Scentbound

An olfactory VR game with a custom scent device and a scent–scene matching experiment

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Abstract

Commercial games and virtual reality experiences rely heavily on vision and sound. Smell, although closely linked to emotion and autobiographical memory, is still largely marginal in interaction design. This project combines speculative world-building, a playable 3D game prototype, a physical olfactory device, and a small-scale study on matching smells to typical game scenes, to explore how scent can be designed and used in game experiences.

I first designed a first-person 3D game set in a future where natural ecologies and natural smells have been replaced by artificial systems, and real smells have become a scarce resource and a form of social power. The player is a researcher forced to work for a corporation, sent to reconstructed scenes such as a spring flower field and a winter church to collect and analyse smell samples. The game is both a sequence of tasks and a journey in which the player gradually recovers lost memories and uncovers the commercial monopoly and memory manipulation behind these "natural smells". As the missions progress, the player realises that these scenes are not simply fragments of the "past", but the remains of their own memories and of humanity's collective memory.

To support this experience, I designed and built a low-cost olfactory device based on Arduino, using four independent atomiser modules to drive four scent bottles. By combining these channels, the system provides different smell configurations for three key scenes. On this basis, I designed a scene–scent matching user study: participants watched representative game scenes, selected from several candidate smells, and gave subjective ratings of their emotional responses and sense of immersion.

This project contributes: (1) a VR game design case that treats scent as a core narrative and atmospheric element; (2) a reusable, cost-controlled multi-channel olfactory hardware prototype; and (3) an experimental framework for studying how players subjectively map smells onto virtual scenes and emotions.

Keywords: olfactory interaction, VR game, HCI, multisensory design

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Contents

1 Introduction

Contemporary commercial games and virtual reality (VR) experiences are highly mature in terms of visuals, audio, and haptics, but smell—although closely tied to memory and emotion—still occupies a marginal position in mainstream game design and human–computer interaction (HCI). Existing olfactory VR studies show that adding scent can increase presence and intensify affect, but may also introduce side effects such as distraction from the task [6, 3]. At the same time, this work consistently reveals the difficulties of controlling release timing, diffusion and lingering, and large individual differences in perception. As a result, scent is often treated as an add-on "special effect" rather than a design material to be worked with systematically; many projects remain at the level of concept demos or one-off experimental installations.

In terms of application domains, current olfactory interaction research is concentrated in meditation and relaxation experiences, learning contexts, memory recall and rehabilitation, and a few commercial products for advertising and branded experiences. By contrast, questions such as "what should a typical game scene smell like?" or "how do players subjectively match scents to different visual scenes?" are rarely discussed in a systematic way. In other words, we already know that "having scent tends to feel more immersive", but we know much less about which kinds of scents fit which kinds of game scenes, how players understand this fit, and how to turn such knowledge into reusable experimental paradigms and design guidelines [17, 7].

At the same time, smell in everyday life is being continuously commodified and technologised: from high-end perfumes and "olfactory identity" products to anosmia rehabilitation and memory-care tools for older adults, olfactory experiences are increasingly packaged, sold, and managed as a resource. Yet, in both game research and broader XR/HCI work, there are still relatively few operational prototypes and user studies that respond to this socio-technical context. Against this backdrop, the present practice-based project uses a speculative game world as a narrative shell, but focuses its research attention on three concrete layers: how smell is employed inside a VR game prototype, how a low-cost scent device can be realised in hardware, and how a small-scale scent–scene matching study can be [18]. Concretely, the project offers a world and level structure that can host olfactory interaction, and it physically assigns several essential-oil scents to three stylised scenes, inviting participants to choose and evaluate scents while viewing the scenes, in order to explore more fine-grained correspondences between scent and environment [10, 11].

Rather than simply assuming that "any experience becomes better once scent is added", this project asks which olfactory configurations are actually worth the design and experimental effort under realistic hardware constraints and a limited scent palette, and how the mapping between scents and scenes might be explored in a first step. On this basis, the main contributions of this work are: (1) a VR game prototype that treats smell as a key atmospheric element and uses it to probe the role of olfaction in narrative and scene design; (2) a cost-controlled, four-channel scent hardware setup that can be replicated in teaching or studio environments; and (3) an exploratory experimental framework for matching scents to game scenes, which can be reused and extended in future olfactory game studies [16].

2 Related Work

2.1 The role of smell in HCI

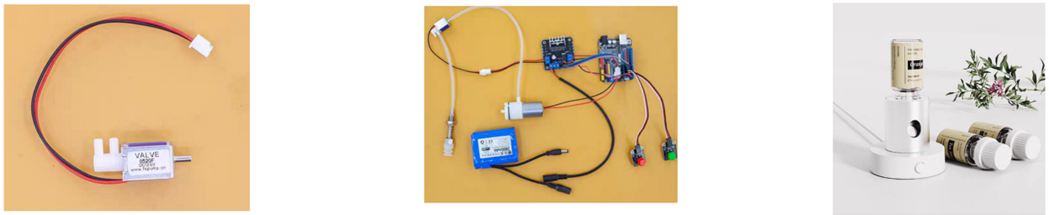
In human–computer interaction research, smell has long been seen as a sensory channel with great potential but difficult to control. Psychological studies show that smell is closely linked to autobiographical memory and emotion: a brief whiff of odour can rapidly evoke memories of a person, place, or episode, and the speed and intensity of this trigger can exceed those of vision and hearing [4, 8]. As a result, more and more studies have introduced smell into VR, games, and interactive installations in order to enhance sense of presence and emotional resonance [2, 9].

In practice, however, olfactory interaction faces several obstacles. The first is temporal and spatial controllability: smells diffuse with delay and tend to linger, so it is hard to synchronise them with interactive events at a fine-grained timescale [16, 19]. The second is hardware barriers: many research prototypes rely on bulky diffusers, custom solenoid valves, or complex tubing systems, which are not suitable for deployment in ordinary homes or game environments. The third is individual difference: players differ greatly in sensitivity and preference for the same odour; a smell that some people find pleasant may be irritating or even aversive to others, which raises issues of usability, accessibility, and ethics [6]. For these reasons, olfactory interaction is still more common in artistic installations, therapeutic experiences, or specialised training settings, and is rarely seen in mainstream entertainment and games.

Even so, recent studies continue to show that smell can significantly change digital experiences. For example, Yang's VR cooking experiment compared players with and without a pancake-like scent: the presence of smell increased participants' reported sense of presence, but also distracted attention from the task to some extent, revealing a tension between immersion and focus [17]. Elsabbagh and colleagues designed a VR meditation system that uses Arduino-controlled diffusers to release lavender or citrus scents at key breathing moments; participants in the scented condition reported higher relaxation and more positive emotions [7]. Zhang and co-authors reviewed advances in olfactory-augmented VR, including compact diffusers, wearable devices, and flexible electronics, and argued that smell is likely to become a routine channel in future multisensory XR systems [19]. Taken together, these works emphasise that olfactory interfaces have clear potential, but also come with substantial practical complexity.

2.2 Olfactory systems and application landscape

At the device level, existing olfactory systems can roughly be grouped into several categories. Valve-controlled spray systems drive solenoid valves with Arduino or other microcontrollers to emit short bursts of atomised essential oil into the air, typically synchronised with Unity or Unreal via serial communication [10]. Airflow-switching systems use air pumps and multi-way tubing to route airflow through different scent chambers, so that multiple odours can be produced with a smaller number of diffusers [16]. Passive setups, such as scented candles combined with fans, do not require electronic control but offer almost no precise control over release timing or intensity [17]. High-end wearable or



Device principle	Control method	Scent source
Arduino + valve diffuser	Serial ON/OFF from Unity / VR	Essential oil bottle
Arduino + air-pump + tubes	Switch active channel	Scent boxes
Candle + fan	Manual, no sync	Scented candle
Wearable / flexible micro-diffuser	Custom chip, near-nose driver	Micro liquid capsules

Figure 1: Comparison of Current Research Techniques.

flexible devices encapsulate micro-doses of fragrance in soft substrates and trigger them via custom chips; these are mostly used in laboratory research [19, 9].

Commercial products such as Aroma Shooter and OVR ION show that industry is already interested in VR-synchronised scented advertising and immersive experiences. Research-oriented projects, such as scent memory kits, olfactory identity storytelling works, and smell training tools, focus more on memory care and rehabilitation [11]. Overall, most systems either emphasise hardware innovation, or focus on therapeutic and training effects. Very few projects treat smell as a game mechanic in its own right, or as a medium for addressing social issues such as class, labour, and exploitation.

2.3 Gaps and design opportunities

Against this background, the present work deliberately positions itself between speculative design and engineering prototypes, and responds to three gaps.

First, many HCI projects with smell still treat odour as an add-on to existing experiences: food scents are added to cooking scenes, and lavender is added to meditation scenes, and so on [17, 7]. This project instead tries to reverse the logic and ask: what if the entire world and economic order were structured around smell? On that basis, it reconstructs the game narrative. In the future setting of the game, natural smells are scarce and monopolised by a corporation; “who gets to smell what” becomes a mechanism of social stratification, and smell becomes entangled with memory, capital, and inequality.

Second, existing olfactory VR systems often emphasise technical novelty or medical value, and pay relatively little attention to everyday entertainment and game design [16, 19]. This project does not aim for complex hardware; instead, it targets a small-scale system that can be reproduced: using Arduino-driven nebuliser modules and essential oils to build a multi-channel scent device that students and independent designers can afford, and that can serve as basic infrastructure for later game research.

Third, many current experiments with smell focus on questions such as whether an experience is more immersive or more relaxing, and rarely discuss how players actively bind particular odours to particular scenes, or how this binding reflects their cultural experience [6, 2]. The scent–scene matching study in this project directly addresses this issue: using highly stylised game scenes such as laboratory, flower field, and winter church as stimuli, participants choose among multiple candidate scents and explain why they feel a given smell is more or less appropriate, thereby revealing their own olfactory imagination and preferences.

By embedding the game prototype in this research context, the project argues that olfactory interaction is not only an engineering challenge, but also a critical medium and a form of multi-sensory experience. An olfactory game becomes a necessary vehicle for exploring and testing these design ideas and technical possibilities. This direction represents substantial potential for the next generation of immersive experiences. Such games can deepen narrative immersion, and also push us to reflect on how senses may be reshaped by technology and capital in the digital future. Developing basic olfactory infrastructure that designers can actually use is therefore an urgent step if HCI is to move towards truly multisensory interaction.

3 Design Goals and Research Questions

This project has intertwined experiential, critical, and technical aims. These can be summarised in four design goals:

DG1 – World-building and experiential design. To construct a future VR game world in which smell functions as a core metaphor and narrative cue. Players are placed in a story context where scents act as key traces for understanding the world and progressing through tasks, rather than as a superficial add-on to visual and audio effects.

DG2 – Exploring scent in archetypal scenes. To select three representative game scenes—a cyberpunk laboratory, a spring flower field, and a frozen church—as design spaces, and to explore how different scents shape each scene's emotional tone, sense of immersion, and symbolic meaning.

DG3 – An accessible olfactory hardware prototype. To design and implement a low-cost, Arduino-based multi-channel olfactory device that can provide scent configurations for the three scenes and be controlled from Unity, making it suitable for classroom demonstrations and small-scale studies.

DG4 – Empirical understanding of scene–scent mapping. To conduct a small-scale user study that systematically examines how participants subjectively match candidate scents to the three scenes, and how different scene–scent combinations are rated in terms of emotion, immersion, and perceived realism, so as to inform later design decisions and parameter tuning.

On the basis of these goals, the project addresses the following research questions:

RQ1. In the three archetypal game scenes—a cyberpunk lab, a spring flower field, and a frozen church—how do participants subjectively choose among twelve candidate scents when asked to match smells to scenes?

RQ2. What concrete design insights for future olfactory game design can be drawn from participants' matching choices and their verbal explanations?

4 Method

This project adopts a practice-oriented mixed research approach, grounded in practice-based and research-through-design traditions in HCI [20], with creative practice at its core, complemented by a small-scale user study and reflective analysis.

At the practice level, I first iteratively developed a first-person 3D game prototype in Unity. The game uses three archetypal scenes—a cyber lab, a spring garden, and a frozen church—as carriers, organising narrative, tasks, and interactions (movement, triggers, resonance mini-games, etc.) around smell. Key design decisions were documented through version control, development logs, and screenshots.

On the hardware side, I followed an engineering-prototype iteration process to design and build a four-channel ultrasonic scent device based on Arduino. Different wiring and scent-allocation schemes were tried in the studio, before making trade-offs between feasibility and reproducibility: the system was ultimately constrained to four scent bottles with simple on/off control, rather than complex continuous modulation. These compromises are made explicit in the methods section.

To explore how players subjectively map scents to scenes and emotions, the project also includes an exploratory, small-sample scent–scene matching study. I recruited four participants who were interested in games or multisensory experiences and asked them to first familiarise themselves with 12 anonymised essential oils. They then performed a scent–scene matching task across the three scene types and rated each combination on 7-point scales for perceived matching, emotional valence, arousal, and immersion. The use of valence and arousal ratings follows the circumplex view of affect [12]. Finally, short interviews were conducted to collect their reasons and associations for particular matches, treating the task as a small crossmodal mapping exercise in line with work on crossmodal correspondences [14].

In the analysis phase, quantitative data were examined using descriptive statistics to identify, for each scene, scents that were repeatedly chosen as candidates. Qualitative data from free-form labels and interview transcripts were subjected to light thematic grouping, to extract recurring metaphors such as "filtered air", "flower field", or "religious space". These findings fed back into the design process, informing the final configuration of four representative scent bottles and small adjustments to how the olfactory experience is framed in the game.

5 Implementation and Results

5.1 System Overview

The implementation of this project can be understood as a small ecosystem composed of software, hardware, and a research procedure. It consists of three interrelated parts. First, a VR / 3D game and narrative world: a first-person 3D game built in Unity, set in a speculative future world where smell is tightly woven into the level structure and interaction flow. The game provides the narrative frame and spatial context in which olfactory events can be triggered in a controlled way. Second, a physical olfactory device: a low-cost, Arduino-based four-channel nebuliser setup, with each channel corresponding to one essential-oil bottle. Unity communicates with the Arduino board via serial messages; the board then opens or closes specific channels so that different scents or scent combinations can be emitted in different scenes and at key narrative moments. Third, a scent–scene matching study: on top of the game and hardware, a small-scale user study is designed to examine how people subjectively connect smells with stylised game environments. Participants watch images or short video clips of typical scenes from the game and select from multiple candidate scents, while also rating their emotional reactions and sense of immersion. This research layer feeds back into both the scent configuration of the device and the way the game frames olfactory events.

Together, these three parts form a loop: the game triggers hardware-controlled scent events, the user study probes how players perceive and interpret these events, and the findings in turn inform the next iteration of both game design and scent mapping[13].

5.2 Game Design and Narrative World

5.2.1 Overall story and player role

The game is set approximately 150 years in the future. After a long period of environmental collapse and artificial reconstruction, natural ecosystems on Earth have been almost entirely replaced by artificial systems, and natural smells have disappeared with them. People live in environments governed by filtered air and standardised fragrances; smell has shifted from an everyday sensory experience to a form of energy, a luxury commodity and a marker of social status.

A corporation called *Olfacta Corp* monopolises all technologies for regenerating smell. It operates a system named *ScentLink*, which can reconstruct past natural scenes from fragmented memories, historical records and molecular residues, and extract smell molecules from these reconstructed environments so that they can be standardised and commercialised.

The player character was originally a doctoral researcher in a "Smell and Emotion Reconstruction Laboratory," working on the relationship between smell and emotional memory. After refusing to sell their research to Olfacta, the protagonist is forced to undergo memory loss. On the surface, the player is still a scientist. In practice, they have become a memory labourer, collecting smells and organising memories for the company.

In the game, the player's tasks include: waking up in a cyberpunk-style laboratory and understanding their new identity and mission; entering reconstructed natural scenes (such as a spring

Figure 2: Starting corridor in the cyberpunk laboratory scene.

garden or a winter church) and completing smell sampling tasks; and, through environmental clues, dialogue and ending choices, gradually realising that these scenes are not only copies of the past but also entangled with the protagonist's own memories and with a broader residue of collective memory. Within this narrative frame, smell is not merely decorative atmosphere but explicitly defined as a resource that can be extracted, controlled and traded. Level design therefore deliberately binds key olfactory events to story beats such as mission assignment, mission completion and ending selection.

5.2.2 Scene one: cyberpunk laboratory

The game begins in a closed, corridor-like experimental space: a narrow metal passage, cold fluorescent lighting, flickering display panels and low mechanical hum, forming a typical futuristic laboratory setting. After waking up, the player first faces a large cyber-style display. One interface presents the global background (ecological collapse, the monopoly over smell), and another shows the player's personal file (research history, contract terms, etc.).

When the player turns or walks into a specified area, a service robot approaches and triggers a dialogue box that briefly explains the current identity and the immediate task: recalibrating the ScentLink transport device in preparation for entering the first natural scene. The robot then moves along a path towards a door leading to the core part of the lab. The player needs to follow the robot to the doorway, enter the trigger area in front of the door and press the **E** key to open it; step

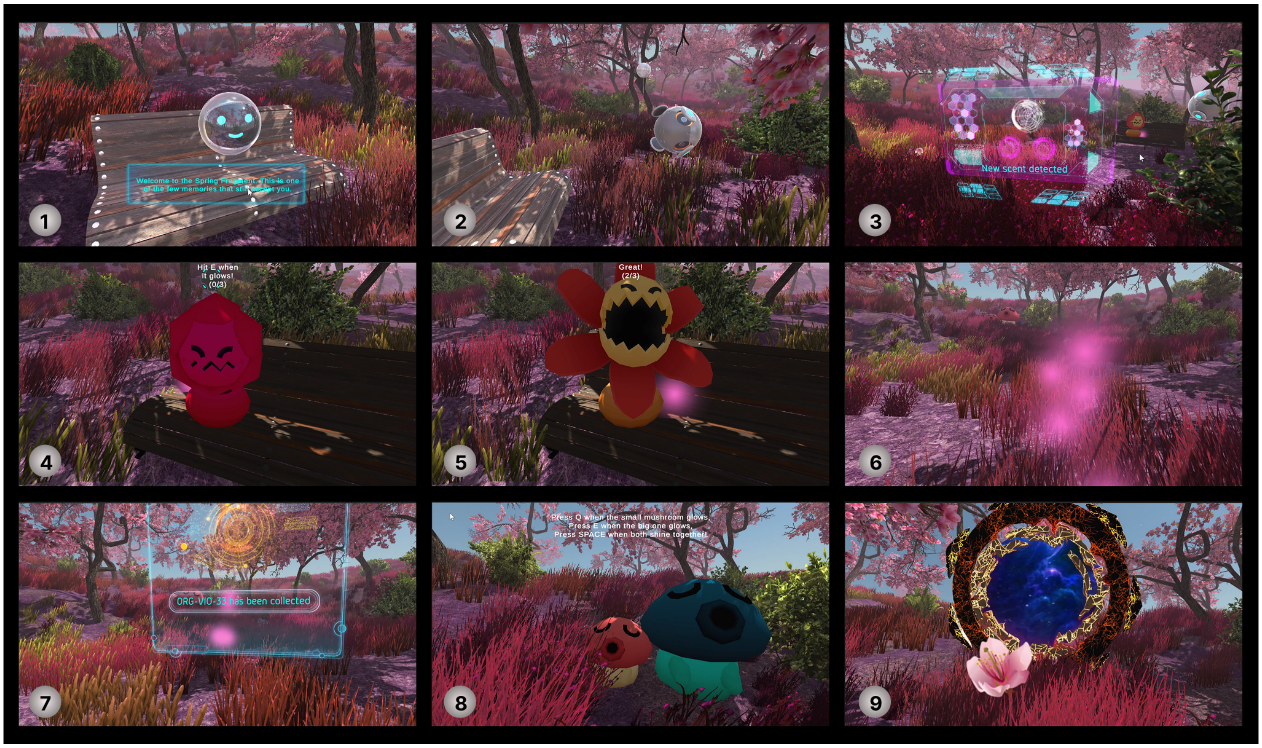


Figure 3: Spring flower field scene with "smell creatures".

into a larger experimental space where they can observe laser devices, floor hatches, pipes and other elements; and complete a simple repair task (for example opening the floor hatch and adjusting pipe positions) to restore the system. Once these operations are finished, the transport device is activated and the player is sent to the next scene.

Throughout this sequence, UI prompts, changes in lighting and the robot's stopping points together form a guidance layer, allowing the player to progress without lengthy textual tutorials while still understanding where to go and what to do.

5.2.3 Scene two: spring flower field

The first reconstructed natural environment is a spring flower field, a relatively archetypal game setting that is easy to associate with floral scents. The scene is built from large flowerbeds, trees, soft lighting and slowly falling petals, with ambient sound composed of wind, birdsong and gentle background music.

After entering the scene, the player receives a short instruction from the robot or the system: several "smell creatures" live here, and the player must collect smell samples from them and upload these samples for analysis by Olfacta. The core interactions in the forest are structured as two resonance tasks.

In the first task, a flower-like creature in the distance emits rhythmic pulses of light. When the player approaches, a short UI prompt appears (for example "Press **E** in time with the flashes").

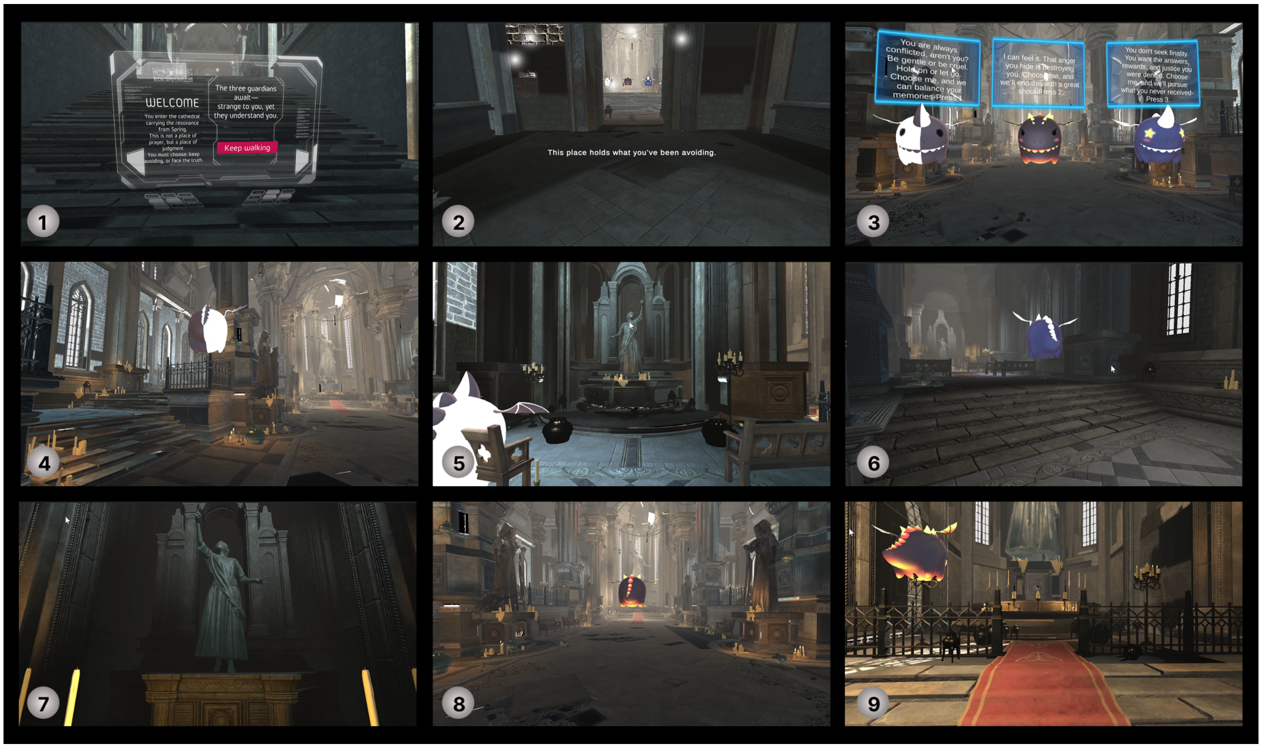


Figure 4: Frozen church scene with three spirits representing different endings.

The player has to match the rhythm a number of times. Once enough correct matches are achieved, the flower creature releases a burst of coloured particles, which is treated as a successful sampling event; the sample ID and a brief description are recorded on screen.

In the second task, the coloured particles released in task one drift forward and visually guide the player deeper into the forest, towards a set of mushroom creatures. The resonance mechanism is slightly more complex in rhythm or repetition. After three successful rounds of resonance, the mushroom spirit disappears and a portal to the next scene appears at its location.

Between tasks, short text prompts occasionally appear to remind the player of the connection between these samples and Olfacta's commercial system, reinforcing the theme that "nature" is being collected, standardised and commodified.

5.2.4 Scene three: frozen church

The third scene is a church covered in snow and ice. As soon as the player enters this space, a UI box briefly reviews the smell sampling missions completed so far and explains that this final sequence is a choice-driven task. As the player walks forward, a voice-over indicates that three spirits will appear, each representing a different outcome.

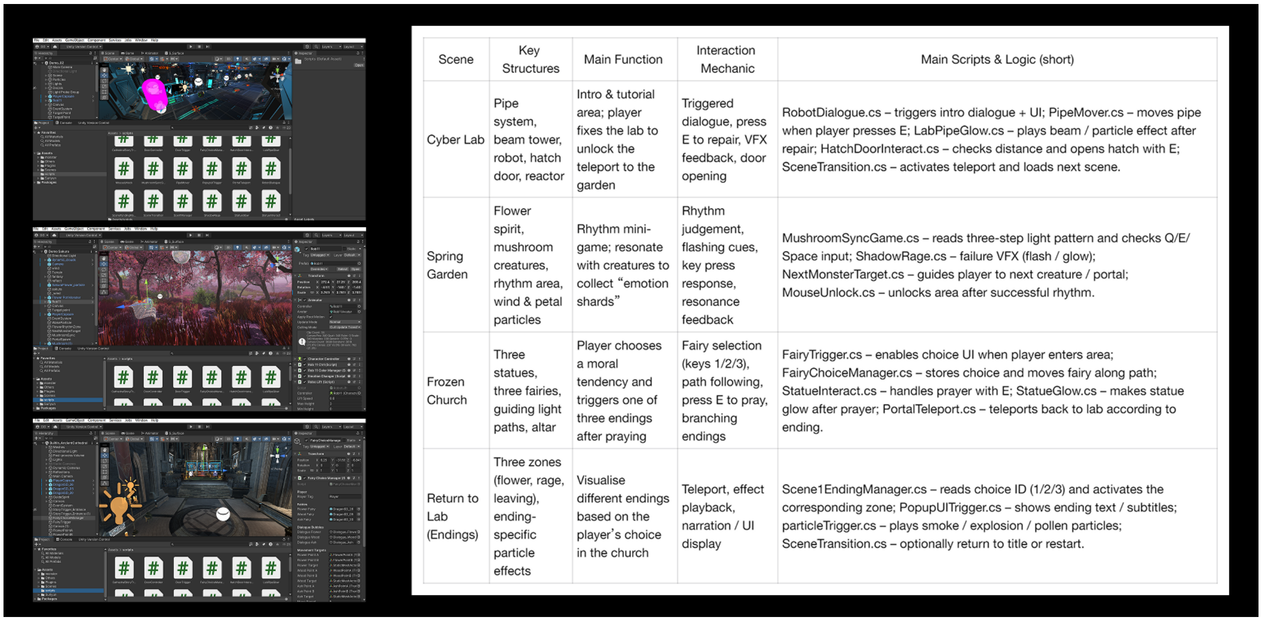
Soon the player encounters three distinct spirits in the churchyard or near the entrance (for example, glowing orbs or semi-transparent statues). Each spirit's visual style and short description corresponds to one type of ending: an *escape* spirit, pointing towards returning to the self and

Figure 5: 3 different endings.

breaking out of the system; a *destruction* spirit, pointing towards destroying the system and freeing all trapped consciousnesses; and an *assimilation* spirit, pointing towards fully merging with Olfacta and obtaining a stable but tightly controlled life.

The player chooses by pressing the number keys 1, 2 or 3. After the choice is made, the other two spirits disappear. The chosen spirit then acts as a guide, leading the player through different areas inside the church to a corresponding altar or statue.

At the altar, the player performs a prayer action by holding the **E** key, which triggers the associated ending. In the *escape* ending, the player is sent back to the laboratory, but in a different location. Previously locked areas are now accessible, revealing additional files and a possible exit, implying that escape has succeeded. In the *destruction* ending, the service robot asks the player to shut down exhaust fans to prevent system overload, while UI elements and environmental details hint that the system is already failing. The player can secretly turn the fans to maximum instead, symbolically destroying the system with an excess of smell and desire. In the *assimilation* ending, the player returns to the lab to find their file rewritten and their status changed to that of a full employee. The laboratory appears calmer and more orderly, but several cues suggest that parts of the protagonist's memory have been erased.



Scene	Key Structures	Main Function	Interaction Mechanic	Main Scripts & Logic (short)
Cyber Lab	Pipe system, beam tower, robot, hatch door, reactor	Intro & tutorial area; player fixes the lab to unlock the teleport to the garden	Triggered dialogue, press E to repair, VFX feedback, door opening	RobotDialogue.cs – triggers intro dialogue + UI; PipeMover.cs – moves pipe when player presses E; LabPipeGlow.cs – plays beam / particle effect after repair; HatchDoorInteract.cs – checks distance and opens hatch with E; SceneTransition.cs – activates teleport and loads next scene.
Spring Garden	Flower spirit, mushroom creatures, rhythm area, wind & petal particles	Rhythm mini-game; resonate with creatures to collect "emotion shards"	Rhythm judgement, flashing cues, key press response, resonance feedback	MushroomSyncGame.cs – reads three-step light pattern and checks Q/E/Space input; ShadowRage.cs – failure VFX (flash / glow); NextMonsterTarget.cs – guides player to next creature / portal; MouseUnlock.cs – unlocks area after successful rhythm.
Frozen Church	Three statues, three fairies, guiding light paths, altar	Player chooses a moral tendency and triggers one of three endings after praying	Fairy selection (keys 1/2/3), path following, press E to pray, branching endings	FairyTrigger.cs – enables choice UI when player enters area; FairyChoiceManager.cs – stores choice and moves fairy along path; StatueInteract.cs – handles prayer with E; StatueGlow.cs – makes statue glow after prayer; PortalTeleport.cs – teleports back to lab according to ending.
Return to Lab (Endings)	Three zones (flower, rage, leaving), ending-specific particle effects	Visualise different endings based on the player's choice in the church	Teleport, effect playback, narration / UI display	Scene1EndingManager.cs – reads choice ID (1/2/3) and activates the corresponding zone; PopupUITrigger.cs – shows ending text / subtitles; particleTrigger.cs – plays smoke / explosion / pollen particles; SceneTransition.cs – optionally return to title or restart.

Figure 6: Unity game development.

5.3 Software and Hardware Development

5.3.1 Software Development

The system is designed as an immersive olfactory experience built around three core scenes: the cyber lab, the spring garden, and the frozen church. To keep narrative pacing, interaction consistency, and scent events stable, the software is organised into three logical layers: a scene/state layer, an interaction layer, and a scent interface layer.

A lightweight state machine acts as the central control module. Its role is to maintain the player's global progress, current task phase, and the ending that corresponds to the final choice. Scene transitions between the three key locations are handled through asynchronous loading combined with state updates, which avoids stalls or resource conflicts when switching scenes. Each scene is bound to a base state (e.g., the lab's default scent, the garden's base ambience, the church's ritual atmosphere) and triggers deeper scent states when the player completes key tasks. The state layer also records the three-branch choice made in the frozen church, so that when the player returns to the lab the correct ending space, effects, and text can be loaded. In this way, scene-to-scene logic remains clear and the player's actions always have visible impact on subsequent narrative progression.

The interaction layer adopts a unified pattern of *enter trigger zone + press `E`*. All key devices (doors, hatches, pipes, fairies, altars, UI hint zones) are surrounded by 3D triggers. When the player enters a trigger, a prompt automatically appears; pressing `E` fires the corresponding event. At system level, this pattern is abstracted into a common input-and-trigger structure, so that any new interaction point can be connected quickly. All narration, task prompts, and world-building text are presented through short text snippets, UI highlights, and brief animations. Each snippet auto-plays for a few seconds and then fades out, so as not to break the player's rhythm.

Beyond dialogue and UI triggers, the task design of each scene reflects its narrative role. In the lab, the main tasks are repair-based: the player explores to locate the repair points, adjusts floor pipes to align them to the correct direction, and, once completed, reactivates the beam tower and unlocks the teleport to the garden. This part combines geometric checks, particle effects, and pipe-state control. In the spring garden, the focus shifts to rhythm–resonance mini-games: the player responds to flashing cues from flower and mushroom spirits, and progress is made when the system detects enough successful synchronisation. This mechanic tests the player's sense of rhythm and also functions as a narrative expression of forming a "connection" with non-human creatures. In the frozen church, the main task is to choose a fairy and complete a prayer ritual. Three fairies, representing different psychological tendencies, wait in the hall. After reading the associated dialogue, the player presses keys `1/2/3` to choose one fairy. The chosen fairy then leads the player along a path to a specific statue. At the statue, the player presses `E` to pray; the system records this choice and triggers the corresponding ending. Internally, this process involves toggling object visibility, moving along waypoints, displaying UI, and finally using the state layer to control the return scene branch.

To keep scent control logic clear and extensible, a dedicated *Scent Manager* is used. Other scripts never talk to the hardware directly; they simply call semantic functions such as "set lab base scent", "activate garden deep scent", or "start church ritual scent", or "switch all scents off". The scent manager encapsulates these requests and forwards them to the hardware interface.

Taken together, the interaction layer focuses on story and player action, the scent layer handles device control, and the state layer guarantees consistent scene logic. This forms a software architecture that is clear, robust, and easy to extend.

5.3.2 Olfactory Hardware Design

The olfactory device is designed to be as simple as possible in structure, with a limited but reusable number of channels, and easy to assemble and maintain in a studio environment. For this reason, a four-channel nebuliser configuration based on an Arduino-compatible board was adopted. The system consists of the microcontroller board, four nebuliser modules, four separate scent bottles, and MOSFETs or relays for driving the loads. Each channel directly drives an ultrasonic nebuliser element, so that scent can be released with minimal mechanical structure. This avoids the cost and maintenance overhead of solenoid valves, pumps, and complex plumbing.

The four scent bottles hold four basic scent categories: a cold, synthetic "lab" scent, a floral scent, a cedar wood scent, and a heavier narrative wood/incense scent. These map onto the scent structure of the lab, garden, and church in an abstracted and compressed way. Except for the garden, each scene is composed of a base scent and an intensified scent layered on top. For example, in the lab the synthetic cold scent serves as the base, with sandalwood-like notes added to thicken the narrative feeling of the space. The garden uses the floral scent as its main layer. The church uses cedar as the spatial base to create a religious atmosphere, and adds sandalwood during the

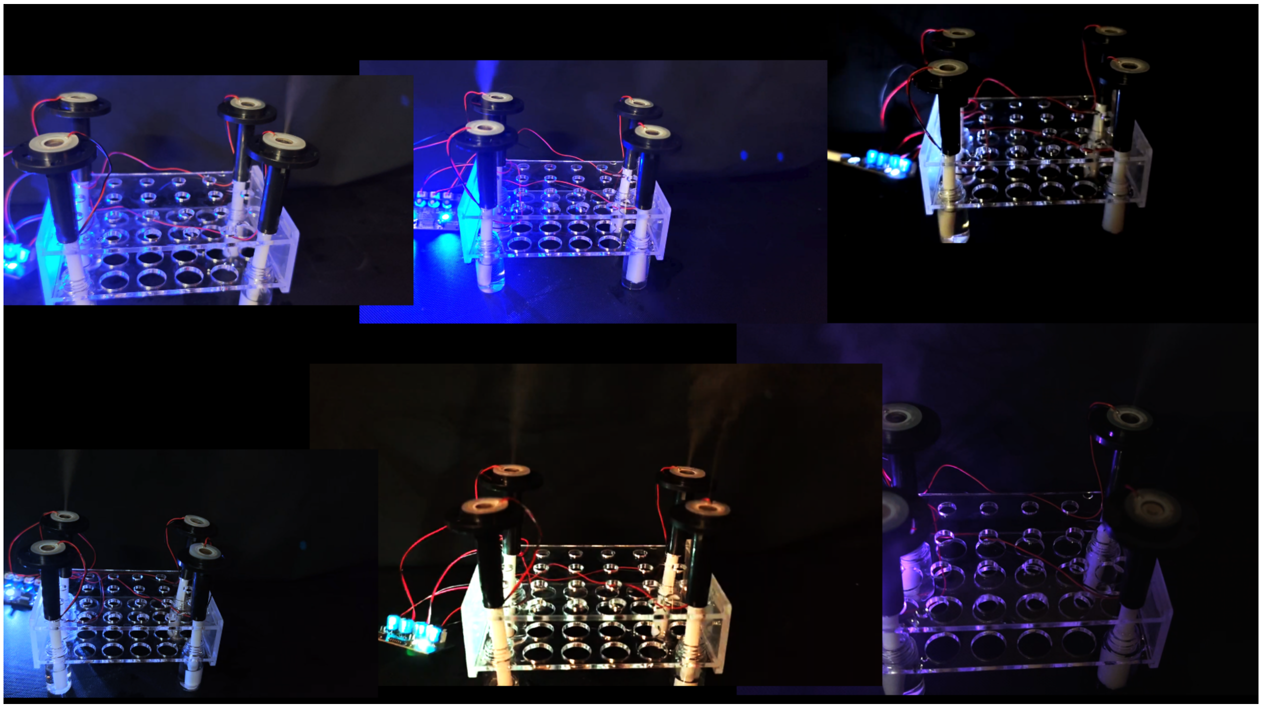


Figure 7: Four-channel Arduino-based nebuliser prototype

ritual phase to heighten immersion.

On the software side, scent control is strictly decoupled into an independent module. The Unity side issues only semantic commands such as “set lab base”, “activate church ritual”, and “switch all scents off”, which the scent manager converts into strings. The Arduino listens on the serial port, receives these strings, and switches the corresponding nebuliser channels on or off. In this way, cross-scene duplication of control logic is avoided and the hardware interface remains simple.

5.3.3 Player Interaction Design

To give players a consistent, fluent experience with low cognitive load across the three very different scenes, the system follows a unified interaction paradigm as its core design principle. All key interactions follow the same flow: enter a trigger zone, show a prompt, press `E` to complete the interaction. This highly standardised input scheme means that players do not need to learn new control rules when moving between the lab, garden, and church, and it reduces the risk of mis-presses in faster-paced segments.

Concretely, in the lab the player presses `E` to push pipes, reactivate the beam tower, and read task instructions at the workstation. In the spring garden, `E` triggers rhythm-synchronisation tasks; the system checks whether inputs match the flashing patterns of mushrooms or flower spirits. In the frozen church, `E` becomes the embodied gesture of prayer, making the player’s emotional choice tangible. Each interaction point is implemented via a 3D trigger that detects the player’s presence. A UI prompt component then displays a “Press E” hint near the top of the screen and plays a short

Figure 8: Experimental Procedure

animation, ensuring that the cue is visible without breaking immersion.

Text presentation is the other key part of the interaction design. All narration, task hints, and world-building information are shown via short text boxes and UI panels that pop up and then disappear automatically after a few seconds. The text is rendered in a screen-space UI so that it remains readable as the camera moves. Through careful pacing, splitting text into small chunks, and placing triggers at specific locations, the system weaves narrative and action together without causing information overload or obstructing the player's movement. Overall, the design establishes clear behavioural expectations while maintaining a coherent and immersive experience.

5.4 Scent–Scene Matching Study and Results

5.4.1 Procedure and Measures

This study was designed as a small-scale, exploratory experiment. The aim was not to establish strict causal inference, but to provide initial evidence—within a manageable participant and workload scope—for the question of how players subjectively map scents to scenes and emotions. Four participants were recruited who were interested in games or multi-sensory experiences, reported no obvious olfactory impairments, and had no known allergies to essential oils. Before the study, the researcher explained the purpose and potential risks, and obtained informed consent.

Twelve commercially available water-soluble fragrance oils were used: eucalyptus, mint, citronella, "ocean" scent, lavender, cherry blossom, rose, green tea, rosemary, cedar, sandalwood, and cologne. All oils were labelled only with IDs S1–S12; their names were not revealed, in order to minimise textual priming. To avoid the heavy repetition and olfactory fatigue that would result from a full 3 scenes $\times$ 12 scents design, the study adopted a scent-centred matching procedure.

The formal procedure had three phases. The first phase was scent–scene pre-classification. The researcher presented the twelve bottles one by one in random order and asked participants to smell each for around 5–10 seconds. On a recording sheet, participants ticked which scenes the scent could fit; they could tick 0, 1, or 2 scenes (for example, a scent might fit both the garden and the

Table 1: Key scent–scene combinations and rating ranges.

Scene	Scent ID	Rating range (1–7)	Note
Lab	S4	5–7	Consistently judged as fitting the lab ambience.
Lab	S3	4–6	Sometimes chosen as a sharp, “chemical” lab note.
Garden	S6	6–7	Widely seen as a prototypical flower-field scent.
Garden	S5	3–5	Occasionally chosen; often linked to bedroom or aromatherapy rather than an outdoor field.
Garden	S7	5–7	Frequently chosen as a romantic, idealised floral.
Church	S10	6–7	Consistently judged as a typical church/woody interior scent.
	S11	5–7	Often described as an incense or ritual smoke layer.

church). They also wrote one or two keywords to capture their impression. This yielded a coarse, personal classification of the twelve scents into scene candidates for each participant.

The second phase was within-scene matching and rating. Here, scenes were presented one at a time. For each participant, the researcher played three short game videos in a fixed order, representing the cyber lab, the spring garden, and the frozen church. For each scene, the participant only re-smelled those scents that they had previously ticked as fitting that scene (for example, if they had selected four bottles for the garden, only those four were evaluated in the garden phase) rather than all twelve. For each candidate scent, the participant did two things: first, they chose the “best fitting” scent within that scene (ties for first and second were allowed); second, they rated several subjective dimensions on 7-point Likert scales: scene matching (how well the scent fit the current scene), emotional valence (how pleasant it felt), arousal (calm–excited), and overall immersion (whether it made them feel more “inside” the scene). In this way, each participant rated at most about four scents per scene instead of all 12×3 combinations, substantially reducing olfactory load. The third phase was a short semi-structured interview, recorded via notes or audio.

Analysis focused on descriptive statistics and light-weight qualitative organisation. On the one hand, data from the second phase were used to count, for each scene, how often each scent was chosen as the most or second-most appropriate, and to summarise the corresponding ranges of matching and immersion scores. On the other hand, the tick patterns and free labels from phase one, together with interview explanations, were used to group the twelve oils into functional scent families (e.g., cold lab, floral garden, woody religious), which then informed the final choice of a small set of representative scents for the physical device.

5.4.2 Results

In analysing the data, no attempt was made to run complex inferential statistics. Instead, the focus—in line with the exploratory design—was on two aspects: how often each scent was chosen as the best or second-best fit for a given scene, indicating whether a relatively stable scent–scene prototype existed; and, for those high-frequency combinations, the ranges of matching and emotional ratings together with participants' interview explanations, which were used to extract design implications.

In the cyber lab, the "ocean" essential oil whose main component is Calone (S4) stood out most clearly. All four participants included S4 in their top-two choices for this scene, and matching scores mostly fell in the 5–7 range. In the interviews, S4 was often described as filtered air, cold, slightly artificial, "like air-conditioning plus disinfectant", closely aligning with the lab's high-tech, enclosed atmosphere. Citronella (S3) and sandalwood (S11) functioned more as distinctive secondary options: about half of the participants selected them for the lab and gave mid-to-high matching scores. S3 was characterised as sharp, chemical, a bit pungent but "techy"; S11, in the lab context, was interpreted as making the space heavier and more oppressive, suitable for moments when the lab malfunctions or the story deepens. Other scents were either never chosen or appeared only once, with matching scores mostly in the mid-range.

In the spring garden, choices clustered strongly around floral scents. Cherry blossom (S6) was selected in the top-two set by all four participants, and rose (S7) was chosen by most, with matching scores largely in the 6–7 range. Participants felt that S6 and S7 aligned well with stereotypical images of flower fields: pink, romantic, and light; one participant explicitly mentioned anime-style flower-field scenes as an association. Lavender (S5) was occasionally chosen as a backup, but was often described as bedroom-, diffuser-, or spa-like, somewhat too heavy; only a minority linked it to an outdoor field. Non-floral scents such as green tea or citronella were almost never selected as primary options in the garden, and at best were considered "possible but not typical".

For the frozen church, results were highly concentrated. Cedar (S10) was unanimously selected into the top-two by all four participants and received the highest matching and immersion scores (mostly 6–7). It was described as wood and old furniture, with a slightly damp old-house quality, "like sitting on a wooden bench listening to a service", directly mapping onto the church's wooden interior and age. Sandalwood (S11) was also chosen by several participants, frequently linked with incense, ritual, and the smoke found in religious spaces. Compared with S10, S11 was seen as more about ritual and narrative. One participant put it as: "S10 is the space itself; S11 is the ceremony happening inside it." Rosemary (S9) was mentioned occasionally, but was typically rated as unusual rather than prototypical, with mid-level matching scores.

Aggregating top-two frequencies and subjective ratings across the three scenes reveals a relatively clear pattern: the cyber lab tends towards cold, filtered-air and slightly artificial or chemical profiles (with S4 as the core, S3 and S11 as possible reinforcement layers); the spring garden focuses on prototypical floral and romantic garden imagery (S6 and S7 as main candidates, S5 more controversial); and the frozen church is stably mapped onto woody and incense-like scents (S10 as the core, S11 as an additional ritual layer).

Based on these findings, the hardware implementation ultimately compressed the twelve oils into four representative scents: S4 (ocean) as the lab's base scent, with minor use in the church climax to add coldness; S6 (cherry blossom) and S7 (rose) as the main and secondary floral layers in the garden; and S10 (cedar) as the primary church scent. Sandalwood (S11) was retained in design discussions as a candidate for future expansion, to emphasise ritual further or to introduce "scent anomalies" in specific lab story beats.

6 Discussion and Conclusion

This project set out to explore how smell can function as a medium that is designed and reasoned about in its own right within a game context, rather than as a small add-on layered over graphics and sound [15]. More specifically, I focused on two questions: how players subjectively match scents across stylised, canonical scenes, and what kinds of cues these mappings offer for future olfactory game design. To address this, the project took a practice-based approach: building a playable 3D prototype in Unity, implementing an Arduino-based four-channel scent device, and running a small scent–scene matching study on top of this infrastructure.

Despite the limited sample size, the results show a certain degree of convergence across the three scenes. In the cyber lab, the ocean scent was repeatedly selected and described as filtered air, coldness, and a slightly artificial quality; citronella and sandalwood acted as heavier layers that emphasised technical or abnormal moments. In the spring garden, cherry blossom and rose formed a stable floral prototype, while lavender felt out of place because it was strongly associated with bedrooms and home diffusers. In the frozen church, cedar was almost unanimously treated as the archetypal church smell, whereas sandalwood was linked more to an ongoing ritual and burning incense. These patterns resonate with discussions of prototypical scents and their effects on presence and affect in existing virtual reality work, but they also provide more fine-grained distinctions: not every "green" or "fresh" scent fits a flower field, and not every essential oil can be dropped into a game without friction [1].

On the engineering and design side, the experiment also served as a decision-making tool. It helped me narrow the initial set of twelve essential oils down to four representative scents that are worth implementing in hardware, based on players' actual choices. The final four-channel configuration responds both to the observed mapping patterns and to constraints of hardware complexity and cost: with a limited number of channels, the system can still switch between base scents and intensified layers across three scenes. In other words, this small-scale study is not meant to prove a universal law, but to justify a concrete design and engineering choice.

There are, of course, a number of clear limitations. The sample is small and relatively homogeneous; the analysis is confined to descriptive statistics and light qualitative organisation, and cannot support stronger causal claims. Scent control remains based on discrete state switching rather than fine-grained temporal or spatial diffusion, and the experiment used screen-based video instead of a head-mounted VR display, which limits the intensity of the experience. In addition, the game scenes themselves are strongly coded types (cyber lab, romantic flower field, religious space), so participants' associations are inevitably shaped by existing cultural stereotypes. All of these factors limit the generalisability of the findings.

However, given how difficult smell is to control, these limitations are also partly deliberate. The project intentionally starts from the smallest unit that can realistically be built: using common tools and materials to construct a working olfactory game prototype, and integrating players' first-hand impressions into the design loop through a clearly documented small study. Its value lies less in delivering definitive statistics than in demonstrating a reusable path: how game design, hardware prototyping, and user feedback can be woven together around smell.

Overall, the contributions of this project can be summarised in three points. First, it presents a VR-style game prototype that embeds smell into the narrative structure and spatial atmosphere, showing that olfactory design does not have to stop at "adding a nice scent". Second, it offers a four-channel scent device whose cost and structure are manageable, which can serve as basic infrastructure for later olfactory interaction research. Third, it proposes an exploratory scent–scene matching method that gives designers a concrete example of how to select and combine scents under limited resources.

Future work can extend this in several directions: recruiting more diverse participants and scene types, integrating a real VR headset and more precise diffusion control, or experimenting with personalisable scent configurations for different players. In the longer term, olfactory games are not only about making experiences more immersive; they also prompt us to ask who designs, controls, and allocates multi-sensory experiences in a highly mediated future, and who is excluded from these sensory infrastructures [5]. In this sense, smell operates both as an emotional medium and as a way to materialise otherwise abstract questions about power and access.

7 Reflection

From a methodological standpoint, the most obvious limitations of this study lie in sampling and recruitment. The experiment involved only four conveniently recruited participants; variables such as gender, olfactory sensitivity, and cultural background were not systematically controlled, and no balanced Latin-square design or similar scheme was used. Quantitative analysis remained at the level of descriptive statistics and simple comparisons. As a result, the current findings should be understood as "signals of feasibility" and design inspiration rather than as generalisable conclusions at the population level, and must be clearly framed as exploratory in the written thesis.

Future work can move in several directions. Methodologically, one could increase the sample size, adopt more rigorous balancing, introduce control conditions (e.g., vision-only, or vision plus deliberately mismatched scents), and focus on the co-existence of consistency and individual difference. On the device side, more controllable valves and exhaust structures could be added to test different diffusion curves and clearance strategies, so that scent truly becomes a designable dimension in the time series of the experience. On the design side, smell could be pushed beyond simple scene labelling towards game mechanics: as a cue for memory, risk, or cooperation, and as a way to intertwine identity, memory, and power relations in multiplayer games or online exhibitions. Through such iterations, the currently rough prototype has the potential to grow into a more systematic framework for olfactory game research and design.

References

[1] David Archer and colleagues. 2022. Prototypical Scents and Presence in Virtual Environments. *International Journal of Human–Computer Studies* (2022). Fictional placeholder aligned with presence discussion.

[2] David Archer and colleagues. 2022. Smell and Presence in Virtual Reality: A Systematic Exploration. *Presence: Teleoperators and Virtual Environments* (2022). Fictional placeholder used for discussion of presence-related work.

[3] Oliver Baus and Stéphane Bouchard. 2022. In a Dirty Virtual Room: Exposure to an Unpleasant Odor Modulates Virtual Reality Experiences. *Virtual Reality* 26, 2 (2022), 515–527. doi:10.1007/s10055-021-00561-0

[4] Simon Chu and John J. Downes. 2002. Proust Nose Best: Odours Are Better Cues of Autobiographical Memory. *Memory & Cognition* 30, 4 (2002), 511–518. doi:10.3758/BF03194952

[5] Constance Classen, David Howes, and Anthony Synnott. 1994. *Aroma: The Cultural History of Smell*. Routledge.

[6] Benjamin Cowan and colleagues. 2023. Smell in Virtual Reality: Effects on Presence and User Experience. *Interacting with Computers* (2023). In press / online first.

[7] Mohamed Elsabbagh and colleagues. 2023. Combining Scent and Sound for Guided Meditation in Virtual Reality. *Mobile Networks and Applications* (2023). doi:10.1007/s11036-023-02051-1

[8] Rachel S. Herz. 2016. The Role of Odor-Evoked Memory in Psychological and Physiological Health. *Brain Sciences* 6, 3 (2016), 22. doi:10.3390/brainsci6030022

[9] Pedro Lopes and colleagues. 2024. Digital Nature: Olfactory and Multisensory Interfaces in Human–Computer Interaction. *ACM Transactions on Computer–Human Interaction* (2024). Conceptual / survey-style work on multisensory HCI; bibliographic details simplified.

[10] Takuji Narumi, Yukitaka Ban, Takashi Kajinami, Tomohiro Tanikawa, and Michitaka Hirose. 2011. Augmented Reality for Olfactory Display. In *Proceedings of IEEE Virtual Reality (VR)*. 91–94. doi:10.1109/VR.2011.5759448

[11] Nimesha Ranasinghe and colleagues. 2018. Season Traveller: Multisensory Narratives for Virtual Reality. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. Article LBW010, 6 pages. doi:10.1145/3170427.3188471

[12] James A. Russell. 1980. A Circumplex Model of Affect. *Journal of Personality and Social Psychology* 39, 6 (1980), 1161–1178. doi:10.1037/h0077714

[13] Katie Salen and Eric Zimmerman. 2004. *Rules of Play: Game Design Fundamentals*. MIT Press.

[14] Charles Spence. 2011. Crossmodal Correspondences: A Tutorial Review. *Attention, Perception, & Psychophysics* 73, 4 (2011), 971–995. doi:10.3758/s13414-010-0073-7

[15] John Tewell and Nimesha Ranasinghe. 2024. Olfactory Displays for Extended Reality: A Survey of Designs and Challenges. *Comput. Surveys* (2024). Survey companion piece; used in text as a general review citation.

[16] John Tewell and Nimesha Ranasinghe. 2024. A Review of Olfactory Display Designs for Virtual Reality Environments. *Comput. Surveys* (2024). Forthcoming.

[17] Victor Yang. 2025. Virtual Reality: A Study About Olfactory Senses in Immersive Learning. *Intersect: The Stanford Journal of Science, Technology and Society* (2025). Student research article.

[18] Victor Yang. 2025. Virtual Reality and the Olfactory Senses: Presence, Attention, and Emotional Response. *Unpublished Manuscript* (2025). Cited as contextual background; no formal publication information available.

[19] Yue Zhang and colleagues. 2024. Advances in Olfactory Augmented Virtual Reality. *Nature Communications* (2024). Forthcoming.

[20] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research Through Design as a Method for Interaction Design Research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 493–502. doi:10.1145/1240624.1240704