci uses S (classes) and O (properties); Odeuropa uses L (classes) and F (properties), taking two letters from "o**lf**action". In the text of this document, we will omit these codes and letters for readability, while keeping them in the figures.

In addition, parts of the following ontologies are used in the Odeuropa Data Model:

- The READ-IT ontology, to represent emotions triggered by events [Antonini et al., 2021];
- The PROV-O Ontology, for representing data provenance [Lebo et al., 2013];
- The FOAF vocabulary, for describing people [Graves et al., 2007];
- Schema.org [Guha et al., 2016], to describe the genre and author of a text or painting.

3.2 A Three-Layered Model

Due to the complexity of the phenomena related to odours, we adopted a layered approach to construct the data model. We identified abstraction levels that roughly correspond to the different aspects that are of interest to scholars in this domain. Accordingly, the Odeuropa data model is organised in the following three levels:

- **Level 1** consists of the CIDOC-CRM and CRMsci classes and properties that were used and/or extended. It represents an observation of a phenomenon;
- **Level 2** is an extension of Level 1 for representing sensorial experiences, not limited to olfaction. This level was developed because we identified commonalities shared by all senses and decided to provide more general classes and properties. This will help future extension of the model, including the representation of synaesthetic experiences;
- **Level 3** extends Level 2 by specifically targeting olfactory information.

The three levels are shown in Figure 2, representing the core of the model. *Smell* (Sensory Stimulus) plays a central role, directly connected to two main types of events, namely *Smell Emission* (Stimulus Generation) and *Olfactory Experience* (Sensory Experience).

In this model, we consider a smell as a unique and non-repeatable entity, with defined time and space coordinates. By way of example, two roses have two distinct (but similar) smells, and

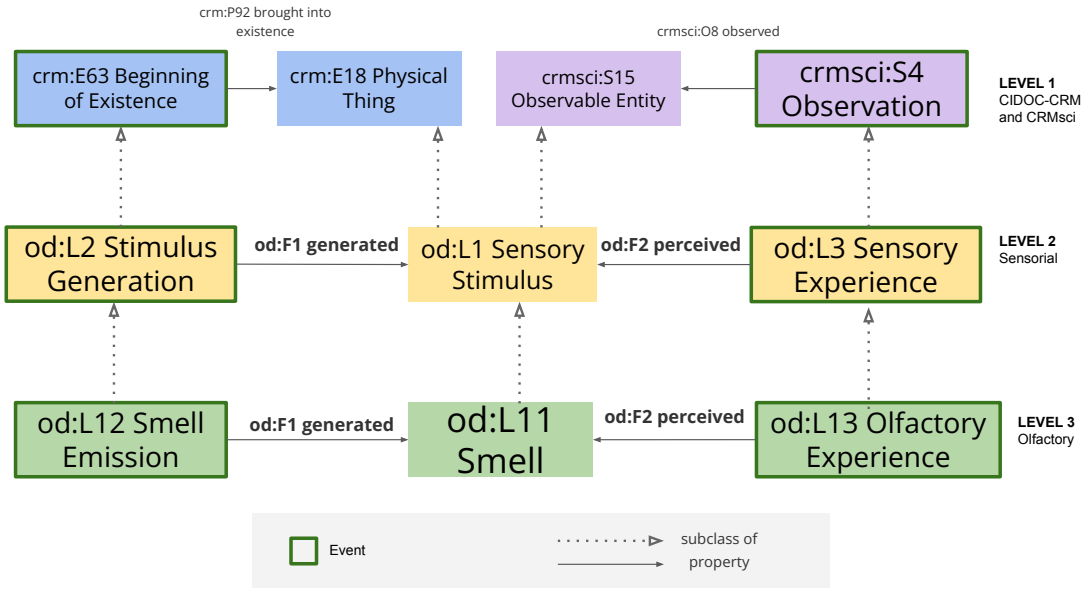

Figure 2: The core of the Odeuropa data model

the "smell of roses" exists only as a generalisation of the smells of all roses. A given smell can be generated by a unique *Smell Emission event*, but can be experienced multiple times, in distinct situations, by multiple people. This captures the fact that each person can perceive and describe the same smell differently.

Figure 3 presents all elements that are part of the Odeuropa data model. The information is organised around the three main types of events, directly linked to the Smell entity:

- The **Smell Emission** allows us to describe the smell generation from a smell source (e.g. tobacco) and the carrier of the smell (e.g. a pipe). These elements can be further described through their components and/or the production process which creates them;
- The **Olfactory Experience** allows us to describe the perception of smell – who perceived the smell, their eventual emotions and gestures. In addition, it records the description that the perceiver makes of the smell, be it through adjectives (typed and linked to vocabularies using the Attribute Assignment class) or through the mention of (i.e., association with) evoked entities such as other smells, people, places, etc;
- The **Odorizing** class allows to describe how a specific smell was used. For instance, it is possible to specify the purpose for which an odour was used – e.g. covering another smell, medical reason, etc. –, who was using it on what the smell is being used – e.g. a room, a part of the body, etc.

The event classes inherit from CIDOC-CRM some common properties to specify the time and space of the event and potentially co-occurring events. Given the subjective nature of the words used for describing smell, we preferred to model them as *Attribute Assignment* connecting the word (*assigned*) to the smell (*assigned attribute to*), with a direct link to the original person (*carried out by*) and the possibility to include the attribute (*has type*) in a category (e.g. hedonic, intensity, character, state, etc.).

Furthermore, the model includes classes such as *Stimuli/Smell Transformation* – to represent events that modify a smell, e.g. opening a window – and *Stimuli/Smell Interaction* – to represent smells that are perceived as a combination of different smells, e.g. different foods in a dining room. Special care was devoted to model perceivers (i.e. the agents perceiving smells), by

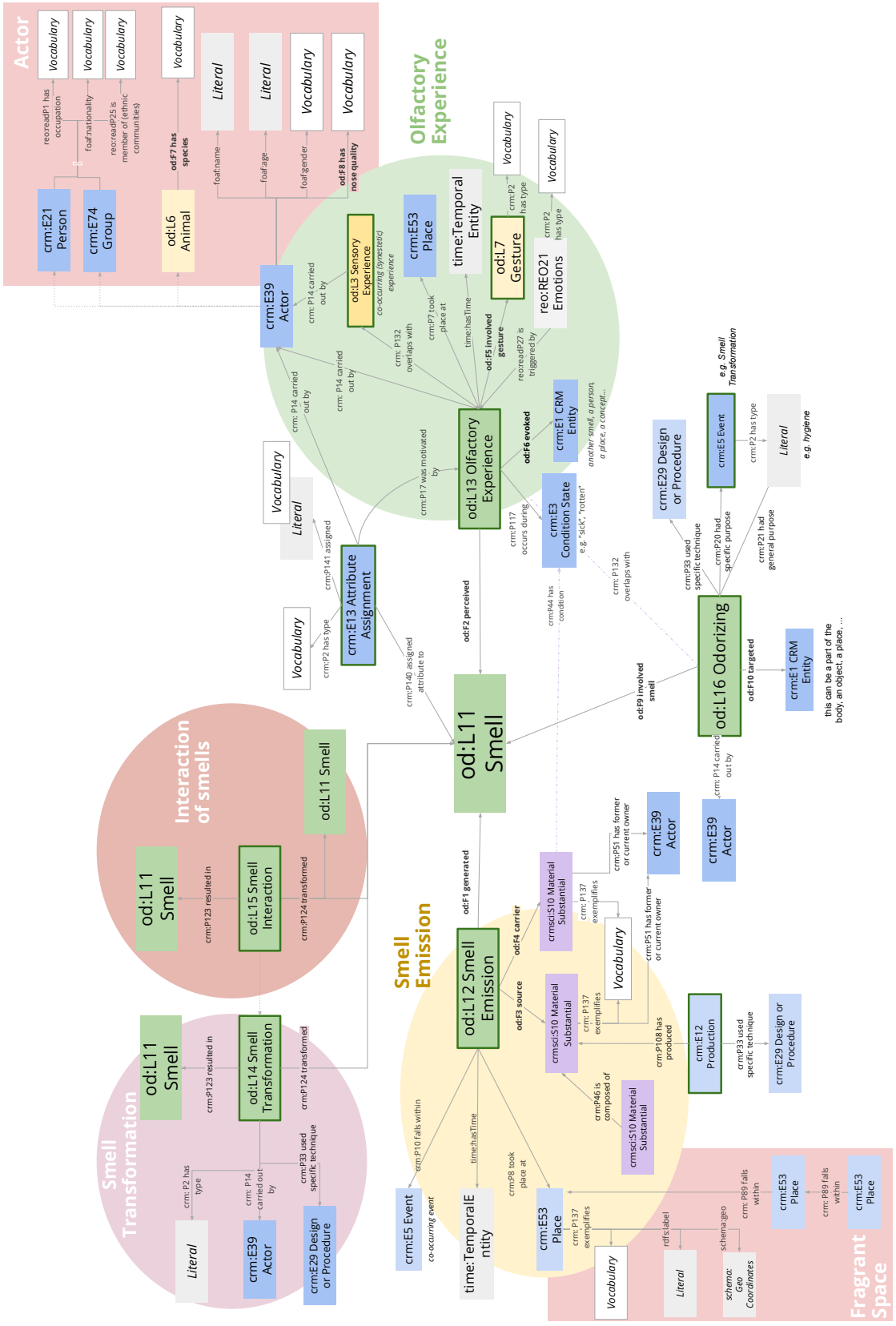

Figure 3: The Odeuropa Model

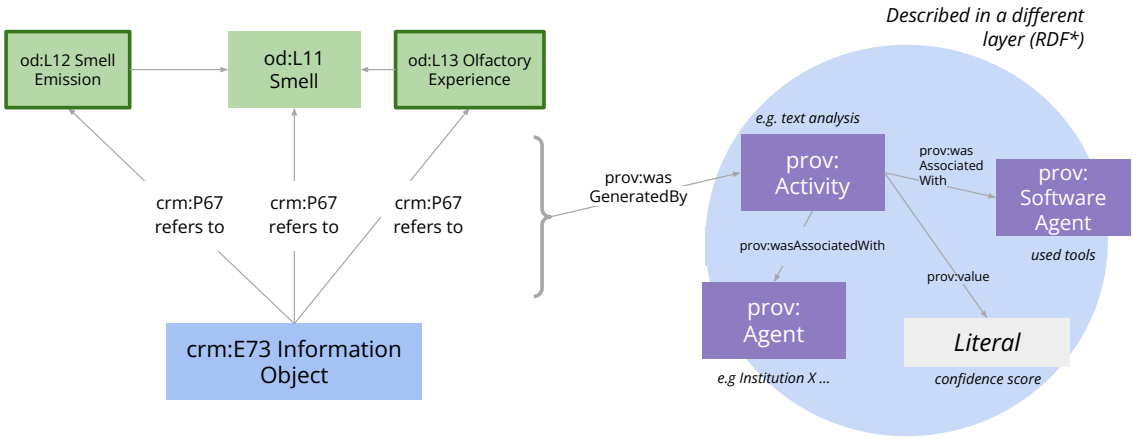

Figure 4: The provenance of information represented in the Odeuropa model

employing and extending the class *Actor* to represent people, groups and animals. Similarly, fragrant spaces are also represented, capturing those attributes that allow us to aggregate them – by type of place or by geographical contiguity.

3.3 Provenance Information

As we intend to trace smells through time, we need to keep track of the sources from which statements in our knowledge graph are derived and through what process. Furthermore, to anchor statements in time and place, we want to keep track of when they were published, and if possible who published them, for example to map a debate on cultural differences with respect to a particular odour. To keep track of this in the EOKG, we apply the following strategy: CIDOC-CRM enables to represent that a text (*Linguistic Object*) or image (*Visual Item*) contains a reference (*refers to*) to an entity, which is, in our domain, a Smell or an Olfactory Event. To include the information without drastically increasing the number of triples in the EOKG, these *refers to* links are instantiated within a subset of the graph, containing at least the core.

PROV-O [Lebo et al., 2013] is used to record the ways this information was extracted from textual and visual sources, including the agent and/or software/algorithm which extracted the information and a confidence score in case automatic processes were involved. To keep the graph clean, we include this information in a second layer. This is realised by applying RDF* [Hartig, 2019] and linking the provenance information to the relevant *refers to* properties, as shown in Figure 4. In this way, the information and the meta-information are kept distinct, while it is always possible (when needed) to retrieve the provenance of a data excerpt.

4 Controlled Vocabularies

For the description of some fundamental olfactory-related concepts, a collection of controlled vocabularies was created. The use of vocabularies helps to better disambiguate entities, grouping synonyms and labels in different languages under a single identifier (URI). Our vocabularies are represented in SKOS [Miles and Pérez-Agüera, 2007], a format that allows us to define, for each concept, preferred and alternate labels, descriptions, broader, narrower and related terms. In this way, we can construct a hierarchy of terms, grouping the related ones and to instantiate bridges between concepts belonging to different vocabularies.

Following previous experiences in constructing controlled vocabularies in Digital Humanities [Lisena et al., 2018, Leon et al., 2020], our collection is composed of previously-existing tax-

Name	Type	Levels	Top Level Concepts	Total Concepts
Drom's fragrance circle	Odour wheel	2	16	77
Michael Edwards' scent wheel	Odour wheel	2	4	18
Odour wheel of historical books	Odour wheel	2	8	43
Nose-first classification of iconographies	Classification	1+1	25	168
Flavornet and human odour space	Classification	1+1	25	495
Zwaardemaker smell system	Classification	1+1	9	9

Table 1: Vocabularies converted in SKOS. Some classification systems have a second level which consists of smell sources rather than smell classes (reported as 1+1).

onomies – which are expressed using SKOS – and vocabularies built from scratch through the collaboration of domain experts and computer scientists.

The list of olfactory vocabularies converted in SKOS format is reported in Table 1 and consists of:

- The Fragrance Circle by Edward Drom, a smell wheel used in perfumery; [Brud, 1986]
- Michael Edwards' Fragrance Wheel, including 4 families and 14 subfamilies of olfactory groups used in modern perfumery;[3]
- the Odour wheel of historical books, realised for smell heritage preservation [Bembibre and Strlič, 2017];
- The Nose-first classification of iconographies realised by Ehrich et al. for linking smells and their representation in art [Ehrich et al., 2021];
- The Flavornet odour space, the compilation of aroma compounds found in human odour space [Arn and Acree, 1998];
- The Linnaeus/Zwaardemaker smell system developed in 1895 [Philpott et al., 2008].

These vocabularies have been manually converted to a common CSV format and then processed and converted to SKOS. In addition, 3 multilingual vocabularies have been developed in a collaboration between knowledge engineers and domain experts, representing:

- **Fragrant spaces**, listing interesting (from an olfactory point of view) places such as churches, buildings, natural environments, etc. The included concepts are intended to be linked to instances of type `E53 Place` through *P137 exemplifies*;
- **Olfactory gestures**, enumerating simple actions which possibly occur during olfactory experiences, e.g. sniffing, covering the nose, etc. The included concepts are intended to be linked to instances of type `L13 Olfactory Experience` through *F5 involved gesture*;
- **Olfactory objects**, including entities (natural or human made) which are particularly relevant because emitting odours – e.g. a flower – or potentially carrying odour sources – e.g. a perfume bottle or a pomander. The included concepts are intended to be linked to instances of type `L12 Smell Emission` through *F3 source* or *F4 carrier*.[4]

The development of these vocabularies was carried out with synchronised spreadsheet tabs – one for each language – to collect the translations of each term. In addition, semantic relationships between terms inside the same vocabulary were instantiated – e.g. "Rose" *skos:broader*

[3] https://en.wikipedia.org/wiki/Fragrance_wheel Last visited: 07/12/2021

[4] While some of these are clearly carriers (*wind*, *bottle*) and other smell sources (*jasmine*, *sulphur*), some specific elements can embody any of the two role depending on the context (*smoke*). For this reason, we decided to have a single vocabulary including all terms, reporting the preferred role when possible.

"Flower" or "Pipe" *skos:related* "Tobacco – and between vocabularies – e.g. "Library" *skos:related* "Book". An overview of the available languages is shown in Table 2. Please note that a given concept does not always have an appropriate translation in all languages.

Name	Total Concepts	EN	DE	FR	IT	NL	SL
Fragrant Spaces	110	110	4	108	106	110	4
Olfactory Gestures	35	35	0	33	32	16	0
Olfactory Objects	417	400	172	378	381	390	402

Table 2: Multilingual vocabularies for English (EN), German (DE), French (FR), Italian (IT), Dutch (ML), and Slovene (SL)

5 Evaluation with Competency Questions

To guide the design of the data model and to provide a way to evaluate it, we used the set of 74 Competency Questions (CQ) [Noy and Hafner, 1997] collected in Section 2 before the development of the model. These CQ were proposed by domain experts – historians and scholars with expertise in olfactory heritage – and are organised in 7 categories, reported in Table 3.

These questions allowed the team to iteratively improve versions of the data model, in sequences of development and check, until we could write a SPARQL query for each proposed question. In the final version of the model, we distinguish 4 different cases:

- The vast majority of questions can be answered with a SPARQL query.
  Example: *What are the most frequent smell sources in London in the 18th century?*
- A few questions cannot be answered by simple SPARQL queries, but require more AI methods to find a proper solution. For example, we may need to compute word embedding for understanding which words are more positive or negative.
  Example: *Was muck perceived as more disgusting than smog?*
- 4 questions are answerable with SPARQL, but require external information that are outside the scope of the model – e.g. with the addition of knowledge bases such as Wikidata.
  Example: *Which smell could be perceived during World War I (or Q361 in Wikidata)?*
- 1 question requires an extension of the model. Given that the challenging element of this question is not directly related to the olfactory/heritage information but to time representation, we decided to keep this issue open for future work.
  Example: *Which smells were perceived during morning?*

Apart from the last group, we consider the other cases satisfied by the model. Our results are summarised in Table 3

6 Showcase: Modelling the Smell of a Location

To better understand and appreciate the expressiveness and flexibility of the proposed data model, we provide a modeling example in Figure 5. In this example, we model the olfactory information contained in a passage from Vita Sackville-West's *Knole and the Sackvilles* (1922). In this book, the author describes the house she grew up in but could not inherit due to aristocratic inheritance customs:

> "They [**galleries** of **Knole**, ed.] have the **old**, **musty** smell which to **me**, whenever I met it, would bring back Knole. I suppose it is really the smell of all **old houses** –

Category	OK	AI	ExtData	Extension	Total
A. Smells	10	0	0	1	11
B. Noses and Gestures	6	0	0	0	6
C. Identities	6	0	0	0	6
D. Emotions	6	0	0	0	6
E. Practices	8	5	0	0	13
F. Sites and contexts	10	0	2	0	11
G. Texts and images	19	0	2	0	21
TOTAL	62	7	4	1	74

Table 3: The number of competency question per category, together with the number of answerable one with the sole model (OK), in combination with AI techniques (AI), with the addition of external data (ExtData) and only with a further extension of the model (Extension)

Ontologies	Prefix	Reused Classes	Reused Properties
CIDOC-CRM	crm:	10	16
CRMsci	crmsci:	1	0
FOAF	foaf:	0	4
PROV-O	prov:	3	3
READ-IT	reo:	1	3
Schema.org	schema:	1	4
Time	time:	1	1

Table 4: Re-used classes and properties in the Odeuropa Data Model

> a mixture of **woodwork**, **pot-pourri**, **leather**, **tapestry**, and the little **camphor bags** which keep away the moth, and specifically about the pot pourri: **bowls of lavender** and **dried rose-leaves** stand on the window-sills; and if you **stir them** up you get the quintessence of the smell, a sort of **dusty** fragrance, **sweeter** in the under layers where it has held the damp of the spices."

The different olfactory sources mentioned are not physically combined together as in a recipe,[5] but they separately emit different smells which are combined (*Smell Interaction*) in the galleries of Knole. The author perceives this ensemble smell and describes it as *old* and *musty*. In the text, one of the member smells emitted by the pot-pourri is described as *dusty* and *sweeter*, also mentioning the procedure of its realisation from lavender and rose leaves. Elements of the graph can be interlinked with the controlled vocabularies of olfactory objects – e.g. leather, camphor bags – and fragrant spaces – e.g. old house. Further examples can be found in the Data Model presentation (see Table 5).

7 List of published resources

The model is implemented in OWL (Web Ontology Language) format and published at http://data.odeuropa.eu/ontology under a Creative Commons 4.0 CC-BY License, along with its documentation. Odeuropa proposes 13 new classes and 10 new properties to capture olfactory information, defined as subclasses and subproperties of CIDOC-CRM and CRMsci. In addition to these, classes and properties from other models have been reused, as reported in Table 4.

Table 5 provides pointers to all resources that we developed and published in the context of this work, available as resources to the whole community. In addition to the ontology and the

[5] In that case, there will not be a Smell Interaction, but a single Smell Emission having as source the union of the different ingredients.

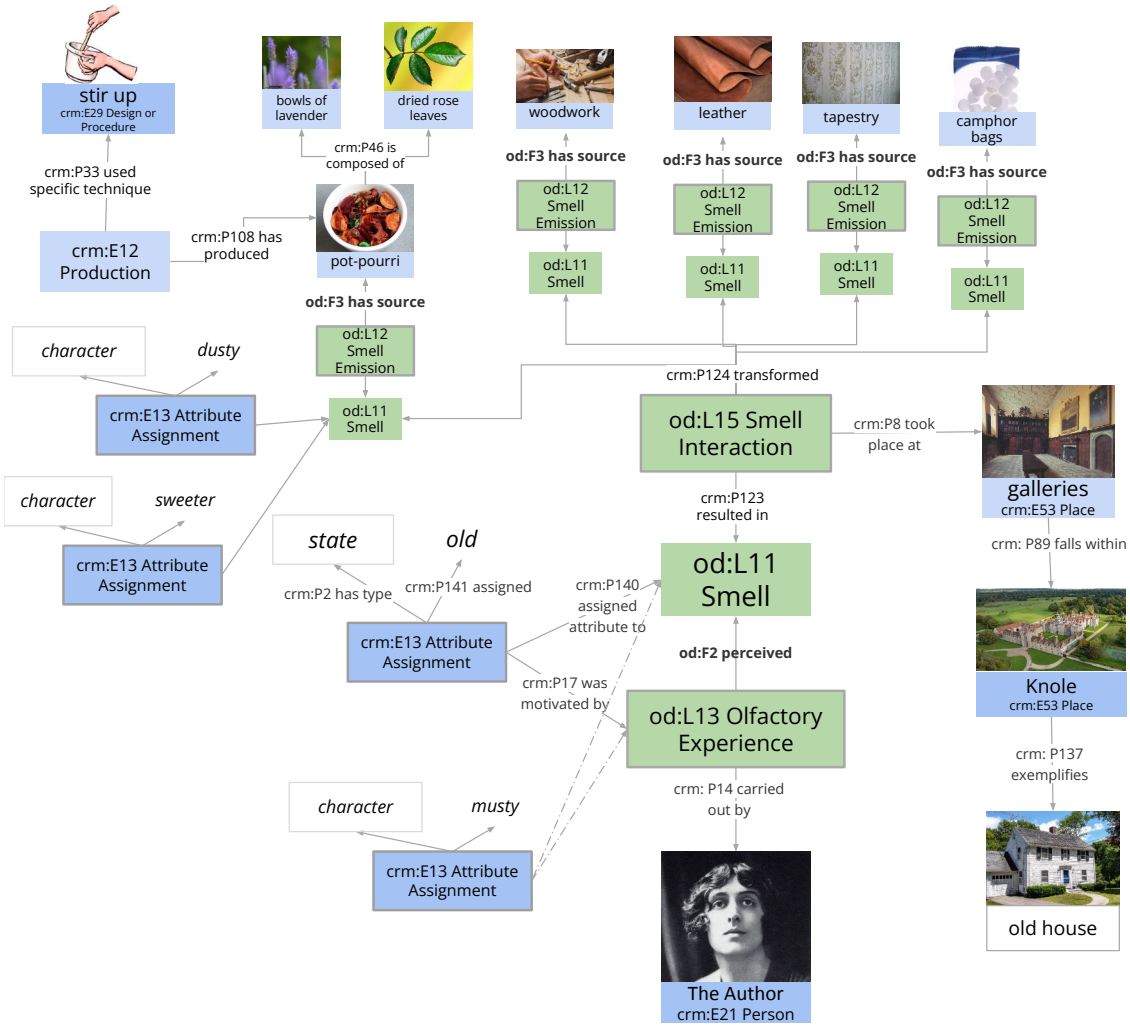

Figure 5: An excerpt of the Odeuropa Knowledge Graph using the Odeuropa model given a passage of Vita Sackille-West's *Knole and the Sackvilles* (1922)

competency questions, some olfactory controlled vocabularies are available via different access points:

- In RDF (Turtle format) using SKOS;
- In a wide-public visualisation based on SKOSmos [Suominen et al., 2015];
- Through a HTTP API which can be used for interlinking.

The ontology and the vocabularies have been loaded into the EOKG hosted at http://data.odeuropa.eu/. Both the ontology and the vocabularies may be improved and/or extended according to new project needs which may arise in the future.

The results of the work realised in the context of this deliverable has been submitted for publication in the Resource Track of the Extended Semantic Web Conference (ESWC) 2022.

Resource	URL
Data Model complete presentation	https://bit.ly/3GuIHzL
Ontology (OWL)	https://github.com/Odeuropa/ontology
Ontology (Documentation)	http://data.odeuropa.eu/ontology/
Competency Questions	https://bit.ly/odeuropa-cq
Vocabularies (RDF)	https://github.com/Odeuropa/vocabularies
Vocabularies (SKOSmos)	http://vocab.odeuropa.eu/
Vocabulary API	http://data.odeuropa.eu/api/vocabulary Doc: https://github.com/D2KLab/vocabulary-api
Odeuropa KG	http://data.odeuropa.eu/

Table 5: Resource table

References

[Antonini et al., 2021] Antonini, A., Suárez-Figueroa, M. C., Adamou, A., Benatti, F., Vignale, F., Gravier, G., and Lupi, L. (2021). Understanding the phenomenology of reading through modelling. *Semantic Web*, 12:191–217. 2.

[Arn and Acree, 1998] Arn, H. and Acree, T. (1998). Flavornet: a database of aroma compounds based on odor potency in natural products. *Developments in food science*, 40:27–28.

[Bembibre and Strlič, 2017] Bembibre, C. and Strlič, M. (2017). Smell of heritage: a framework for the identification, analysis and archival of historic odours. *Heritage Science*, 5(1):2.

[Brud, 1986] Brud, W. (1986). Words versus odours, how perfumers communicate. *Perfumer and flavorist*, 11:27–44.

[Carriero et al., 2020] Carriero, V. A., Daquino, M., Gangemi, A., Nuzzolese, A. G., Peroni, S., Presutti, V., and Tomasi, F. (2020). The landscape of ontology reuse approaches. In *Applications and Practices in Ontology Design, Extraction, and Reasoning*, pages 21–38. IOS Press.

[Doerr, 2003] Doerr, M. (2003). The CIDOC Conceptual Reference Module: An Ontological Approach to Semantic Interoperability of Metadata. *AI magazine*, 24(3):75–75.

[Doerr et al., 2015] Doerr, M., Kritsotaki, A., Rousakis, Y., Hiebel, G., and Theodoridou, M. (2015). Definition of the CRMsci an extension of CIDOC-CRM to support scientific observation. *Forth-Institution of Computer Science*.

[Ehrich et al., 2021] Ehrich, S., Verbeek, C., Zinnen, M., Marx, L., Bembibre, C., and Leemans, I. (2021). Nose first. towards an olfactory gaze for digital art history. In *First International Workshop on Multisensory Data & Knowledge (MDK)*, Zaragoza, Spain.

[Graves et al., 2007] Graves, M., Constabaris, A., and Brickley, D. (2007). FOAF: Connecting People on the Semantic Web. *Cataloging & Classification Quarterly*, 43(3-4):191–202.

[Guha et al., 2016] Guha, R. V., Brickley, D., and Macbeth, S. (2016). Schema. org: evolution of structured data on the web. *Communications of the ACM*, 59(2):44–51.

[Hartig, 2019] Hartig, O. (2019). The RDF* and SPARQL* Approach to Annotate Statements in RDF and to Reconcile RDF and Property Graphs. In *W3C Workshop on Web Standardization for Graph Data*, Berlin, Germany.

[Lebo et al., 2013] Lebo, T., Sahoo, S., McGuinness, D., Belhajjame, K., Cheney, J., Corsar, D., Garijo, D., Soiland-Reyes, S., Zednik, S., and Zhao, J. (2013). PROV-O: The PROV ontology. Technical report, World Wide Web Consortium.

[Leon et al., 2020] Leon, A., Gaitán, M., Insa, I., Sebastián, J., and Alba, E. (2020). SILKNOW. Designing a Thesaurus about Historical Silk for Small and Medium-Sized Textile Museums. In Ortiz Calderón, P., Pinto Puerto, Verhagen, P., and Prieto, A., editors, *Science and Digital Technology for Cultural Heritage*. CRC Press, London.

[Licon et al., 2019] Licon, C. C., Bosc, G., Sabri, M., Mantel, M., Fournel, A., Bushdid, C., Golebiowski, J., Robardet, C., Plantevit, M., Kaytoue, M., et al. (2019). Chemical features mining provides new descriptive structure-odor relationships. *PLoS computational biology*, 15(4):e1006945.

[Lisena et al., 2018] Lisena, P., Todorov, K., Cecconi, C., Leresche, F., Canno, I., Puyrenier, F., Voisin, M., and Troncy, R. (2018). Controlled Vocabularies for Music Metadata. In *19th International Society for Music Information Retrieval Conference (ISMIR)*, Paris, France.

[Lisena and Troncy, 2020] Lisena, P. and Troncy, R. (2020). Representing Complex Knowledge for Exploration and Recommendation: The Case of Classical Music Information. In Cota, G., Daquino, M., and Pozzato, G. L., editors, *Applications and Practices in Ontology Design, Extraction, and Reasoning*, volume 49 of *Studies on the Semantic Web Series (SSWS)*, pages 107–123. IOSPress.

[Miles and Pérez-Agüera, 2007] Miles, A. and Pérez-Agüera, J. R. (2007). SKOS: Simple knowledge organisation for the web. *Cataloging & Classification Quarterly*, 43(3-4):69–83.

[Noy and Hafner, 1997] Noy, N. F. and Hafner, C. D. (1997). The state of the art in ontology design: A survey and comparative review. *AI Magazine*, 18:53.

[Philpott et al., 2008] Philpott, C. M., Bennett, A., and Murty, G. E. (2008). A brief history of olfaction and olfactometry. *The Journal of Laryngology & Otology*, 122(7):657–662.

[Sanchez-Lengeling et al., 2019] Sanchez-Lengeling, B., Wei, J. N., Lee, B. K., Gerkin, R. C., Aspuru-Guzik, A., and Wiltschko, A. B. (2019). Machine learning for scent: learning generalizable perceptual representations of small molecules. *arXiv preprint arXiv:1910.10685*.

[Suominen et al., 2015] Suominen, O., Ylikotila, H., Pessala, S., Lappalainen, M., Frosterus, M., Tuominen, J., Baker, T., Caracciolo, C., and Retterath, A. (2015). Publishing skos vocabularies with skosmos. *Manuscript submitted for review*.

[Wu et al., 2019] Wu, D., Luo, D., Wong, K.-Y., and Hung, K. (2019). Pop-cnn: Predicting odor pleasantness with convolutional neural network. *IEEE Sensors Journal*, 19(23):11337–11345.