The POMS Effect: Measuring the impact of overlapping architectures on User Engagement in Virtual Reality

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***Abstract*—Natural walking offers high immersion in Virtual Reality (VR) but is constrained by physical space. Overlapping architectures, which reuse physical space, are a potential solution. Building on foundational principles of Architecturally Consistent Maze Generation in VR [1], we developed,implemented, and evaluated the Procedural Overlapping Maze System (POMS). POMS procedurally generates and prunes right-angled, overlapping maze corridors in real-time, enabling continuous natural walking in footprints $\geq$ 4x4m. This paper presents a controlled, between-group empirical evaluation (N=17 matched pairs) comparing POMS against a spatially equivalent static maze in an 8x8m tracked area using an Oculus Quest 3. Participants performed a time-constrained navigation task. We investigated effects on user engagement (time-on-task), usability (User Experience Questionnaire - UEQ), presence (igroup Presence Questionnaire - iPQ), and cybersickness (Simulator Sickness Questionnaire - SSQ). We hypothesized POMS would lead to increased time-on-task (H1), and that its dynamic nature would not negatively impact user experience, aiming for UEQ, iPQ, and SSQ outcomes comparable to a static environment (H2-H4).**

Results indicated no statistically significant differences in UEQ (H2) or iPQ (H3) between conditions, supporting our hypotheses that POMS could maintain these experiential qualities. Surprisingly, regarding cybersickness (H4), the increase in Oculomotor, Disorientation, and Total SSQ symptoms was significantly smaller in the POMS condition compared to the Static condition, while there was no significant difference for Nausea. This finding demonstrates an unexpected and substantial comfort benefit with POMS, exceeding our initial hypothesis of mere comparability. While POMS did not show a statistically significant increase in time-on-task (H1) in this study, a numerical trend suggesting longer engagement was observed. The markedly improved comfort achieved with POMS strongly suggests that such architectures have the potential to facilitate longer interaction periods, warranting further investigation into task design to fully leverage this benefit. These findings highlight that procedurally overlapping architectures like POMS can enable extended natural walking, not only without degrading core experiential qualities, but also by significantly enhancing user comfort.

***Index Terms*—Virtual Reality (VR), Procedural Content Generation (PCG), Locomotion, Cybersickness, User Experience (UX), Overlapping Architectures, Maze Generation, User Study**

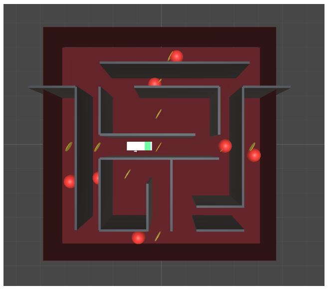
I. Introduction

Virtual Reality (VR) locomotion is a key challenge for creating immersive experiences. While natural walking, leveraging the user's own physical movement, is the gold standard for intuition and presence [2], [3], it is fundamentally constrained by limited physical space. This mismatch hinders boundless exploration. To bridge this gap, various techniques have emerged. Supernatural methods like teleportation [4] bypass physical limits but can reduce immersion and induce cybersickness [5]. Redirected Walking (RDW) aims to preserve natural walking by subtly manipulating virtual-to-real world mapping [3], [6], though it often requires substantial tracking areas [7], [8], sophisticated algorithms [9], [10], and can sometimes lead to perceptible manipulations.

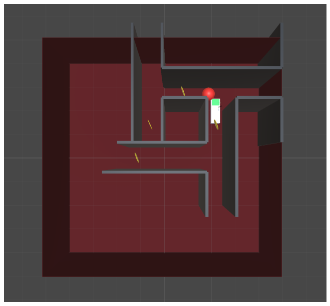
An alternative strategy involves manipulating the Virtual Environment (VE) architecture itself, creating ”overlapping” or ”impossible spaces” [11] that reuse the physical area while maintaining local consistency. Prior work has explored such concepts through tile-based mazes with portals [12] or by leveraging discrete environmental changes [13] though these often involve distinct transitions or suit specific structures.

Building upon the conceptual framework for architecturally consistent dynamic maze generation presented in [1], this work introduces the concrete implementation and rigorous evaluation of the Procedural Overlapping Maze System (POMS). POMS procedurally generates and prunes right-angled, overlapping maze corridors in real-time. Figure 1 visually contrasts the POMS environment, showcasing its dynamic generation during navigation (Fig. 1b-d), with a traditional Static maze

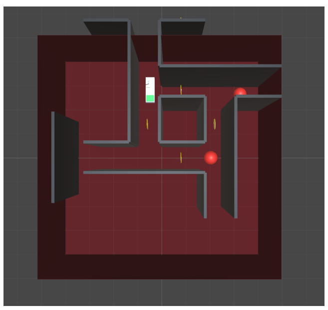
(Fig. 1a), both featuring key interactive elements. This approach is designed to enable a seamless experience of continuous natural walking and theoretically infinite exploration within constrained physical footprints (≥4x4m)



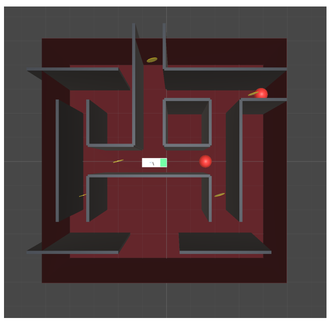
(a) The Static maze condition with a fixed, pre-defined layout.



(b) POMS - first left turn.



(c) POMS - second left turn.



(d) POMS - third left turn.

Fig. 1. Visual comparison of maze conditions and dynamic generation in POMS. The player is represented by a white rectangle with a green indicator denoting the forward direction. Collectable coins (yellow ovals) and obstacles (red spheres) are present as interactive elements. (a) The Static maze condition with a fixed, pre-defined layout. (b–d) A sequence illustrating the Procedural Overlapping Maze System (POMS) where the environment dynamically reconfigures. As the player makes three consecutive left turns (from b to c, and c to d), corridors are generated and pruned in real-time, demonstrating the reuse of physical space to enable continuous navigation.

Despite the promise of such reconfigurable environments, their empirical impact on user experience and comfort lacks rigorous evaluation. This study, therefore, conducts a controlled, between-group empirical comparison (N=17 matched pairs) of POMS against a spatially equivalent static maze. We formulated four primary hypotheses:

Engagement (H1) : *We hypothesized that POMS would lead to a **greater Time-On-Task** (engagement) compared to the static maze, given its potential for theoretically infinite exploration.*

User Experience (H2) : *Recognizing the potential perceptual complexities of a dynamically changing environment, we aimed to determine if POMS could maintain user experience levels comparable to a stable one. Thus, we hypothesized that there would be **no significant detriment** in User Experience (as measured by the User Experience Questionnaire - UEQ) between the POMS and static maze conditions, suggesting that POMS's dynamic nature would not detract from overall usability and satisfaction.*

Presence (H3): *Similarly, for presence, we hypothesized that there would be **no significant detriment** in the sense of Presence (as measured by the igroup Presence Questionnaire - iPQ) between the two conditions, indicating that POMS could maintain immersion levels comparable to a stable environment.*

Cybersickness (H4): *For cybersickness, while the dynamic spatial reconfiguration inherent in POMS could introduce novel perceptual stimuli, the preservation of 1:1 natural walking is a known mitigating factor. Therefore, we hypothesized that POMS would achieve cybersickness outcomes **comparable to the static maze**, resulting in **no significant difference** in the change in cybersickness symptoms (as measured by the Simulator Sickness Questionnaire - SSQ) between the POMS and static maze conditions.*

This paper makes two primary contributions:

1) The design, implementation, and detailed description of the Procedural Overlapping Maze System (POMS), a novel system that realizes and extends the foundational concepts for architecturally consistent maze generation proposed in [1], enabling continuous natural walking through dynamically reconfigured environments.
2) Robust empirical evidence (N = 17, matched pairs) quantifying the effects of this approach on **user engagement**, **experience**, **presence**, and **cybersickness** compared to a traditional static maze. The findings demonstrate that such procedurally overlapping architectures can maintain experiential quality and, **notably, offer significant comfort advantages**, while also highlighting the need for further research to fully translate extended walking potential into demonstrably increased user engagement.

The remainder of this paper details related work, the POMS framework, the experimental methodology, results, and a discussion of their implications.

II. Related Work

Navigating virtual environments (VEs) is a fundamental interaction in Virtual Reality (VR), yet it presents persistent challenges, primarily stemming from the discrepancy between the desire for expansive exploration and the physical constraints of the user's playspace [2]. Addressing this locomotion problem effectively is crucial for user engagement, immersion, and comfort. Over the years, a diverse range of techniques has emerged, broadly categorizable as supernatural or natural locomotion methods.

A. VR Locomotion Techniques: Bridging Virtual and Physical Space

Navigating large Virtual Environments (VEs) with limited physical space is a core VR challenge. Supernatural locomotion techniques, such as teleportation [4] can mitigate cybersickness, they may reduce immersion and spatial understanding. Controller-based movement often induces cybersickness due to visual-vestibular conflicts [5]. Other approaches like Walking-in-Place (WiP) utilize physical gestures detected via sensors [14] or head/hand movements [15] to drive virtual motion. While more embodied than teleportation, WiP still presents a sensory mismatch and can lead to fatigue.

Ideally, users would employ natural locomotion (1:1 physical walking) [2], which provides the most congruent sensory experience, enhancing presence and spatial awareness [16], [17]. However, its direct dependence on the available physical tracking area presents a significant limitation. To overcome this, researchers explore ways to extend the boundaries of natural walking or, alternatively, to manipulate the VE's architecture itself. Our work focuses on this latter strategy, aiming to optimize the VE to accommodate continuous natural walking within constrained physical spaces.

B. Redirected Walking: Extending Natural Locomotion via Imperceptible Manipulation

Redirected Walking (RDW) techniques [3] extend natural walking in limited physical spaces by imperceptibly manipulating the mapping between real and virtual movements. Small "gains" (e.g., in translation [6], rotation [18], or curvature [3]) steer users away from physical boundaries, allowing them to traverse larger VEs. While RDW preserves natural walking's benefits like high presence and low cybersickness, its efficacy is constrained.

Several factors limit RDW. The applied gains must remain below human perceptual thresholds [18], [19] to avoid breaking immersion or causing disorientation. RDW also typically requires substantial physical space (e.g., 6x6 m [7]) for path deviations to accumulate subtly without overly aggressive, noticeable manipulations. Furthermore, implementing effective RDW necessitates sophisticated steering algorithms [9], [20] to predict user paths and apply gains appropriately, which can become complex, particularly in dynamic or multi-user scenarios [8], [21]. Inevitably, when users approach physical boundaries despite these efforts, more overt reorientation techniques like freeze-turn maneuvers [22] may be employed, temporarily interrupting the flow of natural walking and potentially disrupting the user experience. RDW, therefore, presents a powerful yet bounded solution. Our work explores overlapping VE architectures as an alternative that avoids explicit user path manipulation, focusing instead on manipulating the VE's structure.

C. Overlapping Architectures and Impossible Spaces: Manipulating the Environment Itself

Instead of manipulating perceived user movement, 'overlapping architectures' or 'impossible spaces' directly alter the Virtual Environment's (VE) spatial structure to enable extended exploration in limited physical areas [11]. These VEs appear locally coherent but are globally unrealizable. This approach leverages users' frequent failure to notice structural inconsistencies, especially during task focus or perceptual events like saccades or blinks [23], [24].

Suma et al. [11] found users tolerate significant spatial overlap (e.g., 56% in smaller spaces) before detecting impossibility, opening avenues for VE compression. Techniques include exploiting 'change blindness' during transitions (e.g., altering rooms post-doorway passage [13]), or dynamically warping VE geometry, such as curving corridors with Space Bender [25] or using overt 'Foldable Spaces' [26]. Others generate layouts prioritizing content over strict architectural possibility, implicitly allowing overlap [27].

Specifically for maze-like environments, Mittal et al. [28] designed limitless corridors, though not focused on overlap for space reuse. Koltai et al. [12] created procedurally generated, tile-based overlapping mazes, but used portals for transitions between sections, differing from a continuous architectural overlap. Our work, POMS, builds on principles of architecturally consistent dynamic maze generation [1], focusing on continuously unfolding an architecturally overlapping corridor structure through real-time procedural generation and pruning, aiming to maximize immersion within a constrained physical area. The perceptual and cognitive implications of such continuous, dynamic reconfiguration near a naturally walking user, particularly for comfort, warrant the thorough investigation this paper provides.

D. Evaluating User Experience in VR Locomotion

Evaluating user experience (UX) in VR locomotion necessitates assessing cybersickness, usability, and presence, for which standardized instruments are typically employed. The Simulator Sickness Questionnaire (SSQ) [29] is widely used for cybersickness symptoms [5], [30]. The User Experience Questionnaire (UEQ) [31] assesses pragmatic and hedonic qualities related to usability and satisfaction. The igroup Presence Questionnaire (iPQ) [32] measures the subjective sense of "being there," critical for immersive techniques [16].

While these instruments are frequently used to evaluate individual locomotion techniques or compare distinct methods (e.g., teleportation vs. joystick control [4]), a **notable gap exists in their application to rigorously compare architecturally overlapping environments designed for natural walking against equivalent static layouts.** Specifically, a controlled study examining the simultaneous impact of procedural overlapping architectures on engagement, sickness, usability, and presence using this combination of validated measures has been lacking. The present study directly addresses this gap, providing empirical evidence on the user experience afforded by systems like the Procedural Overlapping Maze System (POMS).

III. Maze Generation Framework

This work introduces the concrete implementation and rigorous evaluation of the Procedural Overlapping Maze System (POMS), which realizes and extends the foundational concepts proposed in ACMGVR [1]. A key methodological advancement in POMS is its approach to determining available pathways. While ACMGVR proposed using run-time raycasting to measure available physical space, POMS adopts a more performant strategy by pre-calculating path possibilities based on the known dimensions of the tracked area during initialization. This shift is critical for the real-time generation and pruning required to maintain a consistent $\geq$ 72Hz frame rate, a crucial factor for VR user comfort.

A. Data Representation and Maze Structure

POMS relies on a Tree class managing MazeNode objects. Each MazeNode represents a significant point (junction or dead end) and stores its world-space Position, Depth (Level), parent/child references, and a crucial IncomingDirection vector. This vector, indicating the player's entry direction into the node, is fundamental for maintaining local orientation and enforcing the system's right-angled corridor structure, embodying the rotational indexing concept. The Tree class also manages references to GameObject prefabs for maze components (e.g., nodePrefab for junctions, wallPrefab for corridors, nodewallPrefab for closing paths).

B. Procedural Expansion and Corridor Generation

Maze expansion is triggered by the user's physical movement. The nodePrefab's collider is triggered when the player's avatar enters its volume, which is strategically placed at the center of a potential junction. When the player's VR avatar enters a nodePrefab's collider, its NodeCollisionHandler signals a central MazeGenerator. If the interacted MazeNode is a leaf node (no existing children), the Tree class's createChildren method generates new pathways. This method calculates world-space positions for new Left and Right child nodes based on the parent (current) node's Position and IncomingDirection, using predefined corridor segment lengths and strict ±90-degree rotations (via rotateLeft/rotateRight helper methods). New MazeNode objects are created for these child positions and linked hierarchically.

Visually, the parent MazeNode then instantiates wallPrefab GameObjects to form corridor segments connecting to its new children. Crucially, to maintain the illusion of a continuous, architecturally sound environment and prevent visual access to pruned areas, a nodewallPrefab is also instantiated. This visually closes off the path from which the user just arrived, effectively appearing behind the parent node of the newly generated segment(s) and perpendicular to its IncomingDirection. This real-time, collision-driven expansion ensures new pathways appear seamlessly, facilitating a depth-first exploration experience.

The system also robustly handles backward traversal. If the user turns around and re-enters the collider of the previously occupied node (the parent), the system reverses its traversal through the maze's tree structure. The fixActiveMap method then deactivates the forward branch and reactivates the previous corridor, allowing the user to seamlessly retrace their steps or explore alternative paths from an earlier junction.

C. Visibility Management & Pruning

To enable architectural overlap within a finite physical space and maintain performance, POMS employs dynamic visibility management. Only a small, local subset of the maze surrounding the player—the activeNodes—is kept active (visible and collidable). This subset, typically including the currentNode (player-occupied), its Parent, and direct Left/Right child nodes, is managed by the Tree class's fixActiveMap method, invoked upon node interaction. GameObjects representing MazeNode instances and their associated corridors not in activeNodes are deactivated. This dynamic activation/deactivation prunes distant or unseen maze branches, ensuring the user perceives only a locally consistent environment, prevents views of potentially contradictory overlapping geometry, and significantly reduces rendering and physics load for stable performance.

D. Interactive Element Integration

To provide a structured task and enhance engagement, interactive elements are integrated during corridor generation. When new segments are instantiated, a coinPrefab (collectible, adds to a game timer) and a firePrefab (moving obstacle, subtracts from timer) have a probabilistic chance (50% each) of being placed. A PlayerManager script on the user's avatar detects collisions with these elements (via OnTriggerEnter), triggering corresponding time adjustments and visual feedback (DamageEffect). This transforms basic navigation into a playable, time-constrained game.

E. Implementation & Performance Considerations

POMS was implemented in the Unity Engine (2022.3.5f1) using C # for the Meta Quest 3. Environmental components are instantiated from optimized prefabs. The system targets a consistent $\geq$ 72Hz frame rate, critical for VR comfort, achieved through the efficient tree-based maze logic and aggressive visibility pruning. POMS is designed for physical tracked areas of $\geq$4x4m, with the study evaluation conducted in an 8x8m space.

IV. Evaluation Methodology

To rigorously assess the impact of the Procedural Overlapping Maze System (POMS) on user experience compared to a traditional static maze architecture, we designed and conducted a controlled laboratory experiment. This section details the methodological choices made to ensure valid and reliable comparisons between the two conditions.

A. Participants and Study Design

We employed a **between-group** experimental design to evaluate POMS against a static maze, focusing on user engagement (time-on-task), usability (UEQ), presence (iPQ), and cybersickness (SSQ). This between-group approach was chosen primarily to **prevent potential carry-over effects** that could arise if participants experienced both conditions.

A total of 34 participants (M_age=21.2, SD=2.96; 27 male, 7 female) were recruited from the local university community. Inclusion criteria required normal or corrected-to-normal vision and no self-reported history of significant vestibular disorders or heightened motion sickness susceptibility. The study received Institutional Review Board (IRB) approval, and all participants provided written informed consent.

Prior to the experiment, participants completed a background questionnaire collecting demographic information and assessing experience levels crucial for matching. To account for individual differences influencing VR outcomes, participants were formed into **17 matched pairs**. Matching was based on self-reported:

- **Prior VR Experience:** Participants indicated their experience, categorized as "never used," "used fewer than 5 times," or "used more than five times."
- **Frequency of Gaming:** Participants reported their gaming habits, categorized as "daily," "several times a week," "once a week," "occasionally," or "never."

These categorical responses were numerically encoded, and pairs were formed by minimizing the distance between participants' encoded experience profiles, ensuring both individuals within a pair reported similar levels. Subsequently, one member of each pair was randomly assigned to the POMS condition (N=17) and the other to the Static condition (N=17). This matched-pairs procedure aimed to balance potential confounds related to VR familiarity and gaming proficiency across the two experimental groups.

B. Experimental Setup

1) Apparatus: The experiment utilized a Meta Quest 3 Head-Mounted Display (HMD), chosen for its standalone capabilities and robust inside-out tracking suitable for room-scale VR. A custom application developed in the Unity Engine (2022.3.5f1 LTS) implemented the virtual environments (VEs) for both POMS and Static conditions, including all gameplay logic (timer, interactive elements). All sessions occurred within a precisely measured and marked 8x8 meter physical tracking area, which accommodated the required natural walking and exceeded POMS's minimum 4x4m operational footprint. Standardization of the HMD, software, and physical environment ensured that observed differences were attributable to the maze condition.

2) Task and Conditions: Participants in both conditions performed an identical time-constrained maze navigation task using only natural walking within the 8x8m physical area. The primary objective was to achieve the highest "Star Level" (one star awarded per 60s of active engagement) by managing an initial 90-second game timer. Interacting with coins added 15s to the timer, while colliding with moving fireballs subtracted 30s. The placement logic and density of these interactive elements, along with visual assets (corridor style, width) and task goals, were consistent across conditions; the Static maze was carefully curated to ensure comparable interactable density to what POMS would probabilistically generate. Based on the 50% probability of a coin or fireball spawning in a new POMS segment, we manually placed an equivalent number of these interactive elements throughout the fixed paths of the Static maze to ensure a balanced gameplay challenge. The task ended if the timer reached zero or if the participant chose to quit voluntarily. This standardized task incentivized continuous exploration and provided the context for all subjective measures.

The experiment featured two conditions, POMS (experimental) and Static (control), experienced within an 8x8m virtual room mapped 1:1 to the physical space:

- **POMS Condition (Experimental Condition):** Utilized the POMS framework (see Section III) to procedurally generate potentially infinite, right-angled, overlapping corridors in real-time. POMS dynamically activated/deactivated maze sections to continuously reuse the 8x8m space, creating the illusion of an environment larger than its physical confines without artificial locomotion.
- **Static Maze Condition (Control Condition):** Featured a pre-generated, non-overlapping maze entirely contained within the 8x8m virtual room. It was designed to be visually similar to POMS and employed identical rules and comparable density for interactive element placement, but had a finite, architecturally fixed explorable area without any space-reusing techniques.

The core distinction was the presence (POMS) versus absence (Static) of procedural, space-reusing overlapping architecture.

C. Procedures:

Following recruitment and completion of the background questionnaire for matching (as described in Sec. IV.A), participants attended individual sessions. Upon arrival, they were briefed on the study's general nature, the VR equipment (Meta Quest 3), and the task, without revealing specific hypotheses or condition differences. After providing written informed consent, participants completed a pre-exposure Simulator Sickness Questionnaire (SSQ).

The experimenter then set up the VR system for the participant's pre-assigned condition (POMS or Static). Participants were given standardized instructions covering the task objective (achieving "Star Levels" by managing exploration time), locomotion (natural walking), timer mechanics, interactive element effects (coins/fireballs), and the option to voluntarily quit. A brief practice session in a neutral VR environment allowed acclimatization to the HMD and natural walking before starting the main task.

During the task, the experimenter monitored participant safety. The task concluded when the in-game timer reached zero or the participant quit. Immediately post-exposure, participants completed the post-SSQ, the User Experience Questionnaire (UEQ), and the igroup Presence Questionnaire (iPQ), in that fixed order. A full debriefing on the study's purpose and condition comparison followed. Each session lasted approximately 20 minutes.

D. Measures and Statistical Analysis:

We collected behavioral and subjective data to test our hypotheses.

1) **Time-On-Task (H1: Engagement)** This primary behavioral measure recorded the total active navigation time (seconds) as an indicator of engagement.
2) **Simulator Sickness Questionnaire (SSQ) (H4: Sickness):** The standard SSQ [29] was administered pre-

and post-exposure. Following the original SSQ scoring protocol [29], which includes specific multipliers for item responses, scores were calculated for Nausea (N), Oculomotor (O), Disorientation (D), and Total SSQ. For each participant in both conditions, difference scores (Δ Scores = Post-score - Pre-score) for these measures were then computed. These individual Δ Scores were used for comparing cybersickness changes between the matched pairs across conditions.

3) **User Experience Questionnaire (UEQ) (H2: User Experience):** The full UEQ [33] (26 items, 7-point semantic differential) was administered post-exposure, yielding mean scores for six dimensions: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty.
4) **igroup Presence Questionnaire (iPQ) (H3: Presence):** The igroup Presence Questionnaire (iPQ) [32] (14 items, 7-point Likert scale) was administered post-exposure, providing mean scores for four subscales: General Presence (GP), Spatial Presence (SP), Involvement (INV), and Experienced Realism (REAL).

For statistical analysis, the 17 matched-pair observations for Time-On-Task, UEQ subscales, iPQ subscales, and the SSQ ΔScores were compared between *POMS* and *Static* conditions. The distribution of the differences in these outcome measures between paired participants was assessed for normality using the Shapiro-Wilk test. Based on this, paired-samples *t*-tests or Wilcoxon signed-rank tests were employed. A one-sided test was used for H1 (Time-On-Task: *POMS* > *Static*). For H2 (UEQ), H3 (iPQ), and H4 (SSQ ΔScores), where comparability was initially hypothesized, two-sided tests were used. If a significant difference was found with a two-sided test, appropriate one-sided follow-up tests were planned to determine the direction of the effect, particularly for SSQ to explore potential comfort benefits. A significance level of $\alpha = 0.05$ was adopted. Effect sizes (Cohen's d_z for *t*-tests; rank-biserial correlation r_{rb} for Wilcoxon tests) were calculated.

V. Results

This section presents the outcomes of the statistical analyses comparing the POMS (Dynamic) and Static maze conditions based on the matched-pairs design. Normality of the difference scores (POMS - Static) for each measure was assessed using the Shapiro-Wilk test. Based on these normality checks, appropriate paired statistical tests were employed. An alpha level of α = 0.05 was used for all significance testing.

A. Time-On-Task (H1)

We hypothesized (H1) that POMS would lead to greater Time-On-Task compared to the Static condition. Data involved N=17 matched pairs. Paired differences in Time-On-Task (POMS Time - Static Time) were normally distributed (Shapiro-Wilk W=0.9587, p=0.6064).

Participants in the POMS condition (M=447.35s, SD=402.53s) spent numerically more time on average than those in the Static condition (M=396.06s, SD=251.87s), as shown in Figure 2. However, a one-sided paired-samples t-test revealed this difference was not statistically significant (t(16)=0.3701, p=0.3581; Cohen's d_z=0.0898).

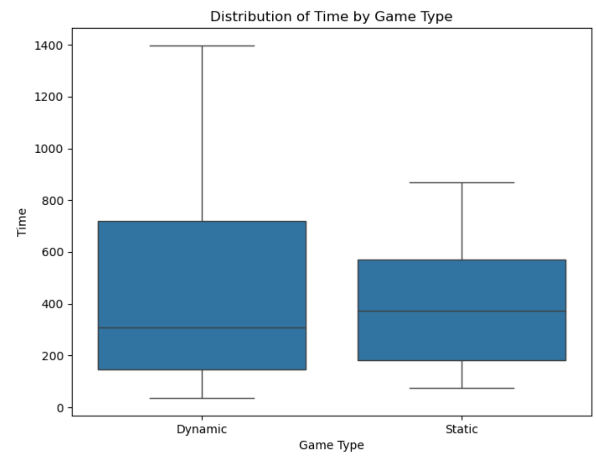


Fig. 2. Boxplot comparing the distribution of Time-On-Task (seconds) between POMS (Dynamic) and Static conditions (N=17 pairs).

Conclusion for H1: Hypothesis 1, predicting significantly longer Time-On-Task in the POMS condition, was **not supported** by the statistical analysis.

B. User Experience (UEQ) (H2)

We hypothesized (H2) no significant difference in user experience (UEQ) between conditions (N=17 matched pairs). Paired differences for UEQ subscales were tested for normality (Shapiro-Wilk). Paired-samples t-tests were used for Attractiveness, Perspicuity, Efficiency, Stimulation, Novelty, and UEQ Total score; a Wilcoxon signed-rank test was used for Dependability (due to non-normal paired differences: W=0.8703, p=0.0275). All tests were two-sided.

As shown in Table I and visualized in Figure 3, and consistent with H2, no statistically significant differences were found between POMS and Static conditions for any UEQ subscale or the total UEQ score (all p > 0.28).

Conclusion for H2: Hypothesis 2, predicting no significant difference in user experience as measured by the UEQ, was **supported**. None of the UEQ subscales nor the total score showed a statistically significant difference between the POMS and Static conditions.

C. Presence (iPQ - H3)

We hypothesized (H3) no significant difference in presence (iPQ) between POMS and Static conditions (N=17 matched pairs). Paired differences (POMS - Static) for all iPQ subscales (General Presence, Spatial Presence, Involvement, Experienced Realism, and Total Presence) were normally distributed (all Shapiro-Wilk p>0.05). Consequently, two-sided paired-samples t-tests were used.

TABLE I
COMPARISON RESULTS BETWEEN POMS AND STATIC CONDITIONS

Measure	Comparison Statistics		
	Test Statistic	***p-value***	***Effect Size***
Attractiveness	$t(16) = -0.7116$	0.4877	Cohen's $d_z = -0.1779$
Perspicuity	$t(16) = -0.6920$	0.4995	Cohen's $d_z = -0.1730$
Efficiency	$t(16) = 0.1687$	0.8683	Cohen's $d_z = 0.0422$
Dependability	$W = 52.0$	0.4031	$r_{rb} = -0.2090$
Stimulation	$t(16) = 0.1974$	0.8461	Cohen's $d_z = 0.0494$
Novelty	$t(16) = -1.1125$	0.2834	Cohen's $d_z = -0.2781$
UEQ Total Score	$t(16) = -0.4574$	0.6539	Cohen's $d_z = -0.1144$

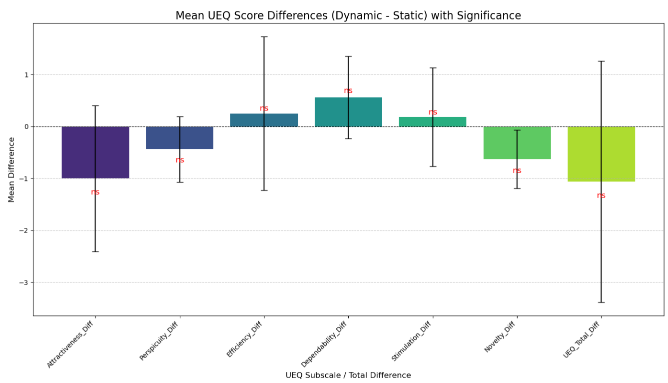


Fig. 3. Mean differences (POMS - Static) for UEQ subscales and total score (N=17 pairs). Error bars represent the standard error of the mean. ns indicates not significant.

As detailed in Table II and visualized in Figure 4, and supporting H3, no statistically significant differences were found between conditions for any iPQ subscale or the total presence score.

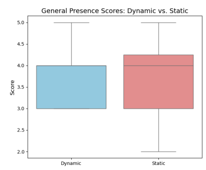
TABLE II
PRESENCE MEASURES: POMS VS STATIC CONDITIONS

Measure	Presence Statistics		
	Statistic	***p***	***Effect Size***
GP	$t(16) = 0.2225$	0.8269	$d_z = 0.0556$
SP	$t(16) = -1.0000$	0.3332	$d_z = -0.2500$
INV	$t(16) = 0.3810$	0.7085	$d_z = 0.0953$
REAL	$t(16) = 1.2585$	0.2274	$d_z = 0.3146$
Total	$t(16) = 0.4909$	0.6306	$d_z = 0.1227$

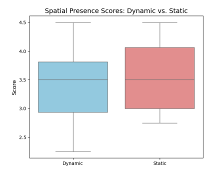
Conclusion for H3: Hypothesis 3, predicting no significant difference in the sense of presence as measured by the iPQ, was **supported**. None of the iPQ subscales nor the total presence score showed a statistically significant difference between the POMS and Static conditions.

D. Simulator Sickness (SSQ - H4)

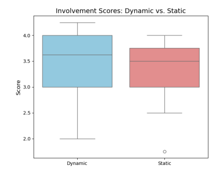
We hypothesized (H4) comparable changes in cybersickness symptoms (Δ Score = Post-exposure - Pre-exposure) between conditions (N=17 matched pairs). Paired differences in Scores



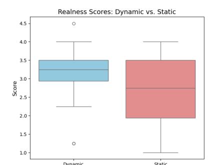
(a) GP Scores



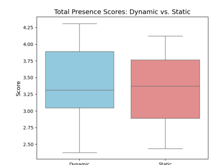
(b) SP Scores



(c) INV Scores



(d) REAL Scores

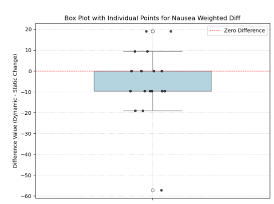


(e) TP Scores

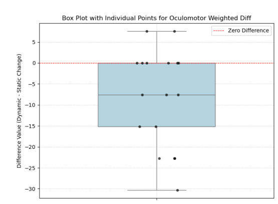
Fig. 4. Boxplot comparison of iPQ subscale scores between POMS (Dynamic) and Static conditions ($N = 17$ pairs): (a) General Presence, (b) Spatial Presence, (c) Involvement, (d) Experienced Realism, (e) Total Presence.

(POMS ΔScore - Static ΔScore) for Nausea, Oculomotor (O), Disorientation (D), and Total SSQ were calculated. Figure 5 visually presents these differences, where scores below zero indicate a smaller symptom increase for POMS.

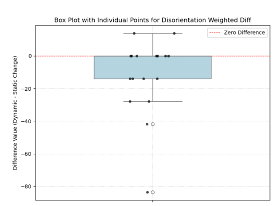
Normality tests (Shapiro-Wilk) on these paired ΔScore differences showed Nausea (W=0.8581, p=0.0143) and Disorientation (W=0.8037, p=0.0023) were not normally distributed, while Oculomotor (W=0.9064, p=0.0871) and Total SSQ (W=0.9279, p=0.2005) were. Initial two-sided tests were conducted: Wilcoxon signed-rank for Nausea and Disorientation, and paired-samples t-tests for Oculomotor and Total SSQ.



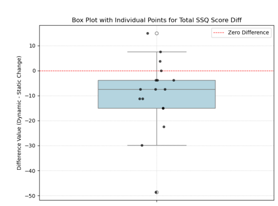
(a) Nausea Δ Score Differences



(b) Oculomotor Δ Score Differences



(c) Disorientation Δ Score Differences



(d) Total SSQ Δ Score Differences

Fig. 5. Boxplots of the differences in SSQ Δ scores (POMS Δ score – Static Δ score; $N = 17$ pairs, n_{eff} varies). A difference below zero indicates a smaller increase in sickness for POMS. (a) Nausea, (b) Oculomotor, (c) Disorientation, (d) Total SSQ.

As detailed in Table III, significant differences were observed for Oculomotor, Disorientation and Total SSQ with the initial two-sided tests (thus not supporting H4 for these measures), one-sided tests were subsequently examined to explore the specific direction of these differences and assess potential comfort benefits of POMS (testing if POMS Δ Scores ¡ Static Δ Scores). The results of these one-sided tests (see Table III) revealed:

1) The increase in Oculomotor symptoms was significantly smaller in the POMS condition compared to the Static condition.
2) The increase in Disorientation symptoms was significantly smaller in the POMS condition.
3) The increase in Nausea symptoms in the POMS condition remained non-significant.
4) The increase in the Total SSQ score was significantly smaller in the POMS condition.

The effect sizes for the statistically significant results (Table III) indicated large effects for the reduction in Oculomotor (Cohen's d = -0.6968), Disorientation (r_{rb} = -0.7455), and Total SSQ (Cohen's d = -0.6448) symptoms in the POMS condition compared to the Static condition. For Nausea, where the difference was not statistically significant, a medium effect size (r_{rb} = -0.3407) was observed, suggesting a trend towards reduced symptoms in the POMS condition. The negative effect size values indicate that lower difference scores (representing a smaller increase in sickness for POMS or a greater increase for Static) are associated with the POMS condition.

Conclusion for H4: Hypothesis 4, predicting no significant difference in cybersickness, was **supported for Nausea**. For Oculomotor, Disorientation, and Total SSQ scores, H4 was not supported as significant differences were found.

However, **these differences indicated a benefit for the POMS condition**, with participants experiencing significantly smaller increases in these sickness symptoms compared to the Static maze. This suggests POMS offered improved comfort regarding these specific aspects of cybersickness.

VI. Discussions

This study provided a controlled, empirical comparison of the Procedural Overlapping Maze System (POMS) against a traditional static maze, evaluating user engagement, experience (UEQ), presence (iPQ), and simulator sickness (SSQ). The findings reveal POMS as a promising technique that not only extends natural walking capabilities in limited physical spaces but also offers significant comfort benefits without compromising core experiential qualities.

A. *Hypotheses and Key Findings:*

Our hypotheses regarding user experience (H2) and presence (H3) predicting no significant differences between POMS and the static maze—were supported. Both UEQ and iPQ scores indicated that POMS's dynamic architectural changes did not negatively impact usability, satisfaction, hedonic qualities, or the sense of presence compared to a stable environment. This crucial outcome suggests that POMS's real-time generation and pruning maintained an immersive experience, aligning with research showing that locally consistent, subtly changing environments can be well-tolerated [11], [23], [24].

Regarding cybersickness (H4), we initially hypothesized no significant difference. This was supported for Nausea symptoms. However, for Oculomotor, Disorientation, and Total SSQ scores, POMS demonstrated a **significant advantage, resulting in markedly smaller increases in symptoms** compared to the static maze, with these benefits associated with large effect sizes.

For user engagement (H1), while POMS participants numerically spent more time on average (M = 447.35 s, an increase of approximately 51 seconds over the Static condition's M = 396.06 s), this difference was not statistically significant with the current task and sample size. Notably, the standard deviation for Time-On-Task in POMS was considerably larger (SD = 402.53 s vs. Static SD = 251.87 s), with some individuals engaging for up to 23 minutes, suggesting a varied response to the theoretically infinite environment.

B. *Interpretation of Results:*

The most compelling finding is the significant reduction in Oculomotor, Disorientation, and Total SSQ symptoms with POMS. This is particularly encouraging, as dynamic environmental changes might intuitively be expected to exacerbate sickness. This benefit likely stems from the continuous natural walking afforded by POMS, which may foster more fluid and predictable movement patterns. In the Static condition, users must navigate a finite space, leading to more frequent abrupt stops and hard turns as they encounter boundaries. In contrast, POMS continuously generates new pathways forward, potentially encouraging a steadier gait and smoother turns, which can mitigate the visual-vestibular conflicts often linked to Oculomotor and Disorientation symptoms [5].

While increased Time-On-Task was not statistically confirmed in this study, **the markedly lower cybersickness achieved with POMS** is a critical factor that directly enables longer interaction durations. We posit that a user experiencing significantly less disorientation and oculomotor strain is more willing and able to continue an experience. Therefore, **the enhanced comfort demonstrated by POMS provides a strong foundation for achieving increased engagement**. The fact that this did not translate to a statistically longer time-on-task in this study likely highlights that the simple task design did not fully capitalize on the potential for extended play unlocked by the system's comfort benefits and theoretically limitless nature.

C. *Implications and Potential Applications:*

The primary implication of this research for VR design is that architectural overlap, when carefully implemented as in POMS, can effectively reuse physical space not only without degrading user experience or presence but also by significantly enhancing user comfort. This combination of maintained experiential quality and improved comfort, particularly the reduction in cybersickness, unlocks considerable potential

TABLE III

COMPARISON OF SSQ ΔSCORES (POMS ΔSCORE - STATIC ΔSCORE) BETWEEN POMS AND STATIC CONDITIONS ($N = 17$ MATCHED PAIRS)

Subscale	**Statistical Analysis**					
	Normality (S-W p)	***Test Used***	***Test Statistic***	***p (2-sided)***	***p (1-sided, POMS ¡ Static)***	***Effect Size***
Nausea	0.0143	Wilcoxon	$W = 30.0$ ($n_{\text{eff}} = 13$)	0.2645	0.1323	$r_{\text{rb}} = -0.3407$
Oculomotor	0.0871	Paired t-test	$t(16) = -2.8731$	0.0110*	0.0055*	$d = -0.6968$
Disorientation	0.0023	Wilcoxon	$W = 7.0$ ($n_{\text{eff}} = 10$)	0.0323*	0.0162*	$r_{\text{rb}} = -0.7455$
Total SSQ	0.2005	Paired t-test	$t(16) = -2.6585$	0.0172*	0.0086*	$d = -0.6448$

*Indicates $p < 0.05$. n_{eff} refers to the number of pairs with non-zero differences used in the Wilcoxon signed-rank test.

across diverse application domains. Here are a few examples to illustrate potential use cases:

- **Expansive Exploration and Visualization:** Virtual showrooms and commercial spaces (e.g., multi-level car dealerships, sprawling retail environments, or architectural walkthroughs) can be comfortably navigated within limited physical footprints. Immersive tourism applications, such as large-scale virtual museums or historical sites, also benefit from more natural and extended walking tours.
- **Engaging Gaming and Entertainment:** POMS is well-suited for endless runners and procedurally generated maze games, enabling longer, more immersive sessions through sickness-free, theoretically infinite paths. The comfort benefits also support broader overlapping reality techniques for large-scale or open-world game experiences.
- **Therapeutic, Rehabilitation, and Cognitive Applications:** POMS supports engaging walking exercises for physiotherapy in constrained clinical environments, where reduced cybersickness may increase adherence. It also serves cognitive training and spatial memory tasks, particularly for older adults, and can enable remote, embodied 'walk and talk' therapy as an alternative to video calls.

VII. LIMITATIONS

This study's findings, while promising, should be considered in light of several limitations. The generalizability of our results is inherently constrained by the relatively modest sample size (N=17 matched pairs for most measures) drawn from a university community, which may not fully capture the diversity of all potential VR users. Future research with larger and more varied populations would be essential for broader validation. Furthermore, the outcomes are context-dependent, tied to the specific time-constrained maze navigation task, the 8x8m tracked area, and the particular algorithmic implementation of POMS. Variations in these experimental parameters could lead to different user experiences and comfort levels. Our reliance on subjective self-report measures, though standard, also presents a limitation; complementing these with objective physiological data in subsequent studies would offer a more multifaceted understanding. Furthermore, this study was designed to isolate the effect of a dynamic, overlapping architecture against a static baseline. A direct comparison to other advanced locomotion techniques, such as Redirected Walking, was considered beyond the scope of this initial evaluation as they manipulate the user-to-world mapping rather than the environment itself. Future work could compare these fundamentally different approaches. Finally, the variable duration of VR exposure, while ecologically valid as it reflected natural task completion, introduced an element of inconsistency that could influence cumulative effects like cybersickness, warranting consideration in future experimental designs.

VIII. CONCLUSION AND FUTURE WORKS

This study demonstrates that the Procedural Overlapping Maze System (POMS) effectively extends natural walking in VR within limited physical spaces, maintaining user experience and presence comparable to static mazes while significantly reducing key cybersickness symptoms (Oculomotor, Disorientation, Total SSQ). This enhanced comfort is a critical advancement for VR locomotion. While POMS facilitated numerically longer engagement, translating this improved comfort and theoretically infinite exploration into statistically significant increases in Time-On-Task requires further investigation into task design.

Future work should focus on three primary areas. Firstly, enhancing user engagement by exploring richer task mechanics and environmental cues that capitalize on POMS's extended walking capabilities. Secondly, deepening our understanding of the underlying mechanisms by analyzing movement kinematics and cognitive load to further optimize comfort and interaction. Thirdly, broadening validation and application, which involves studies with larger, diverse samples, incorporating objective physiological measures, and exploring POMS's efficacy in specific domains such as therapeutic interventions, cognitive training, and procedural entertainment.

In conclusion, POMS offers a robust method for comfortable, extended natural walking in VR. Addressing the interplay between advanced locomotion techniques, engaging content, and user comfort will be pivotal in realizing the full potential of boundless virtual exploration.

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