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Characterizing Office Smellscape Perception through Participatory Approaches and Natural Language Processing (NLP) Techniques

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ABSTRACT

Understanding how individuals experience and perceive the indoor olfactory environment, or smellscape, is essential for achieving indoor air quality (IAQ) that is positively perceived by occupants. Improving the indoor smellscape requires effective methods to assess it, particularly in terms of perceptual dimensions that capture subjective experiences in occupied buildings. This study aims to identify key descriptors of office smellscape perception and establish future research directions towards the development of a measurement model able to evaluate olfactory perception. To achieve this, a set of 118 English-language descriptors, originally developed for assessing other sensory domains, was tested for its applicability to indoor smellscapes using an expert-based participatory approach, resulting in the selection of 37 attributes. An online survey was then conducted with 200 English-speaking participants, ensuring a gender-balanced sample. Participants completed the questionnaire while in their offices, describing their emotional responses to the perceived olfactory environment. This led to the identification of an additional 190 attributes. Natural Language Processing (NLP) techniques were employed to cluster the combined set of 227 attributes (37 expert-validated and 190 participant-derived), resulting in 80 distinct descriptors that capture people's emotional and sensory responses to office olfactory environments. The most frequently used attributes included "familiar" (50%), "clean" (20%), "stale" (20%), "fresh" (15%), "musty" (13%), "warm" (13%), "sterile" (12%), and "artificial" (11%). Offering a comprehensive understanding of our affective responses to indoor smellscapes, this study lays the groundwork for a structured model of smellscape perception. This model will provide assessment scales based on key perceptual dimensions (e.g., for post-occupancy evaluations) and indices to guide the design phase.

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INTRODUCTION

Indoor air quality (IAQ) has significant impacts on office occupants' productivity, well-being and health (Torriani et al. 2024; Tham 2016) The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines Acceptable IAQ the “Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 % or more) of the people exposed do not express dissatisfaction” (ASHRAE 2022). From these definitions, it is evident that IAQ assessment involves both objective (i.e., concentration of contaminants) and subjective (i.e., satisfaction in reference to perceived air quality – PAQ) criteria.

However, most IAQ studies have focused primarily on assessing contaminant concentrations, often overlooking the crucial role of sensory perceptions in shaping PAQ comfort, particularly olfaction (Torriani et al. 2024b). In the available studies that examined sensory perception, the focus is odors that negatively impact human experience, with little attention given to those that can positively influence PAQ (Torriani et al. 2024c).

Recently, the concept of smellscape has attracted the attention of the scientific community, challenging the traditional approach of odour control and advocating for an olfactory experience that can enhance well-being, productivity, and health (Spence 2020; Xiao et al. 2021). The term “smellscape” was introduced in 1985 by Porteous as the smell environment perceived and understood by a person in a place (Porteous 1985). Distinguishing between "smell" (i.e., a sensation detected by inhaling airborne molecules of a substance) and "odour" (i.e., the combined substances in the air causing olfactory sensations), the former emphasizes the human experience as a perceptual construct, making it a user-centred approach within the built environment community.

Despite growing interest, the key dimensions underlying human perceptual responses to the indoor olfactory environment are still not fully understood (Torriani et al. 2024c). One effective method to identify these dimensions, used in previous studies (Axelsson 2010; Torresin et al. 2020), is dimensionality reduction techniques such as Principal Component Analysis, starting from a comprehensive set of descriptors. Identifying the appropriate descriptors is crucial, as dimensionality reduction methods can only reveal key dimensions based on the attributes provided (Torresin et al. 2020). Thus, the goal of this study is to identify a comprehensive list of descriptors for the affective response to indoor smellscapes and to establish future research directions towards the development of a comprehensive measurement system.

METHODS

The descriptors of affective responses to indoor smellscapes were derived from both researchers and laypersons using different methodologies, specifically: (i) expert-based validation of existing descriptors related to indoor soundscapes and outdoor smellscapes, and (ii) questionnaires administered to proficient English speakers. This combined approach was crucial to overcome the limitations inherent in each method. Relying solely on the first approach could result in descriptors that reflect researchers’ interpretations and conceptual frameworks, rather than terms commonly recognized and used by the general public to evaluate olfactory perceptions (Dubois 2000). On the other hand, the second approach may be limited by individuals' ability to articulate specific concepts through language (Payne and Guastavino 2018). Subsequently, semantically similar descriptors were grouped together and the complete list of descriptors of human response to the olfactory environment was provided.

Figure 1 illustrates the flow diagram of the adopted methodology. The following sections provide a detailed description of each process.

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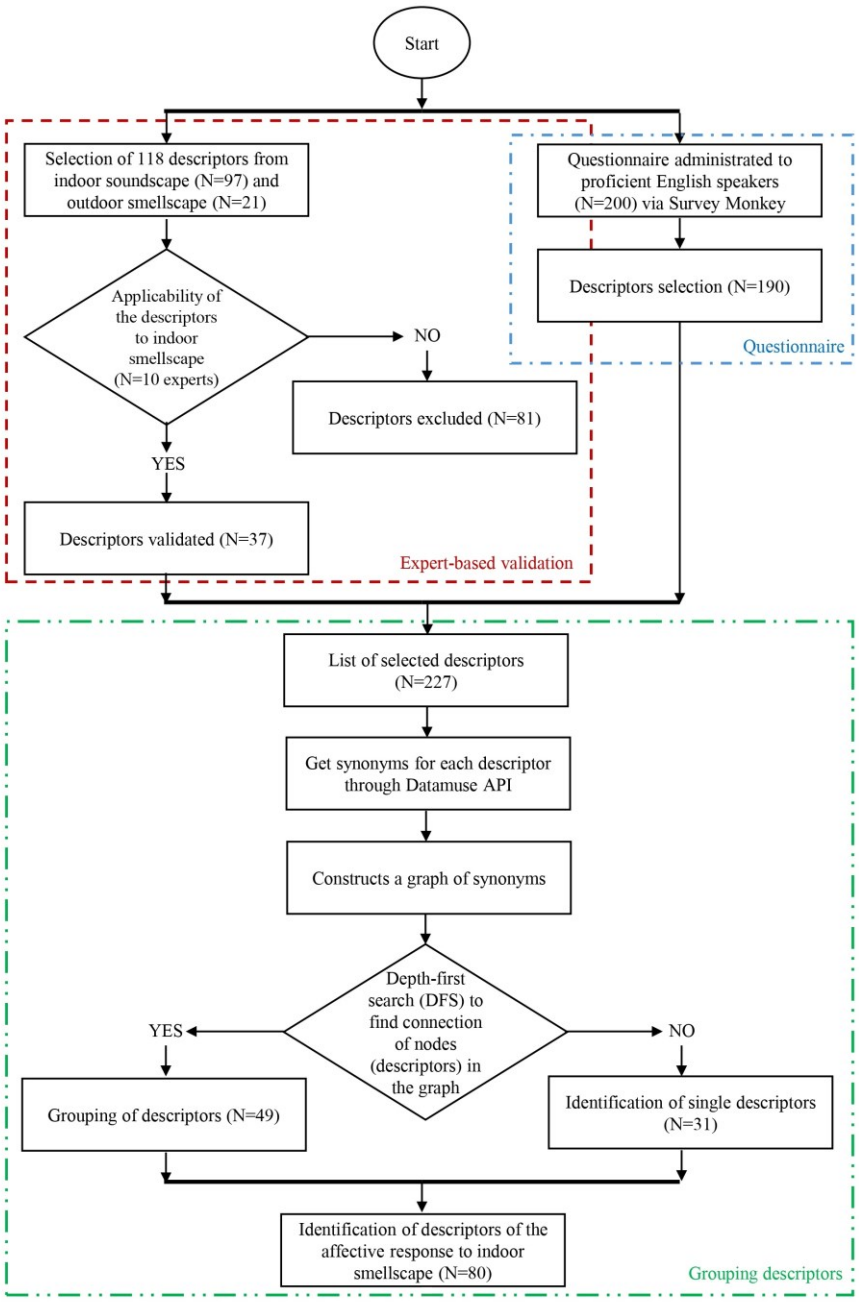

Figure 1 Flow diagram of the adopted methodology. In red: expert-based participatory approach for validating existing descriptors; in blue: questionnaire administered to non-experts; in green: grouping of descriptors using Natural Language Processing (NLP) techniques.

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Expert-based validation of existing attributes

Firstly, 118 descriptors were considered from a list developed for measuring indoor soundscape (N=97 attributes) (Torresin et al. 2020) and outdoor smellscape (Xiao et al. 2018) (N=21 attributes).

Secondly, the extended set of descriptors was piloted with regard to applicability to indoor smellscape with the aid of experts of IAQ and olfactory perception. The descriptors were randomly presented through a Survey Monkey online questionnaire, and expert assessed if these attributes are appropriate for describing the emotional reaction to an office's smell environment. The available options for each descriptor were "applicable," "not applicable," and "not sure". Additionally, an open-ended comment was provided for each descriptor. Moreover, the questionnaire contained an attention check question every 30 descriptors. Recruiting was conducted via email, personally inviting 10 experts in indoor air quality (IAQ) and olfactory perception from various and complementary fields of expertise (Figure 2). Participants were provided with a Participation Consent Form, and the Information on the processing of personal data for scientific research purposes (art. 13 EU reg. 2016/679).

The analysis was performed with pandas package in Python. For each descriptor, the percentage frequency of responses "Applicable", "Not Applicable", and "Not Sure" was calculated. Adjectives were considered validated for use in the indoor smellscape of offices where the frequency of "Not Applicable" was less than or equal to 20. Additionally, open-ended comments were discussed in a following workshop with the experts and taken into account in the validation decision.

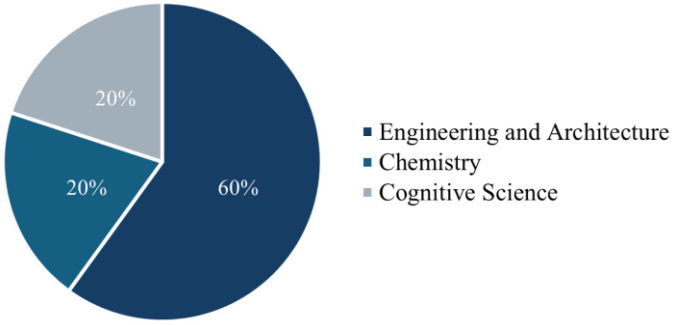

Figure 2 Background of experts in IAQ and olfactory perception.

Questionnaire

An online questionnaire (completion time: about 5 minutes) was distributed via the SurveyMonkey platform, directed to 200 English speakers (Figure 3). Participants were asked to fill the questionnaire while in their office and provide description of their olfactory experience ("How do you perceive the smells (both positive and negative) of your office? Please, provide at least three distinct adjectives that describe your emotional response to the smell environment").

Recruiting was conducted via the Prolific.com platform, opting to have a gender-balanced group. Participants were given a small financial compensation (1 pound). The eligibility criteria were as follows:

- Location: United Kingdom;
- Primary language: English;
- Employment status: Full-time / Part-time;
- Remote / Office work: always working at a central place of work or at least sometimes.

Participants were provided a Participation consent form, and the Information on the processing of personal data for scientific research purposes (art. 13 EU reg. 2016/679).

The autocorrect package in Python (Speller class) was used to detect and correct spelling errors in the participants' responses. Additionally, two native English speakers further reviewed the responses.

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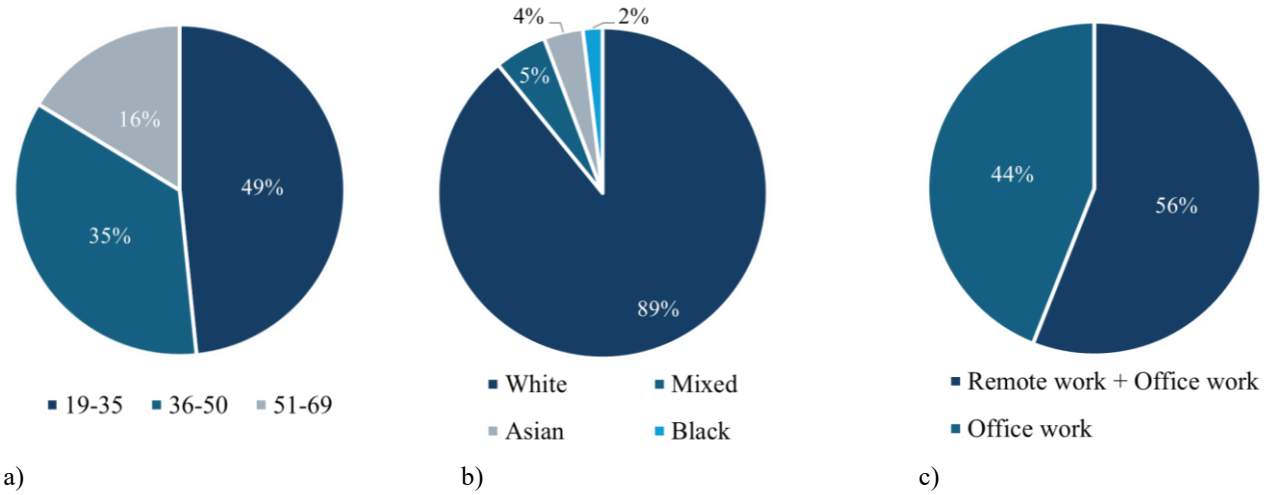

Figure 3 Demographic characteristics of non-experts participants: a) age; b) ethnicity; c) remote/office work.

Grouping descriptors based on semantic similarity

The two lists of descriptors (obtained from both expert validation and the online questionnaire) were merged, and descriptors with similar meanings were clustered through semantic analysis and graph-based NLP (via Python), as well as an interview with two native English speakers.

The requests library was used to make a GET request to the Datamuse API URL, querying synonyms for each descriptor (get_synonyms). The networkx package was used to construct (build_synonyms_graph) and analyze a graph of synonyms, consisting of a set of nodes (descriptors) and edge between them. If two adjectives had at least one common synonym, an edge was created to connect them in the graph. Finally, a depth-first search (DFS) was employed to identify groups of interconnected nodes (descriptors) in the graph (find_synonym_groups).

RESULTS

Firstly, a list of 37 descrptors was identified by experts through the validation of existing descriptors. Secondly, a list of 190 descriptors was identified through the online questionnaire. “Familiar” was the most used attribute describing the human response to the olfactory environment (39% of responses), followed by “Stale, Dusty, Stagnant, Not fresh, Stuffy”(16%), “Old, Ripe” (16%), “Fresh, Airy “ (15%), “Musty “ (13.5%), “Warm, Warming, Hot” (13%), “Clean, Sterile, Antibacterial, Disinfected” (12%), “Artificial, Unnatural, Fake” (11%), “Unhealthy, Toxic, Hazardous, Dangerous, Worrying” (10%), “Chemical”. Thirdly, the 227 descriptors were clustered based on the criterion of similar meaning, resulting in the final list of 80 descriptors, as highlighted in Table 1.

Based on the attributes found, we can observe how human response to indoor environments is often emotional, both positive and negative (e.g., “familiar,” “uncomfortable”) (Fang et al., 2023). Some descriptors explain how smells are sensed and perceived according to people’s perceptual abilities, which involve bodily functions such as vision, hearing, touch, or muscle coordination (e.g., “musty,” “sweet”) (Fang et al., 2023). Other attributes describe how smells can affect cognitive functions such as attention, memory, and decision-making (e.g., “Efficient for working,” “Distracting”) (Fang et al., 2023). There are also attributes that describe the automatic and unconscious effects of smells on the body’s biological systems (e.g., “Nauseating,” “Energizing”) (Fang et al., 2023). Finally, some descriptors reflect the ability of smells to connect us with dimensions of time (e.g., “Nostalgic,” “Lingering”) or space (e.g., “connecting spaces,” “creating a tie with the context”).

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Table 1. List of descritors of human response to the olfactory environment. Expert-based validation of existing descriptors coming from Torresin et al. (2020) (EV (T)), Xiao et al. (2018) (EV(X)), and Questionnaire (Q).

Descriptor(s)	Source	Expert-based validation (%)	Survey response (%)
Agreeable, Acceptable, Pleasant	EV (T) + Q	100.0	6.0
Annoying, Irritating, Troublesome, Upsetting	EV (T)	100.0	n/a
Unacceptable	EV(T)	80.0	n/a
Comfortable, Cozy, Reassuring	EV(T) + Q	80.0	7.0
Uninviting, Inhospitable, Unfriendly	EV(T)	80.0	n/a
Uncomfortable	EV(T)	80.0	5.0
Confident, Uplifting, Encouraging, Motivating	Q	n/a	4.0
Refreshing, Invigorating, Restoring	EV(T) + Q	80.0	3.0
Calming, Soothing, Relaxing, Peaceful	EV(T) + Q	80.0	2.0
Cheerful, Joyful, Happy	EV(T) + Q	80.0	3.0
Heavy, Stifling, Oppresing, Overpowering, Strong	EV(T) + Q	80.0	1.5
Appealing, Attractive, Inviting, Tempting	EV(T)	80.0	n/a
Awful, Detestable, Disgusting, Repulsive, Horrible, Revolting	EV(T) + Q	100.0	7.0
Rotten, Stincky	Q	n/a	4.0
Offensive, Hostile	Q	n/a	3.0
Familiar	EV(T) + EV(X) + Q	90.0	39.0
Bad, negative	EV(T)	90.0	n/a
Beautiful, Delightful, Lovely	EV(T) +Q	90.0	1.0
Intimate, Personal	EV(T)	80.0	n/a
Good, Positive, Nice	EV(T) + Q	80.0	2.5
Making you want to open the windows	EV(T)	90.0	n/a
Unpleasant, Nasty	Q	n/a	9.5
Unusual, Weird, Unpredictable, Odd	Q	n/a	5.5
Outside my control	EV(T)	80.0	n/a
Unhealthy, Toxic, Hazardous, Dangerous, Worrying	Q	n/a	10.0
Warm, Warming, Hot	Q	n/a	13.0
Safe	Q	n/a	3.0
Lively	Q	n/a	0.5
Disharmonious	EV(T)	90.0	n/a
Clean, Sterile, Antibacterial, Disinfected	Q	n/a	12.0
Fresh, Airy	EV(X) + Q	90.0	15.0
Stale, Dusty, Stagnant, Not fresh, Stuffy	EV(X) + Q	90.0	16.0
Musty	Q	n/a	13.5
Aromatic, Fragrant, Scented	Q	n/a	3.0
Clear, Pure, Authentic	Q	n/a	1.5
Simple, Plain	Q	n/a	1.0
Identifiable, Recognizable	EV(T)	90.0	n/a
Unidentified, Unfamiliar, Unknown, New, Mysterious	EV(T) + EV(X) + Q	90.0	7.5
Flavourful, Tasty	Q	n/a	2.0
Generic, Normal, Neutral, Regular	Q	n/a	7.0
Artificial, Unnatural, Fake	EV(T) + EV(X) + Q	90.0	11.0
Light, Non powering, Faint, Bland	EV(T) + EV(X) + Q	90.0	4.0
Natural, Earthy, Botanical, Floral	EV(X) + Q	90.0	8.0
Masculine, Male-orientated	Q	n/a	3.0
Absent	Q	n/a	1.0
Cluttered, Confused	Q	n/a	2.0
Dank, Humid, Damp	Q	n/a	4.0
Odorous	Q	n/a	1.0
Chemical	Q	n/a	10.0
Unclean, Dirty	Q	n/a	5.0
Overcooked	Q	n/a	0.5
Plasticky	Q	n/a	2.0
Sweet	Q	n/a	4.0
Bitter	Q	n/a	0.5
Old, Ripe	Q	n/a	16.0

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Mechanical	Q	n/a	1.0
Adequate, Suitable	EV(T)	100.0	n/a
Efficient for working	EV(T)	80.0	n/a
Interesting, Interest-arousing	EV(T) + EV(X)	80.0	n/a
Inadequate, Unsuitable	EV(T)	80.0	n/a
Distracting	Q	n/a	2.0
Headachy	Q	n/a	1.0
Stressful	Q	n/a	0.5
Energising	Q	n/a	1.0
Nauseating	Q	n/a	1.0
Lingering	Q	n/a	0.5
Ambivalent, Ever-changing, Mixed	Q	n/a	3.0
Nostalgic	Q	n/a	5.0
Mundane, Monotone, Uninteresting, Dull, Repetitive	EV(T) + Q	80.0	1.0
Industrial	Q	n/a	6.0
Non-descript	EV(T)	80.0	n/a
Distinctive	Q	n/a	3.0
Urban	Q	n/a	1.0
Outside	Q	n/a	1.0
Clinical, Medical	Q	n/a	7.0
Non-local	Q	n/a	9.0
Professional, Corporate, Businesslike, Formal	Q	n/a	2.0

The identification of 227 descriptors and their reduction to 80 highlights the complexity of olfactory perception and the need to classify and simplify human responses to odours. The wide range of negative terms (e.g., "Stale, Dusty, Stagnant", "Unhealthy, Toxic") compared to positive ones might suggest that people tend to notice and describe unpleasant odours more easily, a tendency also observed in previous research on olfactory perception (Rouby et al. 2002; Seo et al. 2010). This aligns with the negativity bias, where negative sensory experiences tend to be more salient and memorable than positive ones (Crouzet et al. 2012).

Based on these findings, future work will aim to reduce (e.g., through Principal Component Analysis) the 80 attributes to a few key dimensions that can explain most of the variance in indoor smellscape perception. This will allow for the development of a measurement system structured around an n-dimensional space defined by the principal components (Figure 4). This model would be highly valuable in post-occupancy evaluation (POE) studies, as it would identify the perceptual constructs to be measured and the attribute scales to be employed. Furthermore, understanding human perceptual responses to the olfactory environment will be essential for bridging the gap between predicted and experienced olfactory performance in built environments, ultimately contributing to more effective and human-centered spatial design (Henshaw et al. 2013).

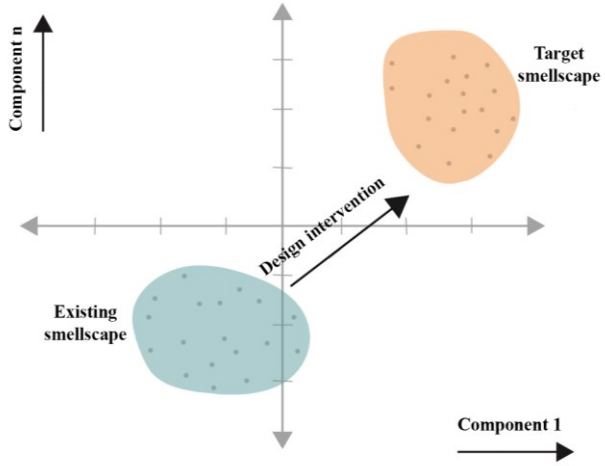

Figure 4 Using a n-dimensions space for target-setting for smellscape design, example of a two-dimensions space. Each point represents a person's perception of the evaluated smellscape (Torriani et al. 2024c).

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CONCLUSIONS

This study provides a structured framework for understanding human responses to indoor smellscapes, integrating expert-valideted and user-generated descriptors. The final set of 80 descriptors offers insights into how smells influence emotions, cognition, and perception. The predominance of negative descriptors reinforces the significance of unpleasant odours in shaping human experiences. Future research should refine these descriptors into a principal components model to support applications in the design and POE of buildings, enhancing sensory well-being in built environments.

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