Best practices in olfactory digitisation

Deliverable D6.3

Version FINAL

NEGOTIATING OLFACTORY AND SENSORY EXPERIENCES IN CULTURAL HERITAGE PRACTICE AND RESEARCH

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Abstract: This deliverable focuses on the development and classification of olfactory vocabulary to characterise smells related to heritage in a manner that allows them to be easily understandable, comparable and re-usable for digitisation. This is essential to ensure knowledge transfer across disciplines, as well as the longevity of digital smell preservation data. We understand olfactory digitisation as the process of converting odour-related information into digital data, as part of the preservation of smells and olfactory heritage. In this report we will first discuss existing taxonomies to characterise quality aspects of odour, with a focus on chemical-sensory characterisation. Secondly we ouline how this state of the art and an existing model for the preservation of smells of cultural significance have formed the conceptual framework for the development of two case studies.

The first case study focuses on the cultural significance of the odour of frankincense. The value of this odour was documented by archival review and participatory research. Furthermore, molecular and sensory properties were described and recorded using analytical techniques and sensory science. The vocabularies developed through these tasks by expert and non-expert panels were compared, revealing this approach can potentially provide new access to knowledge about the past. Finally, novel practices for the digitisation of smells were explored by a pilot study in collaboration with the EU-funded project OligoArchive, leading to 2.13MB of Odeuropa D6.3 data packaged as synthetic DNA, to be preserved for future generations.

The second case study for smell preservation and digitisation concerns a historic Land Rover P5B vehicle which had been owned and used by Queen Elizabeth II. The heritage significance of the smell of the car interior was documented by archival review and participatory research (a group of relevant stakeholders, including classic car collectors, were identified and engaged). Furthermore, molecular and sensory properties for this odour were described and recorded using analytical techniques and sensory science. Finally, a reconstruction of the smell on the basis of the acquired data was conducted as a validation step for the existing preservation model, advancing it as a suitable practice for heritage smell preservation and digitisation.

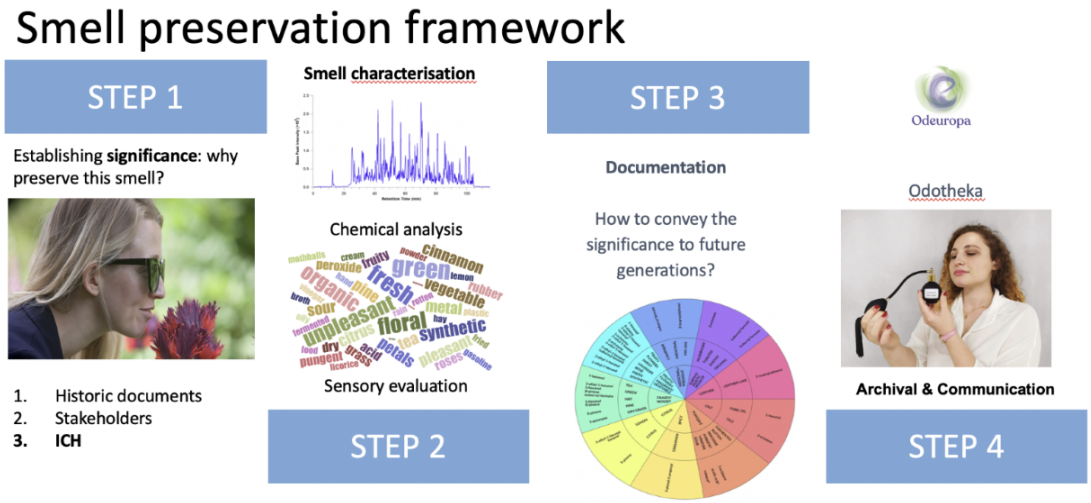
Table of Revisions

Version	Date	Description and reason	By	Affected sections
0.1	1 September 2023	Draft	Cecilia Bembibre, George Alexopoulos, Sanjoli Mathur	All
0.1	29 October 2023	Internal Review	Inger Leemans, Victoria-Anne Michel	All
0.2	30 October 2023	Revision after Review	Cecilia Bembibre	All
1.0	30 October 2023	Final check and approval by project manager	Marieke van Erp	-

Executive Summary

INTRODUCTION
This deliverable describes the development of an olfactory vocabulary to characterise and preserve smells related to heritage in a manner that allows them to be easily understandable, comparable, and re-usable for digitisation.

METHODOLOGY
The novelty and complexity of the task was addressed with a mixed methods approach, including archival research, qualitative research methods (non-participant observation, semi-structured interviews, expert and non-expert sensory evaluation) and analytical methods (volatile organic compound sampling and analysis via TD-GC-MS and GC-O and heritage smell reconstruction). Additionally, synthetic DNA archiving was developed in collaboration with the EU-funded OligoArchive project.



RESULTS AND DISCUSSION: FRANKINCENSE
The smell of frankincense was found to have multiple values. These include those associated with its traditional use, but also religious, spiritual, symbolic, economic, related to protective qualities, aromatic and fumigant. The cultural significance of the odour became more evident when the resin was being burned (compared to when the smell was perceived from the cold resin). Overall, this case study revealed the value of establishing cultural significance in collaboration with stakeholders as an essential step for the archiving and digitisation of olfactory heritage.

RESULTS AND DISCUSSION: HISTORIC CAR INTERIOR
The smell of a historic car was successfully documented and reconstructed from the perceptual and molecular data, supported by stakeholder engagements, validating a systematic, interdisciplinary framework to heritage smell preservation.

CONCLUSION
This work proposes best practice for olfactory digitisation by effectively archiving two smells of cultural significance.

Contents

1 Introduction

This study presents findings from the documentation and taxonomy development of two culturally significant smells, as the basis for best practices in olfactory digitisation. Developing easily understandable, comparable and re-usable archives is essential to ensuring knowledge transfer across disciplines, and for the longevity of digital smell preservation data.
In this work, olfactory digitisation is understood as the process of converting odour-related information into digital data, as part of the preservation of smells and olfactory heritage.
The first part of this report presents a review of approaches to smell taxonomies, with a focus on three main types: (1) chemical-led taxonomies, reporting analytical names and chemical numbers of volatile organic compounds responsible for smells; (2) odour quality taxonomies, conveying human perception of smells in the format of semantic descriptors and (3) historical taxonomies, which enhance our understanding of the longevity and accessibility of olfactory archives and therefore inform best practices in olfactory digitisation.
The second part of this study presents and discusses two case studies of smell preservation, chosen for their historical relevance and cultural significance. One is the smell of frankincense, an aromatic tree resin from the *Boswellia* genus, widely valued for its properties and significance. The second is the smell of the interior of a motor vehicle which belonged to Queen Elizabeth II. Through these case studies, we have conducted in-depth smell vocabulary development and discussed methodological approaches to documenting smells including expert, non-expert and historic vocabularies.
An existing model, *The heritage smell preservation framework* (Bembibre and Strlič, 2017; Bembibre Jacobo et al., 2017), was the foundation for the development of best practices in olfactory digitisation. This framework proposes a four-stage approach to the preservation of odours of cultural significance (Fig 1), as follows:

STEP 1 Assessment of cultural significance
Assessing the historical and cultural significance of a smell item is an important initial step that requires gathering information about the relevant historical context through archival and other resources, while also investigating the values, meanings and associations that contemporary communities attach to the smell through everyday use, socio-cultural, religious and other possible affiliations. Both the historical and contemporary cultural significance were assessed for the smell of frankincense and the historic car leather interior that were selected for this deliverable. While the

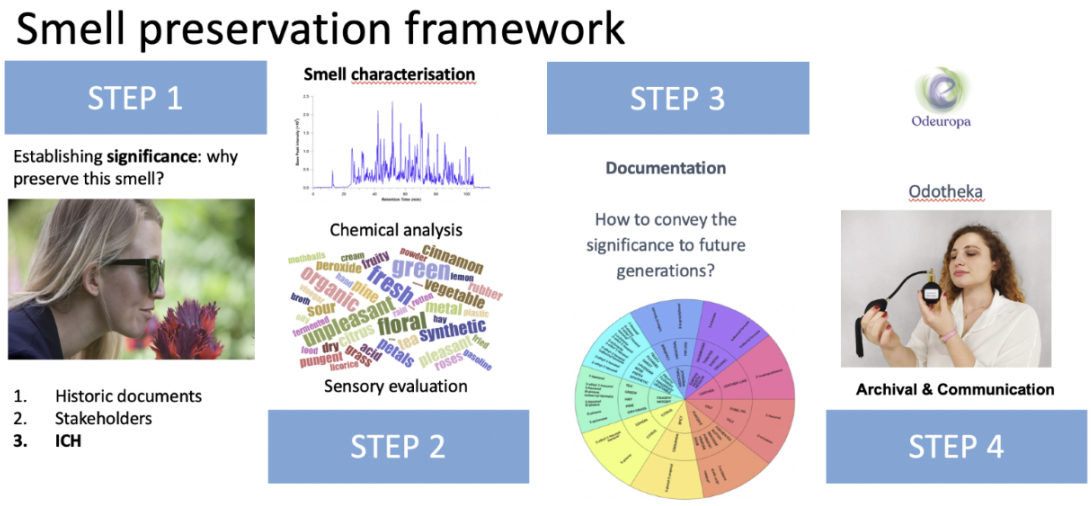


Figure 1: Smell preservation framework (Bembibre and Strlič, 2017).

existing model proposed an archive-based significance assessment, the new model was expanded to include stakeholder significance assessments.

STEP 2 Odour characterisation
Volatile organic compound analysis, coupled with sensory analysis are the basis of odour characterisation. This produces a record of a smell, where human perception complements molecular analysis for a co-interpreted documentation of odour quality, intensity and hedonic tone.

STEP 3 Odour documentation
The recorded characteristics of the smell, along with evidence of its cultural significance, are the basis of a digitised archival package containing chromatograms, sensory evaluation visuals and other data. A validation step for the framework is carried out via a reconstruction of the smell on the basis of the analytical and sensory data.

STEP 4 Archival and communication
Having been successfully validated, the data is digitally archived, with a plan for holistic communication of the sensory attributes in the context of their heritage significance.

2 Literature Review: smell taxonomies

Smell taxonomies are valuable for communicating and documenting human olfactory perceptions, and have been proposed as a central component in an archive of smells with cultural value (Bembibre and Strlič, 2017). This review focuses on three types of smell taxonomies: chemical, sensory, and historical, due to their relevance to the Odeuropa project. It is important to note that this list is not exhaustive and that other equally valuable taxonomies may exist.
In this report, chemical taxonomies refer to taxonomies based on the chemical characteristics of the smell. Sensory taxonomies are derived from the human experience of smell on a nose-first basis. Historical taxonomies are developed on the basis of the historical sources of said smells. In this section, the words ‘taxonomy’ and ‘classification’ have been used interchangeably.

Smells have been defined as “a property of chemical compounds and their mixtures” (Gasior and Wojtycza, 2016). A number of researchers have attempted to classify smells based on an analysis

Odour class	Odour	Odorant
Animal	Fecal	m-cresol CAS 108-39-4
	Acid	isovaleric acid CAS 503-74-2
Citrus	Resin	δ-3-carene CAS 13466-78-9
	Turpentine	α-phellandrene CAS 99-83-2

Table 1: Two examples of Flavornet’s odour classification, with odour and odorant information (Fla, 2023).

of the chemicals behind the smell. In 1963, J.E. Amoore analysed chemical structures and their shapes and size and came up with seven classes, namely: camphor, musk, floral, minty, ether, pungent, and putrid smells (Gasior and Wojtycza, 2016; Fullman, 1963).
Flavornet is another repository for such characterisation of smells. Flavornet is a database of 738 odorants, their chemical properties, and sensory descriptors. This database provides us with 25 odour classes, ranging from animal, raw meat, herbs, dairy, berry, citrus, etc. Each has further odours, with the corresponding odorants under them. Clicking on each odorant provides more chemical information about it. Table 1 presents an example classification of Flavornet. Similarly, Smellspedia (Sme, 2023b) is an online database which contains information for over 55,000 chemicals including their olfactory properties as well as scientific, technical and regulatory aspects.
Finally, the Pyrfume: A Window to the World's Olfactory Data project presents a collection of large, diverse databases which have been cleaned up and presented for open access, making this repository of interest to data scientists, computational neuroscientists, machine learning engineers and olfactory scientists. An overview of the Pyrfume ecosystem is presented in Figure 2.
Saini Ramanathan recorded another chemical method of creating smell taxonomies, focusing on molecular vibrations, weight, shape, etc (Saini and Ramanathan, 2022). A given example is of ester functional group molecules which are reported to have a fruity and floral smell. Poivet et al., however, have critiqued chemical classifications stating that it is not possible to know an odour quality based on only chemical structures (Poivet et al., 2018).
The sense of smell is said to be a very human sense, despite its chemical roots. An odorant turns into a smell when it is perceived by a (non)human. Therefore, a number of the initial classifications of smells that were established used a nose-first approach. It is believed that the first ever smell classification was created by Aristotle (Hoffmann, 2013), who grouped smells into: sweet, sour, harsh, succulent, pungent, and he later added fetid, which he described as the smell version of bitter (Bartoshuk, 2012). Later, Carl Linnaeus, in the 18th century, classified smells as aromatic, fragrant, ambrosial, garlic, hircine, ethereal, and empyreumatic (Gasior and Wojtycza, 2016; Bartoshuk, 2012). His classification was based on the medicinal quality of plants, connected to their odour. A century later, Hendrik Zwaardemaker, the inventor of the olfactometer, adapted Linnaeus' taxonomy to nine odour classes: alliaceous, ambrosiac, aromatic, empyreumatic, ethereal, foul, fragrant, hircine, and nauseous (Zwaardemaker, 1927; Ode, 2023d).
In the 1980s, Dravnieks et al. used literature and industry sources to put together a list of 146 descriptors (Dravnieks et al., 1984; Ode, 2023c) to characterise different odours. He asked participants to rate 10 smells based on their similarity to each of the 146 descriptors to create an odour profile for the smells. This list was developed on a pre-existing list consisting of 44 descriptors. However, this list was found to be too narrow for this method as it would lead to the characterisation of very different odours as similar (Dravnieks et al., 1985). Dravnieks noted that even his list of descriptors must be further populated depending on the odour being reviewed (Wise et al., 2000).
Henning's classification of smells (see Figure 3) was visualised in the form of a prism, with five primary odours: putrid, fragrant, spicy, resinous, and ethereal on each corner. In this classification, odours are placed within the prism based on their resemblance to the 5 primary odours (Mamlouk, 2002).
In the 20th century, E.C. Cocker and L.F. Henderson created a 9-point intensity scale for 4 types of smells: floral, sour, caprine, and burnt (Gasior and Wojtycza, 2016). What posed to be a key challenge for the sensory classifications was subjectivity (Bartoshuk, 2012), which manifested itself in the studies that followed Henning's prism, focusing on verifying his classification (Ibid.). This subjectivity, however, is not a critique only for sensory taxonomies, but applies to chemical taxonomies as well (Wise et al., 2000).
This critique has continued in recent years too. Saini Ramanathan (Saini and Ramanathan, 2022) states that the various factors that contribute to this subjectivity: age, vocabulary, cultural experiences, background, personal experiences (Wise et al., 2000), etc., render such classifications obsolete (Saini and Ramanathan, 2022). However, it can be argued that these subjectivities, though challenging to harness for smell classifications, can provide valuable context for historical

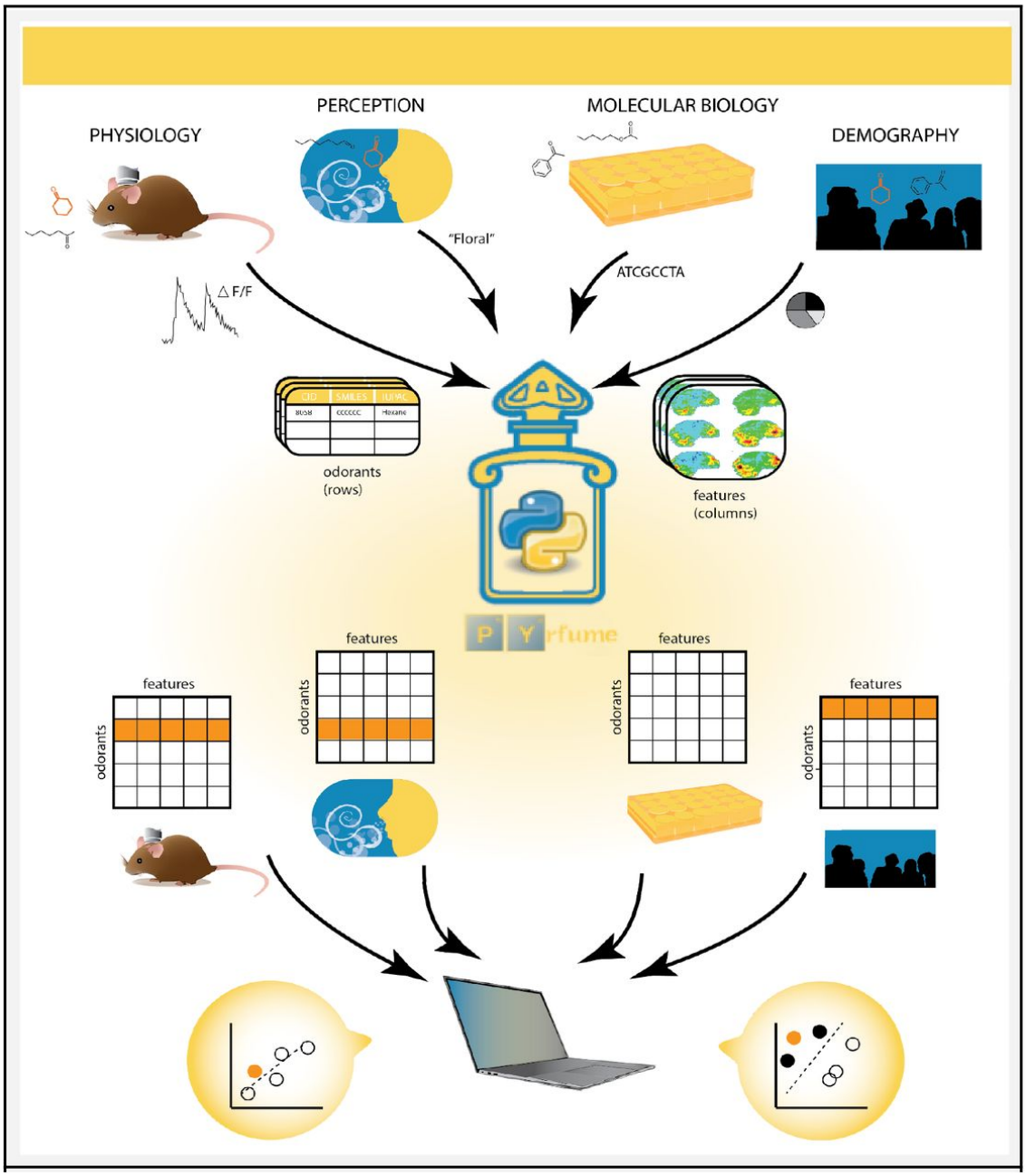


Figure 2: Overview of the Pyrfume ecosystem. Disparate and heterogeneous data are 'bottled' (top) to make them amenable to cross-modal, meta-analysis, or machine learning (ML) tasks, which typically require tabular data in the form of samples x features matrices. Under the Pyrfume standard, data are always linked to the odorant stimuli comprising a given experiment. The features will depend on the particular experiment, but could include data such as amplitudes of glomerular calcium transients, vectorized perceptual descriptors, or receptor sensitivities, etc. Bottled experiments are publicly available through REST APIs or directly via GitHub. Any given data archive on Pyrfume (¿40 to date) can be easily fetched, or 'unbottled' by a user using the Pyrfume API, and used immediately for ML tasks (bottom), with no need for laborious cleaning or formatting. The orange rows of the odorant x feature matrices indicate odorant molecules common to the experiments. The ability to easily extract data about common odorants across experimental modalities and model systems is a unique strength of Pyrfume (Castro et al., 2022).

smells. The subjectivities may force us into broadening our perspectives, and letting in previously unheard narratives (Tullett, 2023b). The ongoing discourse on smell and language has highlighted the need to go beyond the English language to understand odours (Majid and Burenhult, 2014; Majid, 2021). Hoffmann argues that this subjectivity should not hinder our studies of smells (Hoffmann, 2013).

This brings us to historical taxonomies of smells. In the Odeuropa project, Menini et al. have created another taxonomy, which is multilingual as well as historical (Menini et al., 2022). They have created olfactory vocabularies for English, Italian, French, German and Dutch, from between the 17th and 20th centuries. The smell words are then also contextualised in the time period(s) when they were used, and how they were used. Researchers at Odeuropa have created two taxonomies: one is *'a nose first classification system of iconographies, allegories and artefacts'*, which includes 178 terms, including mouldy, rural, body odour, etc (Ode, 2023a). The second is *'Dutch Historical Smell Vocabulary (DHSV) - Smell Words'* which consists of 796 terms(Ode, 2023b).

Another task of the Odeuropa project delved deeper into these historical classifications, looking at digitised museum data, specifically historical artworks, to identify different smell-related elements – odorants, action, indicator, space, and iconography. They visualised this in an odour wheel, which contains smells such as resinous myrrh, which branches into historical references such as The Three Magi, pomander, etc. Another category is food, with historical references such as still life, Jonah in the whale, etc. Each historical reference is linked to an iconclass reference number (Ehrich et al., 2022). In addition to this indexing work, the Odeuropa project developed the Smell Explorer, the first database that can be queried 'nose-first' (e.g., using the sense of smell as an entry point), making it a valuable resource for historical olfactory taxonomies and how smell experiences were recorded. The Odeuropa Smell Explorer contains information about odour-emitting objects and materials as well as fragrant and foul places. The data in the Odeuropa Smell Explorer was extracted from 50,000 images and over 400,000 historical books in six languages (English, Italian, French, Dutch, German and Slovene) available in the public domain (https://explorer.odeuropa.eu/).

All three of the taxonomies discussed here (chemical, perception-based, and historical), though valuable, also have their challenges. To build a holistic understanding of odours, the three taxonomies should complement one another. Scientists have, in the past, pondered over the link

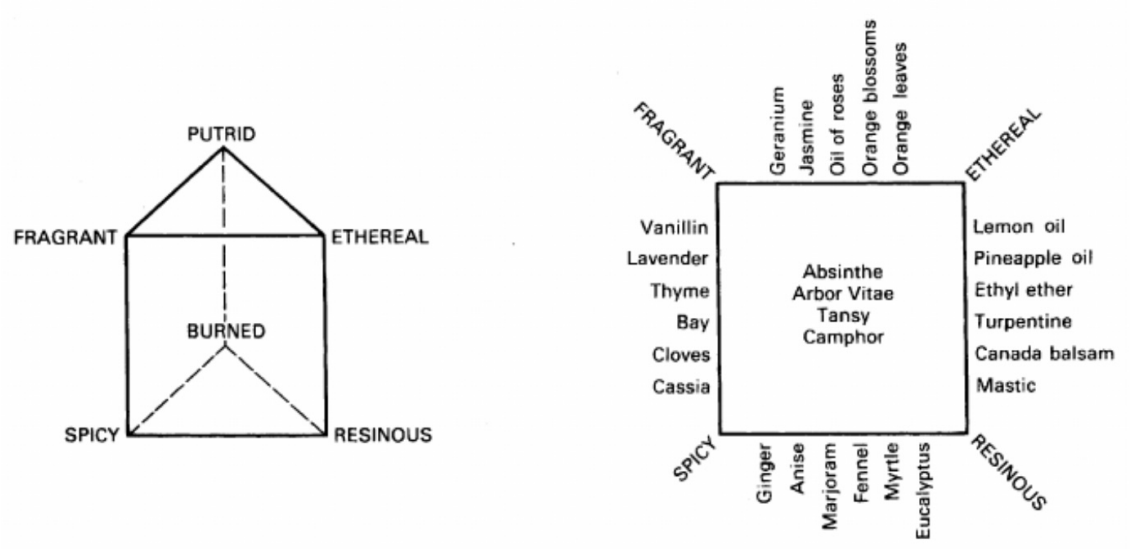


Figure 3: Henning's prism with primary odours (left) and other odours (right) (Mamlouk, 2002).

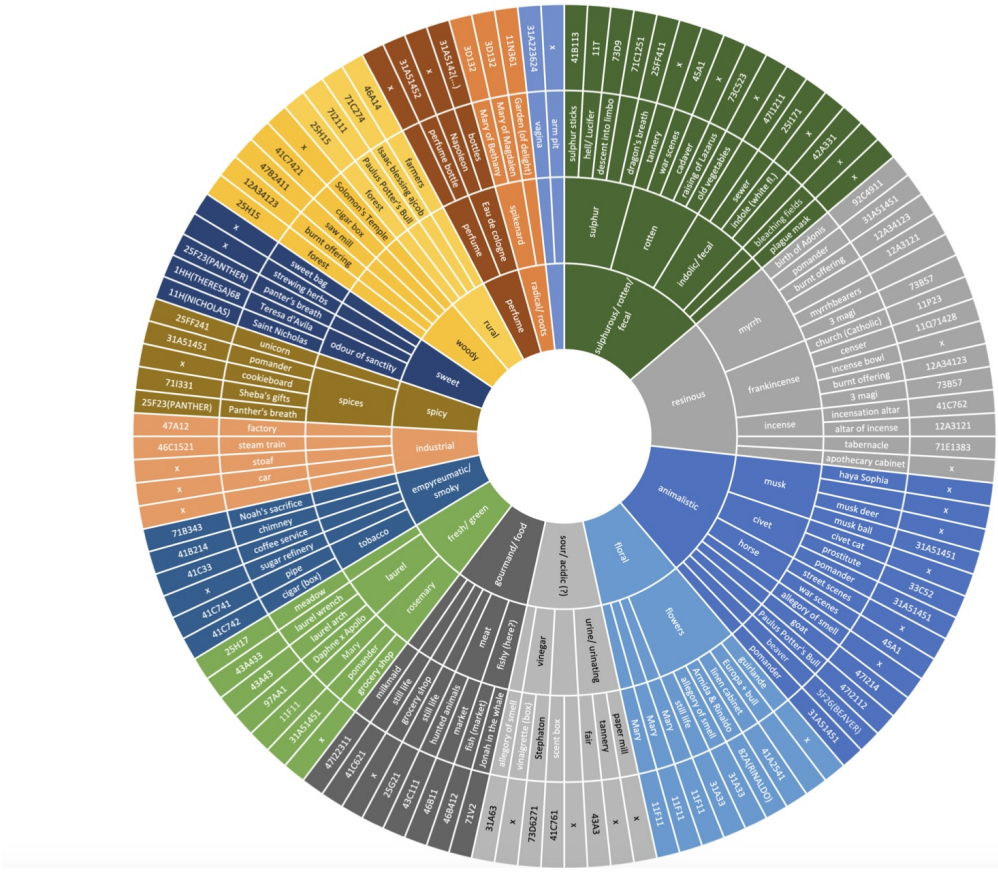


Figure 4: Odeuropa's historical odour wheel (Ehrich et al., 2022).

between chemical and sensory descriptions (Poivet et al., 2018), and recently, developments have been made in the creation of a 'Principal Odour Map' which helps link the two together for any smell (Lee et al., 2023). In a similar strain, Curelo (Cerulo, 2018) suggests an intertwining of "neural operations, corporeal experience, and the cultured environments" to allow a "compelling social science inquiry".

3 Methodology

3.1 Selection of case studies for olfactory preservation

Case studies were selected for their relevance to the project. The criteria for selection developed by the Odotheka project (Her, 2023) with the support of Odeuropa researchers, focusing on evaluating the availability, diversity, significance and ethical dimension of potential case studies (see Appendix A) informed the shortlisting process. The historical relevance of the case study and its connection to European history, leading to examples through which complex narratives could be articulated, were additional, project-specific considerations.

Among the wide variety of frankincense types, green hojari frankincense (from *Bosswellia sacra* trees) was selected for its olfactory properties, cultural significance and an existing body of work on its chemical characterisation, on which the present work builds. Additionally, its historical significance – frankincense has been valued since Antiquity and across many cultures for its sensory, medicinal and symbolic properties – makes it relevant to the period of interest for the Odeuropa project (1600-1920s).

The selected motor vehicle complied with the sample selection criteria for availability and significance, although it fell outside of the period of historical interest for the Odeuropa project. Following thoughtful consideration, and after a review of available alternative historic motor vehicles from before the 1920s had revealed these had an open cabin (rendering the collection of VOCs an impossible task) project members agreed that the significance of this case study still supported its selection.

3.2 Significance assessment

Historical information based on a variety of sources was collated in collaboration with other Odeuropa project work packages (mainly WP2, WP5 and WP7). For the smell of frankincense specifically, the assessment was informed by a relevant entry created for Odeuropa's *'Encyclopedia of Smell History and Heritage'* (Tullett, 2023b), an online reference tool that also draws on the databases of historical texts and images prepared by the Odeuropa project. In addition, the 'Smell Explorer', an application created for the Odeuropa project, served as a useful tool in order to extract historical smell descriptors for both smells (Sme, 2023a).
The cultural significance of the practice of frankincense-burning and of the smell of historic cars was assessed through a combination of methods: participant observation, semi-structured interviews and desk-based research of online resources. Through archival research of the historical context of both of these smells, relevant contemporary stakeholder groups were identified and approached in order to gain insights on the types of values attached to the relevant smell items. Further information about the cultural significance of the smells was recorded through stakeholder sensory evaluation panels (a semi-structured assessment of the perceptual characteristics of the odour in the presence of the material source in original form, and burning form in the case of frankincense). Additionally, the feedback collected through the relevant forms (Appendix C) was not only restricted to odour quality descriptors but extended to comments about memories and other associations held by participants.
For the smell of frankincense, a combination of qualitative and desk-based research was employed. Stakeholder groups approached included members of religious communities, people with a cultural affiliation to the use of frankincense and people who engage with frankincense on a professional capacity. The research included participant observation of liturgical services where incense is burned in a church. This observation took place in a Greek Orthodox church. Discussions were also held with clergy, as in the case of St. Paul's Cathedral in London, and/or members of the multi-denomination religious community, in some cases taking the form of interviews that addressed the significance of frankincense and its olfactory dimension. The aim of this value assessment was not to explore specifically the perceptions of these stakeholders towards the sample of frankincense selected for this study but to gain a broader overview of the types of values and associations attached by these people based on their personal, socio-cultural and religious experience. In addition, comments provided by seven participants of a sensory panel organised in Greece have informed this assessment. Data collected through desk-based research was also used to complement the information gathered. For non-religious stakeholders, a combination of archival research and qualitative methods (video interviews and written correspondence) were used.
A similar approach of combining different methods was followed also for the smell of the historic car leather interior. Stakeholder groups approached included car enthusiasts, owners of Rover cars or automotive marques that have belonged to the same company and other historic car owners. The research included 18 semi-structured interviews conducted at the British Motor Museum in Gaydon on the occasion of the BMC Leyland Show (9th July 2023) and the Gaydon Gathering (11th July 2023) outdoor events. During these interviews, the participants were asked to reflect on the values that they place on the smell of their cars and particularly the car interior as well as the importance of historic car smells in general. In addition, comments provided by 40 participants to sensory panel organised at the British Motor Museum for the assessment of the odour quality of the Queen Elizabeth's Rover P5B have also been considered in this assessment. Discussions

with the Materials Engineering team of the Jaguar Land Rover company as well as data collected through desk-based research provided additional context to the findings.
The research undertaken for this deliverable received ethics approval from the UCL BSEER Ethics Committee via a 'Low Risk' application form. All participants were provided with an information sheet and a consent form (provided in written form for in-person engagements). The studies and the resulting data storage and analysis were carried out in compliance with the UCL Code of Conduct for Research and the European Code of Conduct for Research Integrity and in accordance with the UCL's Data Protection Policy (regulated by the General Data Protection Regulation and the Data Protection Act). All data was anonymised, no personal data was collected and all participants were over the age of 18.

Vocabulary comparison

This study explores the idea that the linguistic representation of the sensory worlds of the past, specifically the historic ways in which frankincense was described and communicated, carry relevant knowledge for contemporary audiences. We were inspired by a model proposed by Ahnfelt et al. where, through a series of sensory workshops, the researchers sought 'to render the tacit explicit' by a process of sensory evaluation and analysis (Ahnfelt et al., 2020). While their work focused on the taste and other sensory properties of medicinal substances of the early modern period, our study adapted this process to a comparison of AI-sourced descriptions of the smell of frankincense from historical texts (see Odeuropa deliverables *D4.3 European Olfactory Knowledge Graph* and *D4.5 Context model for olfactory references in texts* for details of the data-extraction methodology and corpus) with contemporary descriptions of the smell of frankincense (focusing on Boswellia sacra) obtained through stakeholder interviews and sensory panels (for specific details about the methodology for obtaining this descriptions, please see above). For the historical descriptions, a selection was made of entries of texts from the period 1650-1970 which contained information about odour source, odour quality, book source and author, and whenever possible conditions in which the smell was perceived (e.g. burning resin). This is a preliminary exploration and by no means an exhaustive study, which would be a valuable follow-up to this work, since the Odeuropa project has developed extensive archives of this data.
Additionally, we are aware of the limitations of this research, such as the impossibility of establishing whether the historical descriptions refer to Boswellia sacra or other species of the resinous materials commonly called frankincense across the geographical spread of its use (and, even if in fact it is the same species the historical texts refer to, there is significant variation of its physical and sensory properties depending on climate, location, harvest method and other factors). Despite these limitations, this approach can potentially provide new access to knowledge about the past, help us consider historical fragrant materials more holistically and outline novel methods to build sensory bridges between material and intangible typologies of heritage.

3.3 Chemical and sensory instrumental analysis

The samples were obtained as follows:
Historic car interior: 10L of air of the vehicle interior was sampled on material emissions sorbent metal tubes (Markes International, UK) by means of GilAir Plus personal Air Sampler (Sensidyne, USA). The pumps were set with an air flow rate of 0.1 L/min. The accuracy of the flow rate was checked with a UNITY-xr flowmeter (Ellutia, UK).
Frankincense: 0.66g of hojari frankincense acquired in Oman (private collection of Barbara Huber) were placed on a lit charcoal disc (Excelsior, UK) and encased in a glass vessel with a PTFE seal. 0.5L of the headspace of the burning incense was collected on material emissions sorbent metal tubes (Markes International, UK) by means of GilAir Plus personal Air Sampler (Sensidyne, USA). The pumps were set with an air flow rate of 0.1 L/min. The accuracy of the flow rate was checked with a UNITY-xr flowmeter (Ellutia, UK).
The GC-MS and GC-O analysis were conducted at Olfasense GmBH in their laboratories in Kiel,

Germany. Analytical methods are detailed in Table 2.

Chromatographic analysis:	After the adsorption of VOCs, the adsorption tubes were inserted into the thermal desorption unit coupled to GC-MS. The instrumentation system consisted of a gas chromatograph (GC) (TRACE 1310, Thermo Fisher Scientific), a mass spectrometer (MS) (ISQ 7000, Thermo Fisher Scientific) and a thermal desorption unit (Unity2-xr Markes International, UK). After being removed from the tube by thermal desorption (280-330ºC), volatile compounds are captured in a cold trap at a low temperature (0 to 10℃) by thermoelectric cooling. Subsequently, the cold trap is heated to 300-350℃ according to a programmed and optimised temperature profile, to release all volatiles up to the inlet of the GC column through a transfer line for subsequent chromatographic separation. At the end of the GC column, once separated, the compounds reach the MS with different (retention) times (expressed in minutes), where they are fragmented and subsequently identified by the NIST 2017 spectra database based on the fragmentation patterns of each molecule.
Combined Sensory analysis (GC-Sniffing)	In the same analysis and simultaneous to the MS, the odour-active compounds are measured by the human nose of expert assessors. In GC-Sniffing configuration, the chromatographic column is connected to a flow divisor where part of the flow from the main column goes to the MS and the another is connected to a shorter capillary column ending as an olfactory port outside the instrument in a suitable position for the sniffers who perform a sensory evaluation of the VOCs separated by chromatography. As soon as the assessor detects an odour, attribute, appearance time and intensity values (from 1 to 5) are assigned. The classification of odour intensity of each compound is based on a predefined scale: 1: very low; 2: clearly distinguishable; 3: strong; 4: very strong; 5: nasal saturation (nose is removed from the odour port). In terms of odour character descriptors, Olfasense uses its own vocabulary based on continuous training of our sniffers. The smelling task is performed by 2 expert sniffers, at 23ºC and isolated from any distractions. Analysis by GC-sniffing is done in triplicate. During each analysis, only 2 sniffers participate: each sniffer carries out the GC-sniffing task for 15 minutes approx. before giving way to the other sniffer, to cover the 50 minutes of the whole chromatographic process (standard methodology). The process is repeated 2 more times (until complete the 3 replicates).

Quantification:	Registered signals as (chromatographic) peaks are quantified by comparing their size (area under the curve) with the obtained area of a known amount (ng) of a reference substance (Toluene-d8) which is adsorbed (by direct injection by using a syringe) in an additional clean tube. Peak produced by the Toluene-d8 is used as reference peak for quantification of all peaks obtained in the sample analysis, which represents an estimation of a more accuracy quantification based on calibration curves for each detected compound in the samples. This type of quantification based on Toluene-d8 is known as semiquantitative. For this project, the signals (mean) of 3 tubes containing Toluene-d8 were used as the reference peak for quantification.
Quality parameters of the method:	Two blank samples were run before starting the sequence of analysis. Signals produced by blanks are subtracted to the subsequent samples to discard potential quantification errors caused by trace compounds into the clean tubes. Detection limits depend on the chemical nature of the compound and the sampling and instrumental method used. As a general approach, our TD-GC-MS can detect substances 0.01 to 1 ng. The relative standard deviation (RSD) of the values obtained by this method is below 10% Chemical identifications are obtained by GC-Analyzer software which compares all detected fragment ions to allow the detection of very small differences either free from interferences or buried under large peaks. Identification is also checked (and in some cases confirmed) by comparing the detected peaks in replicates or similar samples at the same elution (retention) time or Retention Index (RI). In complex cases (low/saturated or overlapped signals), manual checking is performed and comparison with our own database is also used. The smelling task is performed by 2 expert sniffers, at 23ºC and isolated of any distractions. Analysis by GC-sniffing is done in triplicate.

Table 2: Molecular and sensory instrumental analysis. Gas chromatography-mass spectrometry and Gas chromatography-olfactormetry methods.

3.4 Sensory evaluation – human panels

Sensory analysis was conducted for the two selected historical smells through sensory evaluation panels. These sensory panels aimed to characterise odour quality, intensity and hedonic tone (pleasantness) and generate descriptive vocabulary associated to those smells. The feedback from the sensory panels was also helpful in order to consider how the historic context can impact the perception of the smells.
For the smell of frankincense (see section 4.1), the panels focused on the assessment of both the resin odour and the burning odour of a sample of Omani frankincense (*Boswellia Sacra* genus). For the historical car interior smell (see section 4.2) focus was placed on the assessment of the interior smell of the Rover P5B car that belonged to the late Queen Elizabeth II (1926-2022). The feedback from the sensory panels helped to produce two versions of odour quality descriptors for both smells: one by expert odour assessors (people with experience and training in standardised

odour assessment) and one by non-expert assessors (for the purpose of this study, people for whom the smell had value, e.g. stakeholders). This facilitated the development of a protocol for correlating non-expert vocabulary of historic smell quality with existing, expert-generated published descriptors from GC-O and aroma databases.
For the smell of frankincense, a sensory panel with expert assessors was conducted at Friedrich–Alexander University of Erlangen–Nuremberg (FAU).
Eight trained panelists (7 females, 1 male; age range: 22-29 years) performed an odour profile analysis of the frankincense resin and burned frankincense. The panelists were trained for at least 6 weeks prior to the sensory analysis to recognize and describe the smell of odorants. The results of weekly training sessions, which were part of the training process, were evaluated according to DIN EN ISO 8586:2023-09.
In the first round of the sensory test the panel selected attributes to describe the odour of the frankincense resin and the burned frankincense. In a second round, the panelists were asked to rate the total intensity of the samples and the intensity of the selected attributes on a scale from 0 (no perception) to 10 (very intense). The hedonic value was evaluated on a scale from 0 (dislike) via 5 (neutral) to 10 (like).
For the sensory analysis 2.5 g frankincense resin was mortared and presented to the panel in a 140 ml covered glass vessel. For the evaluation of the smell of burned frankincense, odourless charcoal (Three Kings, Bladel, Netherlands) was lighted and placed in a shell filled with sand. A piece of frankincense resin (1 g) was put on top of the charcoal as soon as the coal started to smoke. The sensory evaluation was conducted when the resin began to burn. The panelists performed the sensory analysis one at a time and the distance between the nose and the sample was approximately 30 cm.
One sensory panel (with 7 participants) with non-expert assessors who had strong cultural and religious ties to incense-burning traditions was conducted in Greece.
For the smell of the Rover P5B car, two sensory panels with expert assessors were conducted at the British Motor Museum (BMM) in Gaydon, and one at FAU.
Eight trained panelists (7 females, 1 male; age range: 24-29 years) performed an odour profile analysis of the odour of Gauze Pads that were placed on the back seat of the rover. Two gauze pads were presented to the panelists in a 140 ml covered glass vessel.
Nine trained panelists (6 females, 3 males; age range: 22-29 years) performed an odour profile analysis of an air sample, drawn from the drivers cabin of the rover onto a Tenax TA tube. The odorants on the Tenax TA tube were eluted with 1 ml diethyl ether. 70 µl of the eluate were transferred on a filter paper in a 140 ml glass vessel. After the solvent evaporated the vessel was closed and presented to the panel.
All panelists were trained at least 6 weeks prior to the odour profile analysis to practice recognizing and describing the smell of odorants. The training process included weekly training sessions which were evaluated according to DIN EN ISO 8586:2023-09.
The panel selected attributes to describe the odour of the samples in the first session of the sensory evaluation. In the second session the total intensity and intensity of the attributes were rated on a scale from 0 (no perception) to 10 (very intense). The hedonic value was rated on a scale from 0 (dislike) via 5 (neutral) to 10 (like).
Furthermore, sensory evaluation forms were also conducted with 10 individuals who were non-expert assessors, predominantly car enthusiasts and/or owners of historic cars or of cars displayed at two motoring events at the BMM. Additional sensory evaluation forms were collected from 24 individuals—also non-expert assessors—who assessed the smell of the boot of the Rover P5B car (without smelling the car interior). Appendix B describes the process followed for the sensory evaluation panels while Appendix C contains the evaluation form employed (‘Protocol for on-site sensory evaluation of the environment’).

3.5 Olfactory reconstruction

As detailed in the introduction, a reconstruction of the smell of the historic car interior was carried out as a means to validate the preservation framework for olfactory digitisation and its nose-on accessibility. There is no standard methodology for the reconstruction of historic smellscapes; in fact, this matter is currently the subject of many conversations in the field of olfactory heritage, olfactory museology, heritage science and perfumery (Leemans et al., 2022; Reynaud Chazot et al., 2023; Bembibre, 2022).
In this study, the main objective was to validate the potential of the digitised archive to serve as the basis of a perceptually accurate reconstruction of the smell. Starting from the molecular and sensory data, three approaches were designed:

Method 1 - based on compound contribution to odour
Compounds were semi-quantified according to their odour active value (OAV, abundance in sample expressed in L/m3) and a formula was developed to achieve a concentration of 8% of fragrance oil in alcohol, equivalent to Eau de Toilette.

Method 2 - based on a perfume structure
Compounds were classified according to their vapor pressure, considering:

- Those within 130-155 C were considered top notes
- Those within 150-180 C were considered middle notes
- Those with 180 C and above were considered base notes

The mixture was prepared following the structure of 50% base notes, 25% middle notes and 25% top notes (adapted from (Carles, 2006)), to achieve a 8% concentration of fragrance oil on alcohol (EdT).

Formula 3 - based on equal OAV
Stock solutions were prepared in ethanol at low (e.g.1%), medium (e.g.10%), and high (e.g.50%) v/v and each stock solution was selected after odour appraisal by the research team to achieve a similar (medium) OAV for all compounds.

3.6 Synthetic DNA archive

The best practices in olfactory digitisation involved the archiving of one of the case studies in this work in the form of synthetic DNA as part of a collaboration between the Odeuropa and OligoArchive projects (Fig. 5). The aims and relevance of the OligoArchive project are presented as follows:

> The “digital universe” of all known data worldwide is expected to grow to 250 Zettabytes by 2025. Unfortunately, all current storage media face fundamental limitations that threaten our ability to store, much less process, all this data. Hard Disk Drives (HDD) suffer from well-known scaling issues that have resulted in a meager 16% annual density improvement over the past decade compared to the 60% rate of data growth. Tape drives suffer from media obsolescence, as data stored in tape has to be continuously migrated to deal with technology upgrades. If we are to preserve even just a fraction of the world’s data, we are in desperate need of a radically new storage media with substantially better density and durability characteristics. In this proposal, we focus on one such media that has received limited attention recently -synthetic Deoxyribonucleic acid (DNA). Using DNA as a digital storage media has multiple advantages. First, DNA is an extremely dense storage medium. Second, DNA can last several centuries; HDD and tape have life times of five and thirty years. Third, technology used for storing data on DNA (synthesis) and retrieving data back from DNA

(sequencing) have eternal relevance; as long as there is life on earth, there will always be the need to synthesize and sequence DNA. Fourth, there is the potential to process the data stored in DNA using biomolecular mechanisms. Doing so is substantially faster and requires much less energy than traditional computing. Despite such benefits, DNA storage and DNA data processing are new areas of research. In this proposal, we outline a research agenda which will develop the fundamental technologies needed to build an intelligent DNA storage system. The resulting prototype system will support the full cycle of encoding data, synthesize it as DNA and read it back through sequencing. It will optimally store a variety of different types of data and enable near-data processing in the storage'(Cor, 2023).

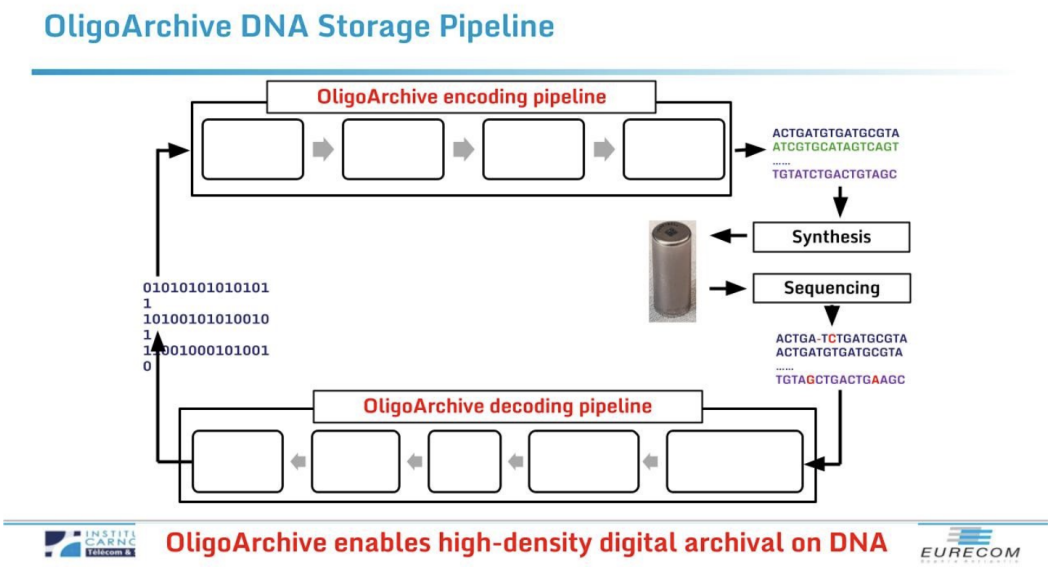


Figure 5: OligoArchive DNA Storage Pipeline. Credit: EURECOM

4 Results and Discussion

4.1 Frankincense

4.1.1 Historical significance

Frankincense, also known as Olibanum, is an aromatic gum resin derived from the trees of the Boswellia genus through incisions made on their trunk. The most famous of these trees is *Boswellia Sacra* that grows in Oman, Yemen and Somalia. Other species include *Boswellia serrata, frereana, papyrifera* and *dalzielii* that grow in a geographic region that includes mainly the Arabian peninsula (Oman, Yemen) and the Horn of Africa (Somalia, Ethiopia, Eritrea, and Sudan) but also parts of Central and West Africa and South Asia (India, Pakistan). Frankincense is known to have been used by people of ancient Egypt, Greece and Rome and was traded as far as China. In a Christian context, frankincense became famous from the biblical story of the Three Magi that offered myrrh and frankincense to the infant Jesus. There is evidence of the use of frankincense imported from the Arabian Peninsula or India already in medieval Europe (Baeten et al., 2014; Baum, 2018) .
In historical sources 'frankincense' and 'incense' are used interchangeably and on a practical level the incense burnt in both religious and medicinal contexts has been and very often still is a mixture of fragrant gums that include but are not restricted to frankincense (Tullett, 2023a).

Figure 6: Historical and cultural significance of frankincense. From top left, clockwise: A caretaker of frankincense trees at Wadi Dawkah natural park in Oman; Adoration of the Kings (Anon, 1534); Botafumeiro in use at Santiago de Compostela since 1971; David in the Temple (Pieter Lastman, 1618) and Jason and Medea (Thomas Willeboirts Bosschaert, 1647). Credits: Abdullah Geelah CC BY-SA 3.0; Fernando Pascullo CC BY-SA 4.0 and images in the public domain.

The burning process necessitates the employment of charcoal or another combustion source in order to help burn the blocks, or granules of resin. Today, over-exploitation and environmental degradation pose threats to the sustainable production of frankincense (Bongers et al., 2019; DeCarlo et al., 2020). In 2000, the 'Land of Frankincense' (originally termed 'Frankincense Trail') site in Oman, encompassing a natural and cultural landscape which includes the *Boswellia sacra* trees in Wadi Dowkah, was inscribed in UNESCO's World Heritage List as a recognition of the outstanding universal value of the frankincense trade across the ages (UNE, 2023).

The key practices in which frankincense has been used have revolved around burning and perhaps the most famous value attached to the use of frankincense is its significance in religious and spiritual activity. Within Christianity, frankincense and various mixtures of incense (that may or may not contain this particular resin) have been traditionally used for nearly two millennia and are still used today in liturgies and other religious activities (Harvey, 2006). The Book of Exodus provides a recipe for the preparation of holy incense which includes frankincense. Frankincense holds not only a practical use value but also a more direct religious significance. Adherents of the Catholic and Orthodox churches more specifically have retained feelings and associations towards the scent of burned frankincense that are more religious. The smoke and fumes have been seen to symbolise the prayers ascending to God. On the other hand, for the Protestant churches, the use of incense was mostly seen as a metaphor for prayer (Tullett, 2023a). Overall, frankincense has been burned in spaces such as churches, chapels, monasteries, cemeteries and various outdoor activities such as feasts and religious processions. The objects employed for burning frankincense have ranged from portable swinging thuribles, to stationery vessels and incense boats. In Europe, frankincense has been frequently used also in major monarchical and state ceremonies (such as coronations) and even in theatrical performances (Tullett, 2023a).
The smell of frankincense relates to cultural activities and traditions that represent a number of communities worldwide. People in Asian (e.g. China, India), North African, Middle Eastern and European nations have used frankincense for domestic and other activities: as a purifying and fumigating substance (covering unpleasant smells), as air or breath fresheners, as insect, pest and vermin repellent, in cooking and for warding off evil spirits. A range of products have been produced for cosmetics and in both traditional and contemporary perfumery but frankincense has also been applied traditionally for natural medicines and remedies, for personal hygiene and in aromatherapy. Frankincense's medical significance includes various qualities that are believed to boost memory and have anti-microbial, anti-metastatic, antibiotic and other healing properties (Van Roode, 2021; Burridge, ; Weston-Green et al., 2021; Khajehdehi et al., 2022). Overall frankincense is steeped in folklore, customs and cultural beliefs.
For the purposes of this research, a sample of Omani frankincense derived from *Boswellia Sacra* trees was examined. Research has indicated that frankincense's olfactory profile is determined by odorants such as alpha-pinene and Linalool that render frankincense its 'woody', 'resinous', 'turpentine', and 'pine-like' qualities as well as the 'fruity', 'citrus', 'aromatic', and 'sweet' notes respectively (Niebler and Buettner, 2015; Dravnieks et al., 1985). Common contemporary descriptors for frankincense include 'woody', 'earthy', 'resinous', 'aromatic', 'citrus', 'green', 'balsamic' and 'spicey' (Tullett, 2023a).

Stakeholders
In the Anglican Church incense is used at many services (including Festal Eucharists) and special services throughout the year. Objects commonly used are thuribles, handled by a thurifer at Eucharists, and braziers (cake tins inside a sand-filled brass bucket on an iron stand). Both the Catholic Church and Orthodox Christians (Eastern Orthodox Church) use incense in everyday religious activities for purifying and sanctifying both religious (churches, chapels) and other spaces. Objects commonly used to distribute incense are censers that are both swinging and stationary/standing.
The culture of frankincense burning and the associated tangible and intangible heritage elements have great universal value and there is scope for significant further research in terms of the relevant sensory and olfactory aspects. In addition to the 'Land of Frankincense' inscription in UNESCO's World Heritage List – which covers one of the most prominent areas from which frankincense is sourced – there are several other regions that could become the focus of systematic efforts to preserve the heritage values of frankincense burning traditions: Sudan, Ethiopia, Somalia, and Somaliland, just to name a few. Furthermore, numerous already inscribed World Heritage Sites have stakeholders, custodians and associated communities that practice incense burning. Among these are some examples of Orthodox monasteries (Mount Athos, Meteora) and churches ranging from the Balkans and Eastern Europe to Ethiopia (Lalibela); Catholic cathedrals and monasteries in Europe (e.g. Santiago De Compostela with the famous Botafumeiro, one of the largest censers

in the world), Central and South America. At the same time, UNESCO's 'Representative List of the Intangible Cultural Heritage of Humanity' contains several religious festivals, traditions and activities (e.g. Ethiopian Epiphany, Byzantine Chant) where the use of frankincense plays an active role.

In contemporary Oman, the frankincense-producing industry is a vital source of income for the communities that live in the areas where Boswellia trees grow. In fact, for local people until the 1960s frankincense was more valuable than oil. In addition to the industry that caters for the supply of frankincense resin to the worldwide market, a heritage tourism industry has also been created in areas such as the natural park of Wadi Dawkah in the Dhofar region which is part of the UNESCO inscription to the World Heritage List. An interview with Ahmed al-Awaid, supervisor of the Wadi Dawkah reserve and World Heritage Site, highlighted the important role that frankincense plays for Omani people. Frankincense is first of all, part of the daily life and culture of Omani people as it is widely used at home as an insect repellent and air freshener. The smell of frankincense is deemed as an essential part of the experience of the landscape of frankincense trees. Omani frankincense is steeped in folkloric traditions and particular older generations believe in its ability to ward off evil spirits and to keep people from harm when burned at home – although this quality is not supported by the Islamic religion. Frankincense overall has a heritage value as it connects Omani people with their history and the related century-old traditions. In order for the younger generations not to lose the awareness and connection to this past and to frankincense, the Wadi Dawkah reserve makes a significant investment on educational programmes with schools, but also on the preservation of the skills and knowledge involved in taking care and harvesting frankincense trees. Nevertheless, the sustainable production of frankincense and by extension this heritage is currently threatened by several human and environmental factors.

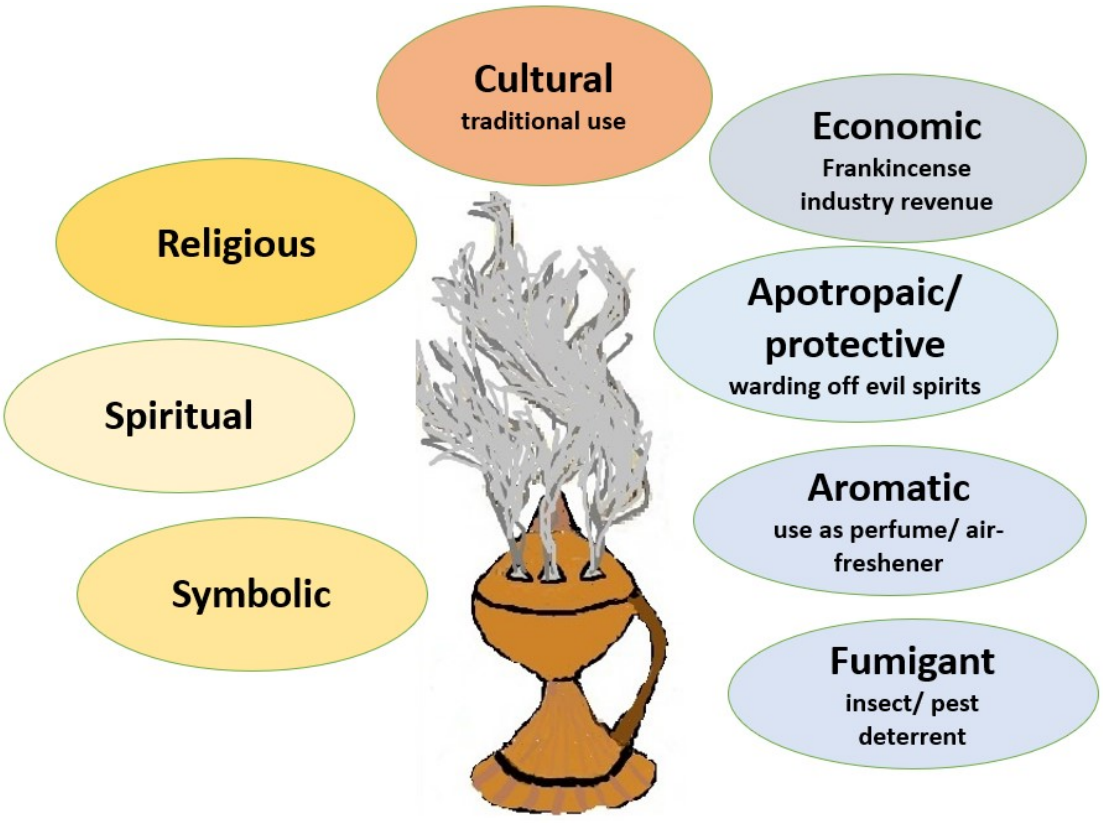


Figure 7: The values attached to the practice of burrning frankincense

Limitations
The burning of different types of incense, including frankincense from the *Boswellia* trees, is so geographically spread and encompasses so many different countries, cultures, religions and uses that a study like this could not possibly capture all stakeholders and aspects. To remain within the aims and objectives of the Odeuropa project we have inevitably placed an emphasis on the presence of frankincense-related traditions in the wider European region and we have examined both the cultural values of the use of this resin and some religious associations that relate to the three largest denominations (Catholic, Protestant and Orthodox churches).

Why is it significant to preserve both the resin and burning incense smell?
As seen from the assessment above, frankincense holds value both in its resin form and as part of the practice of burning it. Therefore, it was deemed essential that the preservation of the smell as a heritage scent comprised these two aspects of the odour. Extensive chemical and sensory analysis had been conducted on the resin form of Boswellia sacra. The original contribution of this work is to build on this body of work by discussing it in the cultural heritage landscape, and to develop additional documentation of the burning smell of incense as an expression of heritage for future generations.

4.1.2 Characterisation of the smell of frankincense

Frankincense resin:
This work draws from existing literature on the characterisation of the odour of the Hojari frankincense – previous analyses conducted by Andrea Büttner and her team at the FAU Department of Chemistry and Pharmacy, Chair of Aroma and Smell Research are especially informative, since the same sample of incense was used in the study led by J. Niebler (characterisation of the resin, (Niebler and Buettner, 2015)) and in the current study, which focused on the characterisation of the burning resin.
A total of 23 odorants were identified in the resin sample (Table 3).

In addition to the instrumental characterisation, a sensory panel with experts was conducted. Fig. 8. shows the odour profile of the frankincense resin. The sample was described on a scale out of 10 as citrus-like (average intensity: 6.1), ginger-like (4.5) pine needle-like (4.0), resin-like (3.9) and ethereal (3.8). The overall odour intensity was rated as 7.5. The hedonic rating showed that the sample was perceived as pleasant (average rating: 8.1 out of 10).

A sensory panel with non-experts was also conducted in Greece with assessors that have strong ties with the cultural and religious use of incense. In terms of the odour quality descriptors, most of the participants (4 out of 7) agreed that the smell was ‘conifer-like’ while 3 out of 7 described the smell with words that relate to herbs and hot herbal beverages (‘mountain tea’, ‘chamomile’, ‘thyme’) and ‘mild’ (Figure 9). It is worth noting here that ‘mountain tea’ refers to ‘Sideritis’ (ironwort), a very popular herbal tea in Greece and the Balkans. In terms of the intensity, the smell was considered ‘faint’ (average of 2.42 on a scale from 0-6). With regard to the hedonic tone, only one participant (out of 7) found the smell unpleasant. The average hedonic level was ‘1.5’ (between neutral and moderately pleasant).

The majority of the participants (5 out of 7) found the smell of frankincense resin familiar but only two of these associated it with a church activity and memory while another two mentioned that it reminded them of mountain tea (Sideritis). Overall, memories related to spending time in the countryside or nature were mentioned by 3 (out of 7) assessors.

Table 3
Odorant compounds and their FD range as identified in six *Boswellia sacra* samples.

Nr.	Substance	*Rt* DB5	*Rt* FFAP	FD range DB5	FD range FFAP	Median FD DB5	Median FD FFAP	Frequ.	Odor quality	Identification[d]
1	α-Pinene	939	1013	1024–4096	1024–4096	3072	1536	6	Rosiny, pine	MS, *Rt*, O, RC
2	β-Myrcene	993	1089	256–1024	128–1024	512	384	6	Geranium	MS, *Rt*, O, RC
3	p-Cymene	1028	1257	n.d.–128	n.d.–64	32	32	5	Solvent, fruity	MS, *Rt*, O, RC
4	Limonene[a]	1033	1185	n.d.–256	32–64	128	64	6	Citrus, soapy, fresh	MS, *Rt*, O, RC
5	1,8-Cineol[a]	1035	1190	n.d.–256	128–256	256	192	6	Eucalyptus	MS, *Rt*, O, RC
6	Carvone	1249	1713	64–256	n.d.–128	192	64	6	Mint/caraway, spicy	MS, *Rt*, O, RC
7	trans-Carveol	1238	1850	n.d.–32	n.d.–128	32	80	3	Mint, eucalyptus, green	MS, *Rt*, O, RC
8	Linalool	1103	1536	256–512	128–256	512	256	6	Flowery, fresh, balsamic	MS, *Rt*, O, RC
9	Thymoquinone	1255	2212	64–1024	32–256	256	96	6	Flatbread, black cumin	MS, *Rt*, O, RC
10	Verbenone[c]	1212	1682	n.d.–128	n.d.–128	48	48	6	Spicy, soup, bread	MS, *Rt*, O, RC
11	α-Copaene	1385	1472	32–512	32–256	64	96	6	Spicy, broth, woody	MS, *Rt*, O
12	Germacrene D	1490	1685	n.d.–512	32–512	128	128	6	Fruity, woody, cherry	MS, *Rt*, O
13	Serratol	2174	2684	n.d.–64	n.d.–32	64	32	3	Woody, rosiny, incense	MS, *Rt*, O, RC
14	p-Cresol	1083	2072	64–256	128–1024	192	384	6	Fecal, stable-like	MS, *Rt*, O, RC
15	o-Methylanisole	1012	1394	n.d.–64	n.d.–128	48	48	5	Mint, toothpaste, fresh	MS, *Rt*, O, RC
16	Sotolone[b]	1111	2200	n.d.	n.d.–256	–	128	5	Savory, spicy	*Rt*, O, RC
17	Ethyl 3-methylbutanoate	851	1061	n.d.–64	n.d.–128	32	32	5	Strawberry, creamy, fruity	MS, *Rt*, O, RC
18	Unident. sesquiterpenoid A	1685	2255	1024–16384	1024–16384	4096	2048	6	Broth, meat, spicy	–
19	Unident. sesquiterpenoid B	1707	2274	512–4096	512–4096	1024	1024	6	Coniferous, woody, peppery	–
20	Unknown	1120	1417	n.d.–64	n.d.–128	48	96	3	Herb-like, fresh, mint	–
21	Unknown	1151	1662	n.d.–32	32–256	32	64	6	Earthy, herb-like	–
22	Unknown	1365	2436	n.d.–32	n.d.–256	32	64	5	Green, geranium, herb	–
23	Unknown	–	2513	n.d.	512–2048	–	768	6	Incense, geranium	–

n.d. = not detected, i.e. FD < 32.
Stereochemistry of chiral compounds was not determined. Median FD: Samples below detection limit (<FD32) were not taken into account. FD Range: range of FD factor variation for the given column type. *Rt*: retention index for the given column type. frequ.: detection frequency in a set of six samples.
[a] Coelution of Limonene and Eucalyptol leads to overlap of odor impressions on DB5.
[b] Linalool covers odor impression on DB5.
[c] Potential coelution with Germacrene D on FFAP.
[d] Compounds were identified by: MS: mass spectrum, *Rt*: retention indices on DB5 and DB-FFAP columns, O: odor quality, RC: comparison of all data with reference compound.

Table 3: Gas chromatography-olfactometry results for Boswellia sacra resin (Niebler and Buettner, 2015).

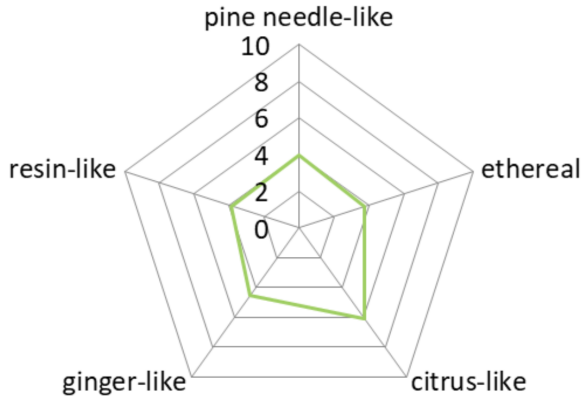


Figure 8: Odour profile of frankincense resin by expert panel. The intensity of each attribute was rated on a scale from 0 (no perception) to 10 (very intense). The sensory evaluation was performed by trained panelists (7 females, 1 male; age range: 22-29 years). The values are presented as the mean values.

Figure 9: Odour profile of frankincense resin by non-expert panel. The intensity of the whole sample was rated on a scale from 0 (no perception) to 6 (very intense). The sensory evaluation was performed by untrained panelists (7).

Burnt frankincense:

Figure 10: Characterisation of the odour of burning Boswellia sacra resin. From top left, clockwise: Frankincense burning in a metal censer; Hojari Boswellia Sacra resin; Experimental setup for sampling burning incense VOCs; GC-O setup for sensory analysis. Credits: MilosMuskinja, Formulatehealth, Luciano Vera.

Fig.11 shows the odour profile of burned frankincense. The attribute with the highest average intensity was citrus-like (5.9), followed by ginger-like (4.0) and smoky, burned (4.0), pine needle-like (3.9) and ethereal (2.8). The total intensity of the sample was rated as 7.1. The burned frankincense was described as pleasant according to the average hedonic rating of 6.8.
Nearly all of the participants (6 out of 7) of the non-expert assessors of the sensory panel conducted in Greece described the smell of burned frankincense as 'smokey' and more than half (4 out of 7) as 'ginger-like' (Figures 12). More than half (4 out of 7) also used words that describe the strength of the smell (they used the words 'intense', 'strong', 'heavy' and 'intoxicating'). In terms of the intensity, the vast majority (6 out of 7) indicated that the smell was strong. With regard to the hedonic tone, most assessors found the smell unpleasant (4 out of 7). The hedonic level average was '-2' (moderately unpleasant) on a scale from -4 to +4.
All participants found the smell of burned frankincense familiar. Nearly half of them (3 out of 7) associated the smell with incense burning in a domestic or church context and were able to recall a relevant memory. It is worth noting that the rest of the panelists associated the smell with ginger, pine, Aloysia citrodora and old women's perfume. Overall, memories related to spending time in the countryside or nature were mentioned by 3 (out of 7) assessors. Some examples of memories evoked by the smell of burned frankincense: *'Because I'm in my village, an image came to me as a*

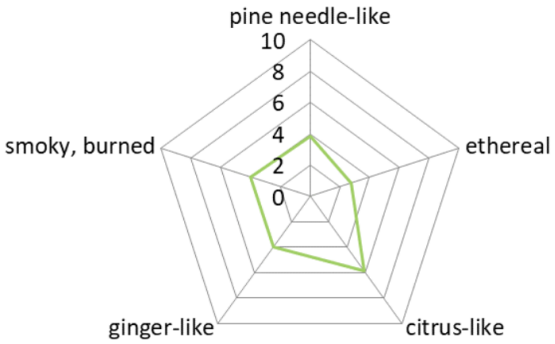


Figure 11: Odour profile of burning frankincense resin by expert panel. The intensity of each attribute was rated on a scale from 0 (no perception) to 10 (very intense). The sensory evaluation was performed by trained panelists (7 females, 1 male; age range: 22-29 years). The values are presented as the mean values.

Figure 12: Odour profile of burning frankincense resin by non-expert panel. The intensity of the whole sample was rated on a scale from 0 (no perception) to 6 (very intense). The sensory evaluation was performed by untrained panelists (7).

memory, of the priest conducting the anointing in the old stone house with the wall tapestries, the sofas with the textiles', 'Family moments. My mum or grandmother burning incense', 'It reminds me of monastery smells'.
Additional discussions with one of the panelists who strongly disliked the smell of burned frankincense revealed that memories and associations with church services were the cause for the negative feeling. Negative memories included having to attend long and boring church ser-

vices as a child where incense was used. The lack of a religious sentiment while being raised in a religious family and environment was apparently the main reason for these negative associations.

4.1.3 Smell vocabulary development

Odour source	Odour quality	Book/Panel	Author	Year	Conditions	Perceiver of odour
frankincense|all powders of|fran|kincense| other sweet spices	most grate-full	ee041534	Mayer, John, 1583-1664	1653.		in the nos-trils
spices|frankince-nse	best|most odorifer-ous|odorifer-ous	ee046817	Trapp, John, 1601-1669.	1657	when beaten|when cast into the fire	
frankincense	not sweet	ee030586	Ovid, 43 B.C.-17 or 18 A.D.	1658	unless it be melted by the Sun or fire	
with frankincense|st-orax|benjamin|p-itch|rozin|lignum - aloes|lignum rhodium|juni | per - wood|the berries|with rose - wa-ter|with|worm - wood|lavender| mar | jo-ram|peniroyal| costmary|with primroses|violet-s|rose - leafs|borage|bu-gloss|such|such cooling|cooling	cooling|cool-ing	ee03076	Kephale, Richard.	1665	in cold and moist weather|in hot and dry weather|in cold weather|in hot	
the frankin-cense|the spices	best	ee056216	Gell, Robert, 1595-1665.	1676	when they are broken in the Mor-tar	
the sweet frankincense myrrhe|aloes|of their own com-pounding|them	most holy|sweet| noisom	ee040473	Ager, Thomas.	1680	in the pres-ence of God	

on a chafing - dish of wood - coles|storax|frankincense|olibanum	gross|sweet	ee08853		1687		
of frankincense	perceptible| intolerable	ge2353	Thomas Clarkson	1808		Sir George Yonge|to the nostrils
palaces of marble|jasper| groves of cinnamon|frankincense	odoriferous| odoriferous	bl31191	Gibbon, Edward	1825		The vulgar
embers of frankincense|frankincense	fragrant|fragrant|perfumed|perfumed|agreeable	bl505737	HEAD, George	1849		under the nostrils of the dignitary|he
organs|of king solomon's and saffron|calamus| cinnamon|frankincense|myrrh| from the spicy shore of araby	olfactory|olfactory|more acceptable	bl502856	STARK, Archibald G.	1850		our|to the keen senses of a man really hungry
incense|frankincense|some of the luxurious people|the holy|holy	Holy|Holy	ge4296	G. W. Septimus Piesse	1857		
frankincense|frankincense	putrid|so powerful	bl601000	METEYARD, Eliza.	1862	during Divine service	the prior and brethren of the Whitefriars
frankincense	disagreeable	bl60465	RAMAGE, Craufurd Tait.	1868	in a hot climate	
bowls of crocus|myrrh| frankincense	fragrant	bl9419	SHARPE, Samuel	1870		a hundred and twenty boys
camphor|frankincense	agreeable	wi5111		1877	in getting a light	
frankincense|resinous substances	agreeable	wi888	n/a	1879	when burned	
frankincense|frankincense	agreeable agreeable| delightful	bl55433	WILLIAMS, Samuel Wells.	1879	when heated or rubbed	all devotees
frankincense	aromatic	bl09664	GIBBS, Robert	1891		when pressed

a garland of flowers|with frankincense|camphor	fragrant| fragrant	bl0222	TALMAGE, Thomas de Witt.	1891		the Oriental
myrrh|frankincense|of rotting vegetation	dank	wi15622	Edgar Rice Burroughs	1921		in the nostrils of the great Tarmangani
of fruit and bread and flowers|frankincense	heavenly	wi29453	Signe Toksvig	1948		”The ”” infernals|they”
frankincense	Arabian	wi24427	Visvanatha Kanakasabhai Pillai	1979		the merchants

Table 4: Historical descriptions of frankincense.

A comparison between the historical descriptors of the smell of frankincense (see Table 4 for a selection) reveals some recurrent ways in which this odour has been characterised through the centuries, the associations of which still reverberate today.

‘Fragrant’, ‘perfumed’ and ‘agreeable’ were consistently used to talk about the smell of the resin and, especially, the burning incense. Linnaeus and others have described the smell as aromatic, the effect of which on the body has been described as arousing (uplifting), in a spiritual as well as literal sense (Tullett, 2023b). In the contemporary evaluation, ‘ginger’ was found to produce a similar, uplifting effect, although devoid of religious connotations.

In addition to its arousing properties, in historical texts the odour of frankincense is often presented as an analogy with prayer, and the smoke ascending to heaven, building a bridge between this world and the divinity. The word ‘heavenly’ is used in the historic references to allude to the spiritual dimension the smell can evoke. In the contemporary evaluation, ‘ethereal’ appeared as one of the descriptors, which directly evokes an unwordly characteristic.

‘Odoriferous’ is another historical descriptor for the odour of frankincense which can be linked with a particular meaning, in this case the Catholic ‘Odour of sanctity’ (the term evolved however, towards a less religious meaning). This implied ‘sweetness’ is both sensory and moral. In contemporary assessments, though, the smell of frankincense seems to have lost much of its sweet connotation.

Finally, it is worth noting that the material interaction with the resin (rubbed, pressed, beaten, broken, burned) is an important part of the historical descriptions. This is echoed in the non-expert panel experiences, where the burning frankincense elicited meaningful personal memories which the cold resin had not evoked. However, expert assessors considered the resin and the burning sample similar in sensory terms, with just one descriptor –‘smoky’– telling them apart.

4.1.4 Synthetic DNA Archival

OligoArchive recently published promising project results (Yan et al., 2023). Odeuropa content was one of the pilot case studies for synthetic DNA archival. It consisted in the encoding, synthesis, sequencing and decoding of an archive of 2.13MB containing Odeuropa’s research on frankincense as a smell with cultural significance, as well as a framework for heritage smell preservation . This archive was successfully decoded, packaged in a storage shell and will be distributed as a proof of concept to Odeuropa researchers later in 2023.

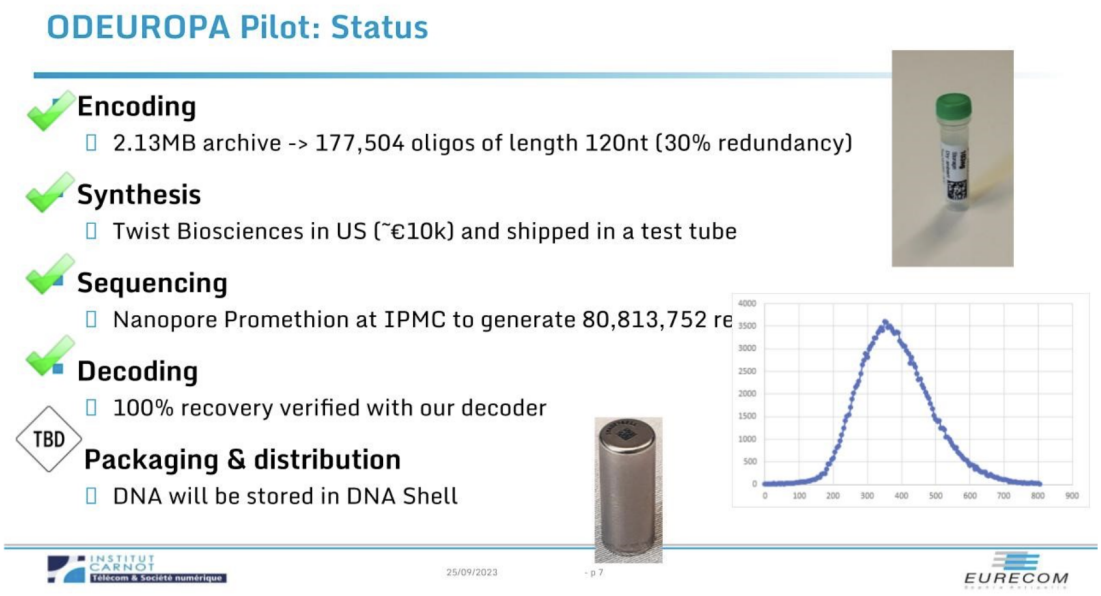


Figure 13: Status of Odeuropa pilot by OligoArchive. Credit: EURECOM

4.2 Rover P5B, HM Queen Elizabeth II

4.2.1 Historical significance

Leather making – referring to the processing of animal skins and hides for the production of clothing, footwear, furniture and other items – is an ancient art that has been practiced since prehistoric times and leather has been widely used and is prevalent within most cultures (Thomson, 2007b). Throughout the ages the treatment methods have been refined in order to better preserve leather with tanning becoming a widely used process that employs chemicals such as tannins, minerals and oils. Tanning has actually been described as 'man's first manufacturing process' (Thomson, 2007b, p. 1). From the 19th century the employment of machinery was introduced in many leather making operations and, at the same time, artificial or faux leather has been increasingly used as a substitute for real animal leather (Thomson, 2007a). Researchers of ancient and historical leather have underlined how important it is not only to examine the material (physical, chemical) properties of leather but also 'how leather, like all materials, is viewed with the dimensions of culture and beliefs which surround it' (Harris, 2014). Hence studies have began to focus more on the aesthetic or visual qualities of leather materials and the full sensory engagement of people with leather through their bodily senses such as touch, sight, sound, taste and smell (Harris, 2014).
Today leather is present in numerous objects and elements of heritage value in historical buildings and museum collections around the world. Conservation techniques and principles for the treatment of leather in historic objects and collections have evolved significantly since the 1970s (Thomson, 2007b). Leather is also an element that for centuries has had a strong presence in items such as horse-driven and rail coaches as well as automobiles and its conservation in such a context has had to consider specific parameters (Thomson, 2007b, pp. 302-306). Inevitably leather is a very important element in historic or classic cars and its smell, along with other elements, is considered to be a very important component of the so-called 'old car smell' (Tullett, 2023b).

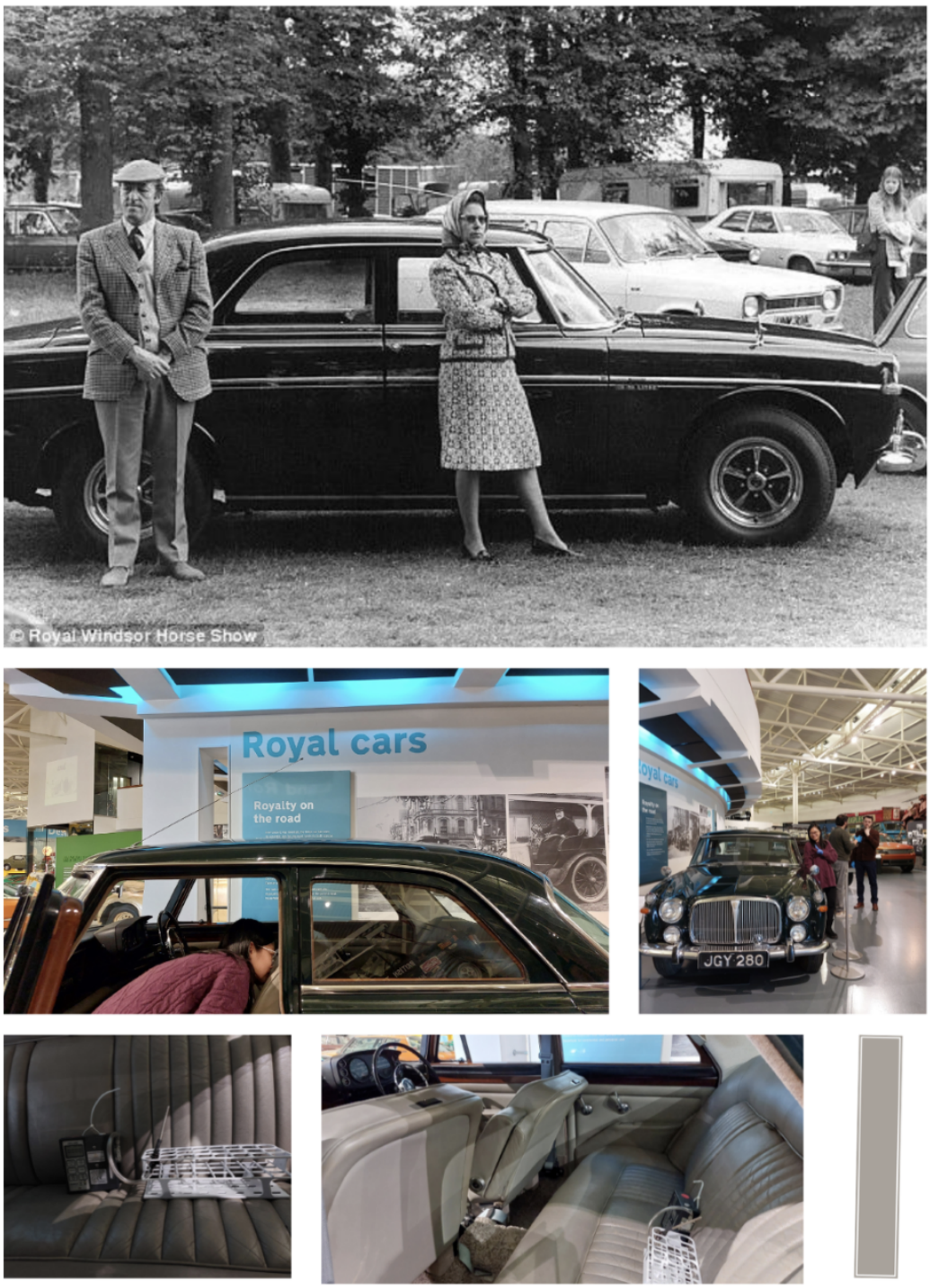


Figure 14: Historic and cultural significance of the historical car interior smell. From top left, clockwise: Queen Elizabeth II in front of the Land Rover P5B; the vehicle in the British Motor Museum in Gaydon, UK; VOC sampling of the car environment by Odeuropa team; researcher Yiwei Chen assessing the odour of the vehicle interior. Credits: Royal Windsor Horse show, George Alexopoulos, Cecilia Bembibre.

Alongside the history of cars, car cultures have been the subject of extensive research (Wollen and Kerr, 2002; Volti, 2006; Miller, 2001). However, viewing cars as cultural heritage has only recently gained a particular dynamic and entered the wider heritage discourse. Cars have been examined as museum objects (Jeremiah, 1995) and conservators have pondered on the best ways to preserve their material qualities (Newey and Meehan, 1999). It is today thought that automobiles are recognised to so deeply being implicated in our lives that 'they must be factored into our heritage language, procedures, developments, systems, and processes' (Stiefel and Clark, 2019). Cars are not only seen to shape our cognitive environments but also 'the ways we think about ourselves' (Mazurek, 2019). It has been underlined that the preservation of automotive-related cultural heritage addresses far more than the vehicles themselves – it is just as much about identities of self and communities and it relates to both material and intangible cultural aspects (Stiefel and Clark, 2019). Furthermore, the layers of meaning that cars hold for their owners extend to very intangible aspects rendering car use a form of living heritage (Wilkins, 2016). In 2011, under the initiative of the Fédération Internationale des Véhicules Anciens (FIVA), historical vehicles acquired for the first time a guide for the preservation, conservation, and restoration of automobiles: the Charter of Turin (FIV, 2023).
From a sensory point of view, for classic car owners, a large heritage community, the sensory appeal and the smells of their car constitute a key attraction – often termed 'old car smell' (Tullett, 2023b). Indeed, the smell of a classic car can be a mixture of leather, wood, old cigars, fuel, exhaust smoke and many other potential sources emitted from the carpets, seats, headlining or other elements of the interior (Tullett, 2023b). The aforementioned developments point towards the value of cars and their olfactory elements as a form of heritage and underpin the purpose of this case study selection: the Rover P5B car owned by the late Queen Elizabeth II and displayed at the British Motor Museum of Gaydon.

4.2.2 Characterisation of the smell of Rover, P5B HM Queen Elizabeth II

Over 700 volatile organic compounds were found in the sample via GC-MS analysis and 93 odours were detected during GC-O analysis, of which 33 were corresponded to VOCs. Table 5 summarises the findings.

r.t.	Descriptors	INT	Compound	CAS No.
16.9	pungent white-glue	3	Acetic acid	64-19-7
17.17	fishy amine unpleasant sharp	2	Triethylamine	121-44-8
17.43	cocoa malt	3	3-Methylbutanal	590-86-3
20.83	plastic rancid sour cheesy	3	Propanoic acid	79-09-4
22.88	acrylate sweet plastic pungent new-plastic	3	1-Hexen-3-one	1629-60-3
23.25	flower fermented	3	Tetrachloroethylene	127-18-4
23.82	fatty juicy grass	3	Hexanal	66-25-1
24.5	cheesy	3	Butanoic acid	107-92-6
25	nuts spicy almond	3	Pyrazine, methyl-	109-08-0
26	cocoa dusty	3	1-Pentanol, 3-methyl-	589-35-5
26.57	cheese fecal	4	Isopentanoic acid	503-74-2
26.8	nutty fishy minty	3	2,6-Lutidine	108-48-5
27.72	solvent	3	candidate: Cyclohexane, propyl-	1678-92-8
27.82	sweet earl-grey tea dry-herbs dusty	3	Heptanal	111-71-7
28.08	pepper pine	4	alpha-Pinene	80-56-8
28.17	cheese fatty	3	Dimethyl Sulfoxide	67-68-5

30.97	fishy onion decayed	3	Dimethyl trisulfide	3658-80-8
31.58	perfume pungent lemon	4	D-Limonene	5989-27-5
33	fresh ether floral resin	3		
34.93	orange fatty burnt	3	Nonanal	124-19-6
36.28	pungent urine unpleasant	3	Dodecane	112-40-3
36.42	phenolic leather fecal	4	Phenol, 3-methyl-	108-39-4
37.88	liquorice phenolic herbal	2	(+)-2-Bornanone	464-49-3
39.12	paper fatty grass	2	trans-2-Nonenal	431026
39.2	woody smoky burnt	3	Benzene, 2-methoxy-4-methyl-1-(1-methylethyl)-	1076-56-8
40	clove carrot smoky	3	Phenol, 2,4-dimethyl-	105-67-9
40.43	garlic onion galic sewer	2	Benzothiazole	95-16-9
41.07	pungent floral herbal	3	Cyclohexaneethanol, beta-methyl-	5442-00-2
42.07	coconut	3	Undecanoic acid, ethyl ester	627-90-7
43.25	perfumed wood	3	4-tert-Butylcyclohexyl acetate	32210-23-4
43.83	sweet cherry dusty	3	Dodecanal	112-54-9
45.32	beet musty soil	3	Geosmin	19700-21-1

Table 5: Gas chromatography-olfactometry results for historical vehicle interior. R.t. column indicates retention time (in minutes), Descriptors column refers to the odour quality detected during analysis, Intensity column reports odour strength on a 0-6 scale (see Appendix C for detail), Compound column indicates identified or highly likely candidate as source of odour, CAS indicates Chemical Abstract Service registry number.

The odour profile of the odour of the gauze pads which were placed in the back seat of the rover is shown in Fig.15. The odour of the sample material was perceived as fecal (average intensity rating: 5.8), leather-like (5.3) and horse stable-like (4.1). The total intensity of the gauze pads was rated as 6.4 and the odour was perceived as rather unpleasant (average rating: 4.0).

In Fig. 16, the average intensity ratings of the attributes which were used to describe the air sample of the cabin of the rover are depicted. The odour of the sample was perceived as leather-like (average intensity rating: 3.4) and car tire-like (2.9). The total intensity was on average rated as 4.2 and the odour was rated as slightly unpleasant (4.6).

British Motor Museum – sensory panels with expert assessors
Two sensory panels with expert assessors and museum staff were conducted on 07/03/2023 and 14/09/2023 at the British Motor Museum. These panels came up with 31 odour quality descriptors for the interior of the Rover P5B car. The most frequent of these descriptors was ‘leathery’, including the descriptor ‘old leather’. In terms of intensity, the expert assessors indicated that the smell of the Rover P5B car was a ‘strong odour’ (average 3.88 on a scale from 0-6). The hedonic level was between ‘mildly’ and ‘moderately pleasant’ (average 1.5 on a scale from -4 to +4).
The majority of the participants to these sensory panels found the smell of the car familiar citing leather furniture, leather objects, the interior of old cars, garages, a military museum, Halfords (large retailer of motoring and cycling products) or DIY shops and the interior of cupboards. Most participants also mentioned specific memories that were evoked by sniffing the Rover P5B’s interior. These included childhood or general memories of specific situations and spaces. The following are some examples: *‘. . . leather sandals and bags hanging in souvenir shops’, ‘Military museum as a child (tanks)!’, ‘My grandfather’s old 15/50 Wolseley of c.1967 and an old Rover P6 I once owned’, ‘Being in a car factory, but more earthy. Being in an old car, but more pungent!’, ‘My father’s big truck, when I was a child’, ‘Spring cleaning at home; cupboards open, old woollens’,*

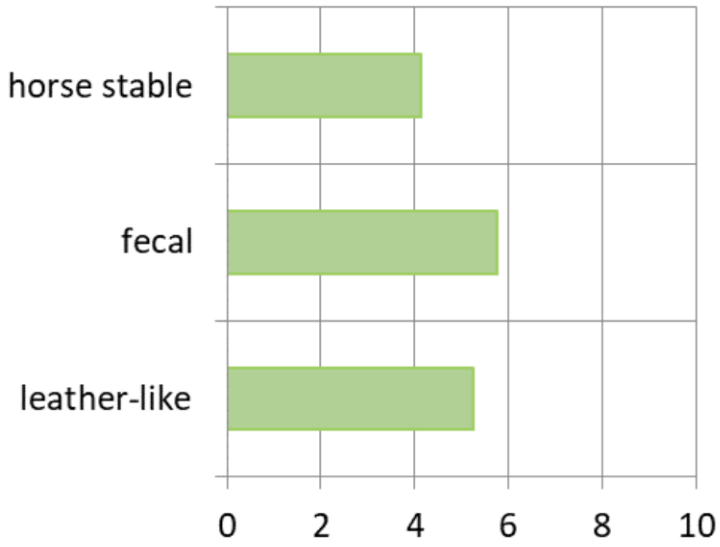


Figure 15: Graphic representation of the sensory analysis of an air sample collected in the cabin of the Queens car on a Tenax TA Tube. The intensity of each attribute was rated on a scale from 0 (no perception) to 10 (very intense). The sensory was performed by a trained panel (7 females, 1 male; age range: 24-29 years). The values are presented as the mean values.

'Having tea and biscuits with my nan (they were smokers)'.

British Motor Museum – sensory panels with non-expert assessors

Two sensory panels with non-expert assessors were also conducted at the British Motor Museum on the 9th and 11th of July 2023. The participants were recruited in the museum galleries and consisted mainly of car enthusiasts, owners of Rover and other classic cars that had come to the museum to participate or observe the motoring events taking place on those two days. This section focuses only on the results gained from the second sensory panel as the 10 participants had the possibility to more directly engage with the smell of the leather seats and car interior (cabin). The participants offered 21 odour quality descriptors for the interior of the Queen's Rover P5B car. The most frequent of these descriptors were 'leather' (including 'old leather' and 'cherry leather') and 'musty'. In terms of intensity, the expert assessors indicated that the smell of the Rover P5B car was a 'strong odour' (average 4.45 on a scale from 0-6). The hedonic level was 'mildly pleasant' (average 0.7 on a scale from -4 to +4).

Nearly all participants (8 out of 10) found the smell of the Rover P5B car familiar and half of them (4 out of 8) associated the smell with old cars: *'Smelt like old car my grandparents had', 'Old Jaguar classic car', 'A mustier version of what I recall of my old cars'.* These participants were also able to recall a relevant memory which in most cases related to specific car trips or the vehicles of a familiar person. Some examples of memories evoked by the smell of the car are: *'Being in the car with my older relatives going to the seaside', 'Visiting stately homes or castles', 'Driving the Rolls Royce of an acquaintance', 'My grandad', 'A former owner, but also of other older vehicles I've owned'.*

Figure 17 summarise all the descriptors given to the Queen's Rover P5B car provided by the expert and non-expert assessors.

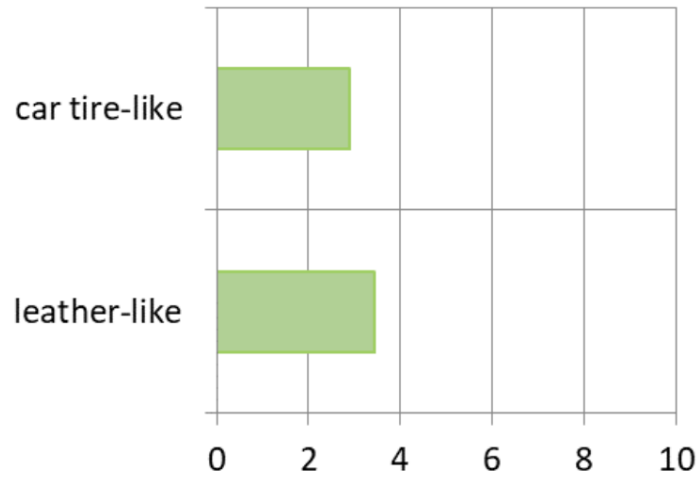


Figure 16: Graphic representation of the sensory analysis of an air sample collected in the cabin of the Queens car on a Tenax TA Tube. The intensity of each attribute was rated on a scale from 0 (no perception) to 10 (very intense). The sensory evaluation was performed by a trained panel (6 females, 3 males; age range: 22-29 years). The values are presented as the mean values.

Figure 17: Odour profile of historic car interior Rover P5B smell assessed in situ by expert and non-expert panel (20 panellists).

A total of 18 semi-structured interviews were conducted at the parking area of the British Motor Museum in Gaydon on the occasion the BMC Leyland Show (9th July) and the Gaydon Gathering (11th July 2023). All participants had brought their own cars to these events and these included a

variety that ranged from a Jaguar XJ 2005 to an old Rover P4 75 made in 1949. The majority of the cars (12 out of 18) belonging to the interviewees had leather seats. Most of the interviewees (8 out of 10) mentioned that they only use these particular cars for shows and special occasions with two people emphasising that the cars serve as their 'toys'. Considering that most of the cars of the participants dated before 1980 the number of people who mentioned that they had not made any changes to the interior or the seats was quite high (6 out of 18).
The majority of the interviewees stated that the smell of their car was important to them and this included both the owners of cars with leather seats and the ones who had vinyl seats. One interviewee in particular praised the smell of leather for giving a sense of being in a 'gentlemen's club'. The smell of both leather and vinyl was underlined as the most important or one of the dominant elements of the car interior smell. Almost all participants (16 out of 18) expressed their dislike for air fresheners and car fragrances and even the ones who admitted to occasionally using some cleaning products specified how careful they are not to spoil the smell of the car interior: *'. . . you need to maintain the leather so I buy the restorations or cleaning stuff that's recommended by the Jaguar so you keep that smell there, you know'*. Some of the car owners, even the former smokers, particularly expressed their dislike towards smoking inside the car as it spoils the original smell. 'Leather' was by far the most frequent descriptor used by the interviewees to describe the smell of their car followed by 'vinyl' showing that the material of the car seats was the dominant olfactory element.

Descriptor	**Frequency**
leather	11
vinyl	5
old	3
petrol	3
age	2
musty	2
wood	2
unique	2
leather tanning	1
burning oil	1
oil	1
carpet	1
cloth headlining	1
dad's car	1
dust	1
engine fuse	1
frostiness	1
fumes	1
fusty	1
grubby	1
hair	1
home	1
horse	1
old British car	1
plastic	1
upholstery	1

Table 6: The most frequent odour descriptors given by interviewees at BMM (18 participants).

The vast majority of the interviewees mentioned that the smell of their car evoked certain memories and in most cases these memories seem to add value to the use of the car and its overall

significance. Examples include: *'my dad's first car was a Ford consul. . . Back in the 50s that would have been. Yes, I remember that sort of. . . that same sort of aroma, fragrance, call it what you will, back then as a kid', 'my father's cars before me. He had the larger [Austin] Princess cars and they were built at the same factory, had the same interior smell as this one', 'Hitching up the caravan and going away. So, holidays and that sort of thing', 'that old car smell goes back in, you know, goes back to when I was a child', 'reminds me of going on holiday every summer with the roof rack and the suitcases on the roof".*
Most of the participants also acknowledged that the smell of their car triggers certain feelings and emotions. The examples given for these sometimes overlapped with the mnemonic qualities: *'Just the feeling of comfort', 'Yeah, you can smell it and it's like nostalgia and old age and past times', 'it smells like dad's car', 'It reminds me of my childhood', 'you feel like you are in your 20s again', 'The car overall it makes you feel more serene and the smell is just part of that, it's the whole experience'.*
Overall, most of the interviewees (11 out of 18) seemed reluctant towards the concept of olfactory heritage and its importance. Quite interestingly, although the majority of the interviewees were not familiar with the idea of smell as a form of heritage to be preserved for future generations and admitted that they had not thought about car smells in such a way, the results provide many comments and answers that highlighted a clear attachment of personal value to the smell of their cars but also to the smell of 'old cars'. Some relevant quotes: *'It is because you can tell part of the history of the car, whether it's been looked after, if it's been cherished or whether it's just been used as a dumping ground', 'That's part of the attraction of the old car'.*

4.2.3 Smell reconstruction

Odorants were selected with the following criteria:

- OAV of 1 or higher (quantity in the sample was above known OTV)
- Compound was below quantification or detection limit but was detected with an intensity of $>$4 during olfactory analysis
- Compound did not present sensory properties similar to another selected compound
- Compound was deemed safe to use at low concentration (e.g. not carcinogenic)

Through this selection process, 8 compounds were identified, as follows:

Compound	CAS	Olfactory description (Published)	OAV
Hexanal	66-25-1	green apple, sweaty,fresh, fruity, grass, green, oil, sharp, aldehyde, fatty, apple; + leafy, vegetative, clean, woody (at 2%); + sweaty (at 1% in dipropylene glycol.), waxy, rancid, acorn, green, grassy	2.19
Butanoic acid	107-92-6	butter, cheese, rancid, sour, sweat, sharp, dairy, fruity, acidic, caprylic, penetrating and obnoxious, fatty acid, musty/rancid cheese, butyric, body odour, fatty, cheesy	1.5
Heptanal	111-71-7	fatty, citrus, dry, fish, fat, green, nut, fresh, aldehydic, fatty, herbal, wine-lee, ozone, cognac, oily, powerful, rancid, very strong, harsh, pungent, herbaceous, fruity, strong fruity, penetrating fruity, waxy, soapy, orange peel, marrow, greasy, little cold store	2.28

alpha-Pinene	80-56-8	cedarwood, pine, resin, sharp, turpentine, fresh, camphor, sweet, pine, earthy, woody, herbal, terpenic, cooling, dry, resinous-piney, warm-woody, fresh-pine, coniferous	0.05
↓D-Limonene	5989-27-5	citrus, mint, orange, fresh, sweet, pleasant lemon-like	0
Nonanal	124-19-6	orange, citrus, fat, green, paint, pungent, waxy, aldehydic, rose, fresh, orris, orange peel, fatty, peely, lemon peel, cucumber, rose-orange, orange, soapy, sweet, rancid, diffusive fatty floral waxy odor	3.63
Phenol, 3-methyl-	108-39-4	dry tarry, fecal, leather, medicine, phenol, sweet tarry, coal tar	6.64
Benzothiazole	95-16-9	sulfury, rubbery, vegetable cooked, nutty, coffee, meat, gasoline, leather, medicine, nut, rubber, similar to that of quinoline, unpleasant, roasted, car wheels, spicy	2.9

Table 7: Odorants present in sample with OAV of one or higher.

To visualise the sensory profile from the instrumental analysis, a wordcloud was developed including all odour descriptors of intensity 2 and above, where each descriptor was multiplied for intensity to reflect odour contribution to sample in word frequency (Fig.18).

Figure 18: Odour profile of historic car interior Rover P5B smell reflecting GC-O analysis.

Three approaches were followed to test different methodologies for the odour reconstruction which

would validate the analytical and sensory data as an effective component of the smell digitisation. The first formula was developed on the basis of the identified compounds (Table 7) contribution to odour. Compounds were semi-quantified according to their OAV (abundance in sample expressed in L/m3) and a formula was developed to achieve a concentration of 8% of fragrance oil in alcohol, equivalent to Eau de Toilette. From the preliminary selection, Benzothiazole was replaced with IBQ (CAS 65442-31-1) due to their similar sensory properties. Based on abundance in the sample and intensity registered during GC-O analysis, the initial formula was developed. A proportional volume of the selected odorants was mixed in an ethanol solution. This approach was not successful, with the result not being representative of the original sample as assessed by a panel of four trained analysts with direct experience of the historic car environment: it was deemed too 'cheesy' not 'dusty' enough.
The second formula was based on a perfume structure. Compounds were classified according to their vapor pressure (see methodology for details) and a mixture prepared in an ethanol solution. From the preliminary selection, Benzothiazole was replaced with IBQ (CAS 65442-31-1) due to their similar sensory properties. This approach was not successful, with the result not being representative of the original sample as assessed by a panel of four trained analysts with direct experience of the historic car environment, since the 'leathery´and 'burnt´ aspect overpowered the overall composition.
The third formula was based on an equal OAV solution for each of the compound. Stock solutions were prepared in ethanol at low (e.g. 1%), medium (e.g. 10%), and high (e.g. 50%) v/v and each stock solution was selected after odour appraisal by the research team to achieve a similar medium intensity OAV for all compounds. From the preliminary selection, Benzothiazole was replaced with IBQ (CAS 65442-31-1) due to their similar sensory properties. An equivalent amount of each was mixed in an ethanol solution to an EdT strength and assessed for similarity to the historic car interior. This approach was considered successful, therefore a fragrance refinement process was carried out to improve the accuracy of the reconstruction.
The main odour descriptors from panel assessment (leather-like, stable-like and fecal) were used as a guide towards achieving sensory accuracy in the developed scent. However, this description was based on the gauze which was directly in the contact of the leather seat. The overall sample had the previous descriptors, plus car tyre-like. To bring this additional tyre, oil and petrol-like dimension to the reconstruction, mineral oil (CAS 842-47-5) was added.
Additionally, acetylpyrazine (CAS 2047-25-2) was also added after the primary odour evaluation of the reconstructed smell reflected the absence of the descriptor 'dusty, nutty' from the original evaluations of the sample. Although this compound was not found during analysis, methyl pirazine (CAS 109-08-0), with very similar olfactory descriptors, was identified at 25min in the analysis timeline. Finally, butanoic acid (CAS 107-92-6) , originally used in a 1% concentration, was reduced to 0.1% to contribute the cheesy note without overpowering the overall composition.
The resulting composition was considered to have sufficiently similar olfactory quality to the original sample to evoke the overall experience of the Rover P5B historic car interior, validating the preservation framework and establishing this approach as best practice in olfactory digitisation of historic smells.

5 Conclusion

This work has comprehensively tested and expanded a framework to document and preserve odours of cultural significance using two different case studies.

The development of vocabularies to record the perceptual characteristics of the odours, as well as their molecular aspects, was tested using expert, non-expert and historic vocabularies. While some aspects of the smell description were common to all stakeholders, others, especially those more connected with the olfactory experience in context (e.g. burning incense in church, sniffing frankincense trees in their natural habitat, perceiving the interior of a beloved classic car as part of

an inter-generational activity) were unique and closely linked to personal and affective meanings, revealing the value of establishing cultural significance as an essential step for the archiving and digitisation of olfactory heritage.

In terms of documentation, the proposed methodologies were deemed effective for olfactory preservation and digitisation, both through the exploration of novel archival technologies (e.g. using synthetic DNA) and through the expansion of an existing preservation model to include stakeholder identification and engagement, systematic molecular and sensory analysis, as well as odour reconstruction approaches to validate the data collected.

A ODOTHEKA's criteria for case study selection

Significance is related to a variety of aspects:
Historical significance represents the historical context of the case study item, as evident from archival resources. This includes information about the conservation and restoration treatments the object may have been subjected in the past.
Cultural significance is critical to the acceptance of the researched smells to the public of today. Some smells are important to specific layers of a population, but may be insignificant for others. Importance could be reflected negatively or positively.
Scientific significance reflects the ability of the ODOTHEKA team to chemically investigate the case study object and reproduce its smell. It is important to choose case studies where there is a prior understanding so that reproduction can be possible.
Ethical considerations around object selection are crucial to consider in relation to the specific social, religious or other aspects of the object's significance. This defines what could be considered acceptable, according to the museum's policies, university research ethics, or general curatorial practice.

B Sensory panels – the process

Number of participants: 6-8
Recruitment criteria: Gender balance in the overall sample, ability to smell and confirmed lack of sensitivity or health issues related to smelling. Individuals were invited to sensory panels that correspond to different stakeholder groups. Each stakeholder group shared commonalities such as experience in smelling (or lack of experience), cultural and/or religious background etc.
Venue: Depended on the smell addressed (frankincense - leather interior of P5B). Either a neutral setting (e.g. lab) for standardised panels, and a culturally-relevant setting for non-expert.
Collection of feedback: During the sensory evaluation panels all participants were asked to complete the 'Protocol for on-site sensory evaluation of environment' (see Appendix C). Individual discussions were held after the completion of the forms.
Step 1: Before smelling the sample participants were asked, through the protocol form, to record their state of mind and feelings. Before the panel, participants were be asked to self-report their sense of smell performance. On the day, they were be asked to report any temporary conditions that might affect smelling ability.
Step 2: Participants were asked to smell the sample following a pre-discussed technique.
Step 3: After and during the smelling session, participants assessed their views on the intensity and hedonic tone (a response scale was provided) and smell quality of the presented smell (a list of descriptors was provided, these descriptors were validated by previous expert analysis). Additional comments were collected about other impressions experienced by the participants focusing on the familiarity of the smell and whether it evoked a memory.
Step 4: Group discussion (with all participants) for validating main associations.

C Protocol for on-site sensory evaluation of the environment

(a) How would you describe your state of mind/feelings before commencing the smell session?
Begin the smelling session.
(I) Intensity
Using the scale below for reference, please rate your first impression of the smell intensity.

Score	Perceived intensity
0	No odour
1	Very faint odour
2	Faint odour
3	Distinct odour
4	Strong odour
5	Very strong odour
6	Extremely strong

(II) Hedonic tone
Using the scale below for reference, please rate your first impression of the smell hedonic tone.

Score	Perceived hedonic tone
+4	Very pleasant
+3	Pleasant
+2	Moderately pleasant
+1	Mildly pleasant
0	Neutral odour/ no odour
-1	Mildly unpleasant
-2	Moderately unpleasant
-3	Unpleasant
-4	Very unpleasant

(III) Smell quality
In your own words, and using the list (below) as a reference if needed, please describe the scent.
(IV) Other impressions
(b) Was the scent familiar? If so, can you recall where you smelled it previously?
(c) If the smell evoked a memory, please briefly describe it below.
(d) How would you describe your state of mind/ feelings immediately after smelling the car?

D Use of incense in religious communities in the UK

In the Anglican Church incense is used at many services (including Festal Eucharists) and special services throughout the year. Objects commonly used are thuribles, handled by a thurifer, at Eucharists and braziers (cake tins inside a sand-filled brass bucket on an iron stand).
Both the Catholic Church and Orthodox Christians (Eastern Orthodox Church) are using incense in everyday religious activities for purifying and sanctifying both religious (churches, chapels) and other spaces. Objects commonly used to distribute incense are censers that are both swinging and stationary/standing.
Many other communities in the UK burn incense regularly for religious or cultural reasons. For example, incense burning inside the home is a common practice in Asian (e.g. China, India), North African and Middle Eastern nations. Incense may be used as a traditional perfume or air freshener as part of religious rituals or to repel mosquitoes. As opposed to incense sticks, the use of incense that is resin-based (e.g. frankincense, oud) necessitates using charcoal or another combustion source in order to help burn the blocks, or granules of resin.

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References

(2023). Cordis (2023). oligoarchive - intelligent dna storage for archival. https://cordis.europa.eu/project/id/863320. Accessed: 2023-10-30.

(2023). Fiva (2023). charter of turin. https://fiva.org/download/charter-of-turin-english-version/. Accessed: 2023-10-30.

(2023). Flavornet. flavornet home page. http://www.flavornet.org/index.html. Accessed: 2023-10-30.

(2023). Heritage research hub (2023). odotheka project. https://www.heritageresearch-hub.eu/project/odotheka/. Accessed: 2023-10-30.

(2023a). Odeuropa. a nose first classification system of iconographies, allegories and artefacts, odeuropa. https://vocab.odeuropa.eu/historical-scent/en/. Accessed: 2023-10-30.

(2023b). Odeuropa. dutch historical smell vocabulary (dhsv) - smell words. https://vocab.odeuropa.eu/dhsv-sw/en/. Accessed: 2023-10-30.

(2023c). Odeuropa (no date). dravnieks' atlas of odors descriptors - descriptors, odeuropa. https://vocab.odeuropa.eu/dravnieks/en/. Accessed: 2023-10-30.

(2023d). Odeuropa. zwaardemaker smell system, odeuropa. https://vocab.odeuropa.eu/zwaardemaker/en/. Accessed: 2023-10-30.

(2023a). Smell explorer (2023). the odeuropa smell explorer: Explore europe's olfactory heriage. https://explorer.odeuropa.eu/. Accessed: 2023-10-30.

(2023b). Smellspedia. https://www.smellspedia.com/. Accessed: 2023-10-30.

(2023). Unesco (2023). land of frankincense. https://whc.unesco.org/en/list/1010/. Accessed: 2023-10-30.

Ahnfelt, N.-O., Fors, H., and Wendin, K. (2020). Historical continuity or different sensory worlds? what we can learn about the sensory characteristics of early modern pharmaceuticals by taking them to a trained sensory panel. *Berichte zur Wissenschaftsgeschichte*, 43(3):412–429.

Baeten, J., Deforce, K., Challe, S., De Vos, D., and Degryse, P. (2014). Holy smoke in medieval funerary rites: chemical fingerprints of frankincense in southern belgian incense burners. *PLoS One*, 9(11):e113142.

Bartoshuk, L. M. (2012). History of taste research. *Handbook of Perception Volume 6A*, 1.

Baum, J. M. (2018). *Reformation of the senses: the paradox of religious belief and practice in Germany*. University of Illinois Press.

Bembibre, C. (2022). *Parfum Royal. A heritage perfume. In: The Smells and Senses of Antiquity in the Modern Imagination*. IMAGINES – Classical Receptions in the Visual and Performing Arts. Bloomsbury Academic.

Bembibre, C. and Strlič, M. (2017). Smell of heritage: a framework for the identification, analysis and archival of historic odours. *Heritage Science*, 5(1):1–11.

Bembibre Jacobo, C., Barratt, S., Vera, L., and Strlic, M. (2017). Smelling the past: a case study for identification, analysis and archival of historic pot-pourri as a heritage smell. Paris: International Council of Museums.

Bongers, F., Groenendijk, P., Bekele, T., Birhane, E., Damtew, A., Decuyper, M., Eshete, A., Gezahgne, A., Girma, A., Khamis, M. A., et al. (2019). Frankincense in peril. *Nature Sustainability*, 2(7):602–610.

Burridge, C. Holy smoke! incense as an ingredient in early medieval medical recipes.

Carles, J. (2006). A method of creation in perfumery. *Fafai Journal*, 8(3):43.

Castro, J. B., Gould, T. J., Pellegrino, R., Liang, Z., Coleman, L. A., Patel, F., Wallace, D. S., Bhatnagar, T., Mainland, J. D., and Gerkin, R. C. (2022). Pyrfume: A Window to the World's Olfactory Data. *bioRxiv*. Publisher: Cold Spring Harbor Laboratory _eprint: https://www.biorxiv.org/content/early/2022/09/12/2022.09.08.507170.full.pdf.

Cerulo, K. A. (2018). Scents and sensibility: Olfaction, sense-making, and meaning attribution. *American Sociological Review*, 83(2):361–389.

DeCarlo, A., Ali, S., and Ceroni, M. (2020). Ecological and economic sustainability of non-timber forest products in post-conflict recovery: A case study of the frankincense (boswellia spp.) resin harvesting in somaliland (somalia). *Sustainability*, 12(9):3578.

Dravnieks, A. et al. (1985). Atlas of odor character profiles. *(No Title)*.

Dravnieks, A., Masurat, T., and Lamm, R. A. (1984). Hedonics of odors and odor descriptors. *Journal of the Air Pollution Control Association*, 34(7):752–755.

Ehrich, S. C., Verbeek, C., Zinnen, M., Marx, L., Bembibre, C., and Leemans, I. (2022). Nose-first. towards an olfactory gaze for digital art history. In *2021 Workshops and Tutorials-Language Data and Knowledge, LDK 2021*, pages 1–17. CEUR-WS. org.

Fullman, B. (1963). Stereochemical theory of olfaction. *Nature*, 199(4896):912–912.

Gasior, R. and Wojtycza, K. (2016). Sense of smell and volatile aroma compounds and their role in the evaluation of the quality of products of animal origin–a review. *Annals of Animal Science*, 16(1):3–31.

Harris, S. (2014). Introduction. leather in archaeology: between material properties, materiality and technological choices. Sidestone Press.

Harvey, S. A. (2006). *Scenting salvation: Ancient Christianity and the olfactory imagination*, volume 42. Univ of California Press.

Hoffmann, B. (2013). Scent in science and culture. *History of the Human Sciences*, 26(5):31–47.

Jeremiah, D. (1995). The motor car from road to museum. *International Journal of Heritage Studies*, 1(3):171–179.

Khajehdehi, M., Khalaj-Kondori, M., and Baradaran, B. (2022). Molecular evidences on anti-inflammatory, anticancer, and memory-boosting effects of frankincense. *Phytotherapy Research*, 36(3):1194–1215.

Lee, B. K., Mayhew, E. J., Sanchez-Lengeling, B., Wei, J. N., Qian, W. W., Little, K. A., Andres, M., Nguyen, B. B., Moloy, T., Yasonik, J., et al. (2023). A principal odor map unifies diverse tasks in olfactory perception. *Science*, 381(6661):999–1006.

Leemans, I., Tullett, W., Bembibre, C., and Marx, L. (2022). Whiffstory: Using multidisciplinary methods to represent the olfactory past. *The American Historical Review*, 127(2):849–879.

Majid, A. (2021). Human olfaction at the intersection of language, culture, and biology. *Trends in Cognitive Sciences*, 25(2):111–123.

Majid, A. and Burenhult, N. (2014). Odors are expressible in language, as long as you speak the right language. *Cognition*, 130(2):266–270.

Mamlouk, A. M. (2002). Quantifying olfactory perception. *Master of Science Thesis, University of Lubeck, Germany*.

Mazurek, M. (2019). Car (acter) s in cinematic culture. In *The Routledge Companion to Automobile Heritage, Culture, and Preservation*, pages 255–267. Routledge.

Menini, S., Paccosi, T., Tekiroglu, S. S., and Tonelli, S. (2022). Building a multilingual taxonomy of olfactory terms with timestamps. In *Proceedings of the Thirteenth Language Resources and Evaluation Conference*, pages 4030–4039. European Language Resources Association.

Miller, D. (2001). *Car Cultures*. Routledge.

Newey, H. and Meehan, P. (1999). The conservation of an 1895 panhard et levassor and a 1922 prototype austin seven motorcar: New approaches in the preservation of vehicles. *The Conservator*, 23(1):11–21.

Niebler, J. and Buettner, A. (2015). Identification of odorants in frankincense (boswellia sacra flueck.) by aroma extract dilution analysis and two-dimensional gas chromatography–mass spectrometry/olfactometry. *Phytochemistry*, 109:66–75.

Poivet, E., Tahirova, N., Peterlin, Z., Xu, L., Zou, D.-J., Acree, T., and Firestein, S. (2018). Functional odor classification through a medicinal chemistry approach. *Science advances*, 4(2):eaao6086.

Reynaud Chazot, I., Camus, A., Borloz, S.-V., David, O., Wicky, E., and Fontaine, T. (2023). PROJET NOMEN La classification des compositions odorantes à visée historique. working paper or preprint.

Saini, K. and Ramanathan, V. (2022). Predicting odor from molecular structure: a multi-label classification approach. *Scientific reports*, 12(1):13863.

Stiefel, B. L. and Clark, J. (2019). Heritage driven: Conclusion. In *The Routledge Companion to Automobile Heritage, Culture, and Preservation*, pages 368–374. Routledge.

Thomson, R. (2007a). The manufacture of leather. *M. Kite & R. Thomson (eds), Conservation of leather and related materials.*

Thomson, R. (2007b). The nature and properties of leather. *M. Kite & R. Thomson (eds), Conservation of leather and related materials.*

Tullett, W. (2023a). 'frankincense'. odeuropa encyclopaedia of smell history and heritage entry.

Tullett, W. (2023b). *Smell and the Past: Noses, Archives, Narratives*. Bloomsbury Academic.

Van Roode, S. (2021). *Silver and Frankincense: Scent and Personal Adornment in the Arab World.* Blikvelduitgevers Publishers, NL.

Volti, R. (2006). *Cars and culture: The life story of a technology*. JHU Press.

Weston-Green, K., Clunas, H., and Jimenez Naranjo, C. (2021). A review of the potential use of pinene and linalool as terpene-based medicines for brain health: discovering novel therapeutics in the flavours and fragrances of cannabis. *Frontiers in Psychiatry*, 12:583211.

Wilkins, L. C. (2016). Officially ridin'swangas: Slab as tangible and intangible cultural heritage in houston, texas. In *The Routledge Companion to Intangible Cultural Heritage*, pages 205–215. Routledge.

Wise, P. M., Olsson, M. J., and Cain, W. S. (2000). Quantification of odor quality. *Chemical senses*, 25(4):429–443.

Wollen, P. and Kerr, J. (2002). *Autopia: cars and culture*. Reaktion Books.

Yan, Y., Pinnamaneni, N., Chalapati, S., Crosbie, C., and Appuswamy, R. (2023). Scaling logical density of dna storage with enzymatically-ligated composite motifs. *bioRxiv*, pages 2023–02.

Zwaardemaker, H. (1927). The sense of smell. *Acta Oto-Laryngologica*, 11(1):3–15.