S(X)OUNDSCAPE DESIGN BASED ON VIRTUAL AFFORDANCES

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Abstract. Our spatial experience is bound to static spatiotemporal patterns, independent of user's changing but specific needs. Senior users, particularly, are at a disadvantage keeping pace with the fast-emerging interfaces due to physical and cognitive limitations. The intervention of VR opens a digital domain that disrupts the conception of space-time linearity as an embodiment of artificial environment, providing a range of spatial possibilities inclusive to users. Currently, acoustic ecology in architecture has the potential to reciprocate well-being in virtual reality. S(X) is an architectural VR project that incorporates Affordance Structure Matrix (ASM) as a user-centric design framework, integrating artefact-user affordances between VR attributes, spatial composition, and user flow. Consequently, the visual and auditory stimulated environments promote sensory and motoric coordination, while considering exposure challenges in VR for seniors. A series of research techniques are performed to collect data samples; literature review on design parameters, respondent survey (n=23) aged 60-90, and design exploration to configure program functions based on acoustic mapping. This includes streaming-masking and lateralization-localization as part of the acoustic exercises. S(X) manifests as a therapeutic mediation of sound that renders immersive and interactive experiences through calculated affordances in a digital frontier.

Keywords. Spatial Experience, Affordances, Meta-architecture, Virtual Reality, Cognitive.

1. Introduction

Spatial experience is perceived through a multimodal sensory input, involving a cognitive process that responds to stimuli. This interplay of senses enables us to resonate with our surroundings as we navigate and comprehend spatial dimensions, fostering a holistic understanding of the world around us (Kwon & Iedema, 2022; Thiel, 2014). In the real world, our spatial experiences are often confined to static spatiotemporal patterns (North, 2021), independent of user's diverse needs. Senior users, particularly, are at a disadvantage keeping pace with the fast-emerging interfaces due to cognitive and physical limitations. To address this disparity, architecture seeks

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to stretch beyond physical design potentials and to lean towards the extents of VR.

The intervention of VR has introduced a digital domain capable of spatial possibilities (Sherman & Craig, 2018; Suh & Prophet, 2018) by appropriately delineating controlled elements, so it may regulate as an inclusive environment to a wide range of users. In doing so, user interaction and experiences in VR disrupt the conception of space-time linearity, such as utilizing locomotion, object interaction (interactables, UI/UX), physics simulation, time manipulation, and spatial audio (Barfield & Furness, 1995). Furthermore, recent interests gather towards the emphasis of auditory sense that can contribute to immersive experiences (Román-Caballero et al., 2018). The idea of acoustic ecology in architecture has the potential to reciprocate well-being in VR by weaving sources of visual and auditory stimuli for user's perception. Hence, we envision S(X) as a dynamic meta-architecture enhanced with virtual interaction and experience distinct from those in the real world.

S(X), short for Spatial e(X)perience, is constructed based on a user-centric strategy to promote user comfort, safety, and feasibility in VR, hence providing equity for users. This includes considering sequences of spatial experience as transition layers bridging between reality and virtuality (Milgram et al., 1994; Sahand & Rice, 2022), and specific challenges susceptible to senior users, such as cybersickness and feeling alienated (Tabbaa et al., 2021) during exposure to novel interfaces, interactions, and environments. As an interactive virtual space, S(X) incorporates exercises or activities (in the form of 'quests') with physical and mental movements injected within altered environments to encourage active participation and cognitive performance. In addition, S(X) also encompasses how visual and auditory information is relayed through optimization in world-building and virtual designs.

This study contributes to design objectives such as design parameters through translation of visual and auditory elements in VR to generate spatial configurations and compositions via aural mapping, design strategy between VR attributes and meta-architecture forms through an affordance structure matrix, and design embodiment of VR environments as user-friendly mediums based on positive key affordances. The end of this study reports the preliminary results and key findings from 3 stages of data collection as part of the research methodology; (1) literature review on theories implemented as the design strategy, (2) user survey with 18 respondents (age 60 and above) to analyse senior patterns in preferences, behaviours, and habits, and (3) design exploration.

2. Research Techniques

2.1. LITERATURE REVIEW

S(X) operates under a design parameter that formulates the scope of design elements, asset and constraints of elements, and the benchmarks to build a holistic meta-architecture. Figure 1 demonstrates the interconnected theories to achieve spatial experience through a network of system for S(X) to operate. How acoustic ecology is integrated into the meta-architecture of S(X) is to execute perceived sound in spatial norms, similar to how we determine interaural, spectral, and temporal differences in the real world. Auditory characteristics such as lateralization and localization, as well as streaming and masking can be segregated into two different concentrations, so users can focus on distinct quests and embedded visual-aural elements. The diverse layers of sound sequences allow users to engage in visual and auditory challenges in S(X) environments. These stimuli are delivered via VR qualities, also known as the 5Is (Tacgin, 2020), which then can be perceived as information to be loaded into our perceptual system, pushing several aspects of cognitive functions as an attempt to process or 'digest' this information. At the end of the chain, spatial experience in VR can be achieved through climbing the progressive steps of each phase, from perceiving visual and auditory stimuli (look + hear), adapting to interfaces and virtual premises (feel), connecting with virtual interactions and experiences (connect), and finally exploring freely and intuitively in S(X) (move). Through these parameters, S(X) is formed with a guided framework to systematically ensure the design process.

S(X) is made possible for users through the implementation of affordances as a user-centric design strategy, where individuals interact with their environment based on the perceived attributes of elements (Alfi et al., 2022; Gibson, 1979). This nature of spatial experience highlights the possibilities of actions offered, but also the constraints imposed by the fixed attributes of elements within a given environment. The affordances can be categorized into 4 distributions: perceptual, navigational, handle-grasp, and goal-oriented affordances between artefact-artefact affordances (AAA) and artefact-user affordances (AUA), which will be discussed further in this paper.

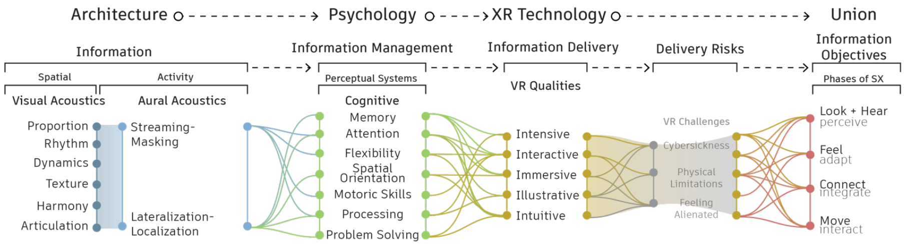

Figure 1. Design parameters constructing the meta-architecture of S(X)

2.2. USER SURVEY

To understand the perspectives of the target audience, a survey was carried out to 23 respondents (potential users) within ages 60-90 to represent seniors' behaviours (responses on technologies as part of their routines), habits (daily activities or exercises to differentiate design potentials and limits of each age group), and preferences (interests on VR technology) towards innovative technologies. Figure 2 indicates that seniors within the oldest age group (aged 81-90) spend more time indoors with technologies equipped with simplified UI. Though their usages might intensify, it does not always be equivalent to their familiarity with other features. On the other hand, seniors within the youngest age group (aged 60-70) are most familiar with technology interfaces and a more complex UI, despite having less interests in accommodating regular practises with advent technologies as tools. Hence, we can be deduced that S(X) should adapt a maneuvered approach to VR, such as a preliminary introduction to interfaces, a pre-determined Point of Interest (POI) within premises as spatial challenge and drive, as well as specific interactables flexible to user's flow and pace.

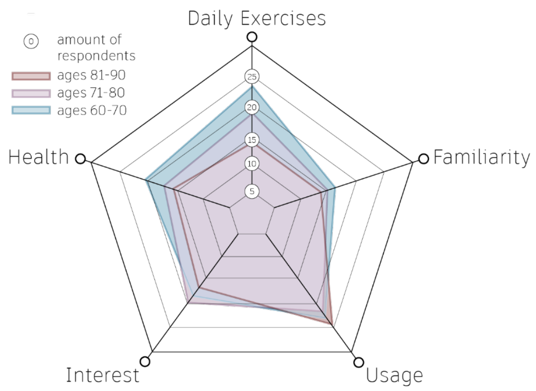

Figure 2. Data collected from respondents' survey, indicating factors related to seniors' perspectives

2.3. DESIGN EXPLORATION

Design exploration conducted for S(X) involves the world-building process in VR, which is directed towards full immersion and intuitive interactions through easy movements within reach. Through iterative design prototyping with the parameters mentioned in Figure 1 (under visual elements), Figure 3 depicts the mass forms of 2 arenas that cater to specific auditory characteristics, including user's circulation around the arena's footprint, starting and ending points, and quest goals in specific placements within the premises. The concept behind the form is to engage users to complete the fixed quests set within the arena, while unconsciously being swept under their own perception of various but arrayed spatial experiences through visual and auditory immersion and interaction.

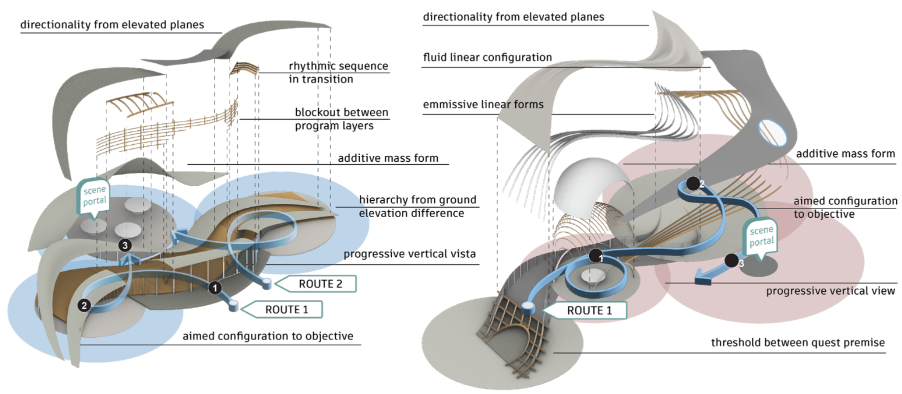

Figure 3. Anatomy of Arena 1 (adapting streaming-masking characteristics) (left) and Arena 2 (adapting lateralization-localization characteristics) (right)

2.3.1. Acoustic Mapping

Distinct auditory characteristics in spatial norms are not only injected as auditory stimuli or elements in S(X) environments just to engage users in the quests. Rather, they reflect certain characteristics into specific placements in programs and configurations (Sinnamon & Miller, 2022). In Arena 1 where we attempt to implore streaming and masking characteristics (determining fore and back sounds in layers), the idea of audio convergence surfaced, where players are encouraged to assemble an audio composition based on the layers of musical ensemble. In Arena 2 where we attempt to implore lateralization and localization characteristics (determining specific location of sound within boundary), the idea of audio sequence surfaced, where players are encouraged to pursue an audio chain towards an audio source hidden within the premise. Therefore, Arena 1 evokes a mass arrangement with clear hierarchy, while Arena 2 evokes a clear pathway.

Figure 4 shows the simulation of how sound particles behave in certain placements within the spatial configuration to underline the link between one audio point to the next. As indicated in Figure 5, the hierarchy of the area is apparent under an additive form, with certain coordinates highlighted as to depict the spectrum of intensity

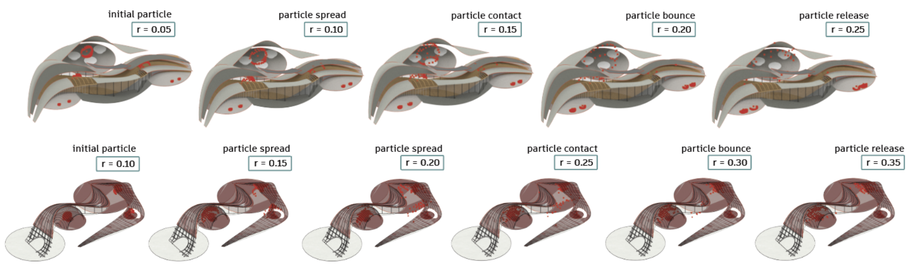

Figure 4. Acoustic simulation on placement of audio coordinates in arena 1 (above) and arena 2 (below) via Grasshopper Pachyderm Acoustics Simulation

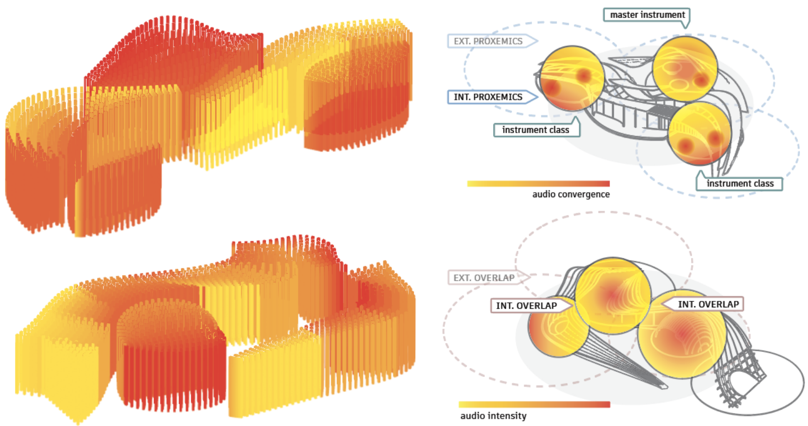

Figure 5. Acoustic simulation on audio convergence for arena 1 (above), showing the overlapping proxemics of audio and audio intensity for arena 2 (below), showing the overlapping radii of audio

distribution within the arena. Arena 1's intensity focuses on how players can distinguish between fore and back sounds, whereas Arena 2's intensity focuses on how players are able to distinguish the intensity of overlapping volumes of audio in specific coordinates of points, leading to a source.

2.3.2. VR Optimalization

Technical latency might result in cybersickness, especially during full immersion. To prevent this casualty, Figure 6 illustrates how a polygon optimization is utilized to reduce excess mesh complexity from 3D models via a decimate modifier. By adjusting the ratio parameter, this controls the amount of decimation applied in LOD threshold to the virtual object, which in this case, each tree element on terrain grounds before import into Unity3D. Moreover, occlusion culling allows progressive or regressive mesh detailing, depending on the distance of player to the target object. This application optimizes graphics rendering performance in VR, hence stabilizing the ideal real-time frame rate at 60-90 fps for senior users.

Figure 6. LOD occlusion on single object's meshes(above) and occlusion culling on whole environments from player's coordinates (below)

3. Key Findings

This part of the study explains and evaluates the key findings of S(X) in correlation to the design objectives and how S(X) corresponds to senior users through artefact-artefact affordances (AAA) and artefact-user affordances (AUA) in determining the dynamism of elements in VR. AAA indicates the relationship between elements and the environment, while AUA indicates the relationship between spatial composition and the player.

3.1. AFFORDANCE STRUCTURE MATRIX

The Affordance Structure Matrix (ASM) as shown in Figure 7 aims to present design strategies interconnecting actualized elements from determined design parameters into the S(X) meta-architecture. The ASM then calculates the level of potential positive and negative affordances via values, distinguished between positive affordances (elements we want to implement into the design) and negative affordances (elements we want to exclude from the design, or at best, to avoid). We compensate the negative values by expanding VR attributes as a form of mediator to balance out between positive and negative elements.

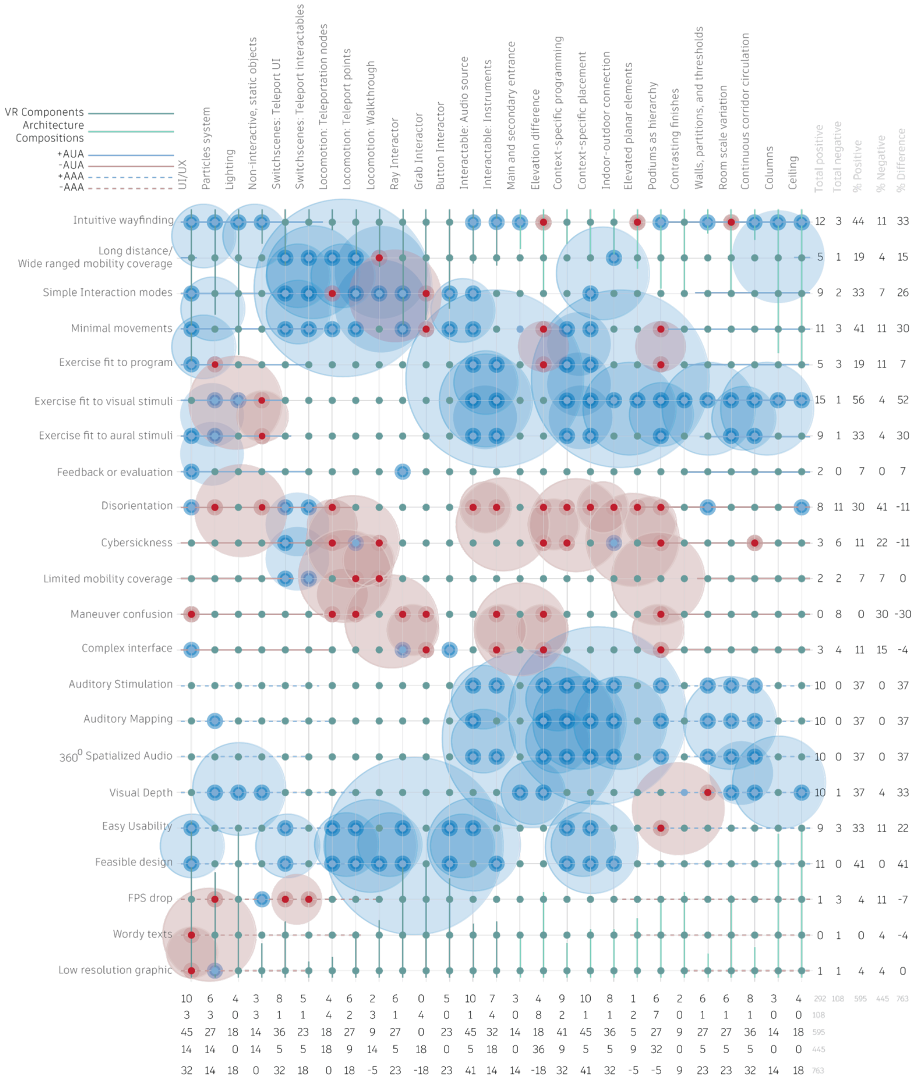

Figure 7. Affordance Structure Matrix between artefact-user affordances, showing positive affordances (blue and positive values) and negative affordances (red and negative values)

3.2. USER AND SPATIAL MAPPING

S(X) is segregated into zones based on respective functions, illustrated in Figure 8 and can be followed as listed below:

- Preliminary area: Layers are progressive by function, accommodating from user maneuver to VR interfaces through a simplified UI before entering the portal room, where players ultimately choose between two arenas. The distinct intensity of functions in between programs are injected with a transitional space.
- Audio convergence: Arena 1 involves players to knock or poke the interactable to trigger an audio reaction. Script-coded interactables are positioned according to instrument proxemics and player ergonomics (see Figure 9 on micro anatomy of elements in Arena 1).
- Audio sequence: Arena 2 involves players to pursue after coordinated audio interactable, mimicking sound behaviours in space. The overlapping radii of audio points will guide players from one sequence to another, forming a chain of audio trails (see Figure 9 on micro anatomy of Arena 2). Particles system aid in subtle visual guidance, taking forms of fauna (fireflies) or water elements (boundaries).
- Common area: Real-time light mapping is projected to manipulate player's sense of time. Lines are blurred between access voids and boundaries, offering a permeable circulation between the area and the surrounding environment. To induce aspects of meditation, floating lights are arranged by progressive scale.

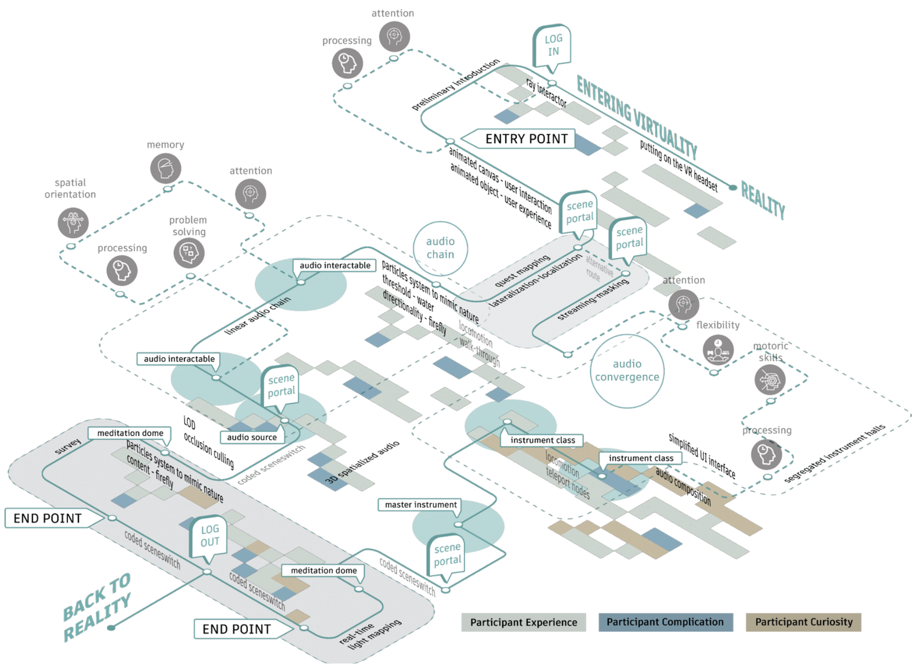

Figure 8. User and Spatial Mapping of S(X)

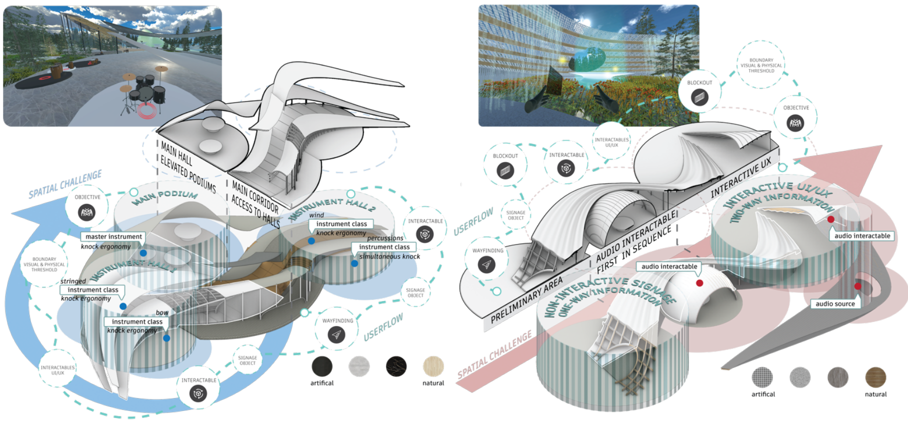

Figure 9. Implemented artefact-user affordances in Arena 1 (left) and Arena 2 (right)

4. Conclusion and Future Works

VR technology has just as much potential in architecture and space planning, especially to improving quality of life and well-being of specific target audience. Senior users demand the existence of inclusive spaces, while VR interfaces aids in feasibility purposes. S(X) serves as a versatile medium that intervenes the perceptions of spatial possibilities and risks through a digital domain and accommodates the design process for vulnerable members of society with the use of innovative technologies. How affordances can be implemented in VR as a design construct is a testament to how virtual elements can bridge an immersive relationship between players, objects, and environment itself in a dynamic scale of flexibility though simple gestures or movements, spatiotemporal manipulation, interaural and spectral control, and mobilization paces regardless of time, duration, events, and order of activity.

The holistic approach of S(X) stipulates the advancements of VR optimalization to evade technical latencies that may bring complications and challenges for senior users to engage in virtual interactions. The ASM can be a toolkit that establishes a systematic delineation of how elements interact with each other within S(X). In essence, S(X) exists not merely as a virtual space, but a dynamic therapeutic medium that manifests inclusive exercises through mediation of sound for seniors' well-being. As means to push cognitive performance, virtual spaces engage players with user-friendly quests through intuitive interactions within immersive spatial experiences. drawing a common thread from theorizing to design application towards senior users' comfort, convenience, and safety.

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