Generative AI and Augmented Reality for Personalized Biophilic Design in Senior Living Environments

Akash Reddy Mallepally[1]; Ruichuan Zhang, Ph.D.[2];
Tanyel Bulbul, Ph.D.[3]

[1]Graduate Research Assistant, Bradley Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University. Email: mallepally@vt.edu
[2]Assitant Professor, Myers-Lawson School of Construction, Virginia Polytechnic Institute and State University. Email: ruichuanz@vt.edu
[3]Associate Professor, Myers-Lawson School of Construction, Virginia Polytechnic Institute and State University. Email: tanyel@vt.edu

ABSTRACT

Biophilic design, which brings natural elements into indoor spaces, has been shown to enhance well-being, cognitive performance, and emotional resilience, particularly among older adults. However, its implementation in senior living environments is often generic and not personalized to individual sensory, cognitive, or mobility needs. To address this gap, we introduce a novel system that uses generative AI to create personalized virtual avatars representing biophilic environments tailored to older adults' preferences, which are then visualized through augmented reality (AR). The system integrates (1) a vision-language generative AI model adapted to indoor biophilic design features and (2) an AR interface that allows older adults to engage with their personalized biophilic environments using tablets. These avatars act as immersive visual surrogates, enabling users to preview and adjust natural design elements from home. The system is informed by profiles and preferences collected from older adults in a senior living facility in Virginia. We validated the system through participatory sessions and AR walkthroughs, assessing perceived well-being, emotional response, and spatial preferences. Preliminary results show increased engagement, higher satisfaction with the indoor environment, and measurable emotional well-being benefits.

INTRODUCTION

The global demographic shift toward an aging society has created urgent demand for innovations that support the health and well-being of older adults. Senior living facilities, including assisted and independent living, are central to this challenge, yet many struggle to provide environments that consistently promote residents' cognitive, emotional, and physical health (World Health Organization 2021).

Biophilic design, which emphasizes the integration of natural elements into built environments, has garnered increasing attention as a strategy to enhance the well-being and quality of life of older adults. Research indicates that exposure to nature within these environments can yield positive outcomes for physical, cognitive, and psychological health. This has led to the growing adoption of biophilic design in senior living spaces, where access to nature is often limited due to mobility or resource constraints (Pandita and Choudhary 2024, Yin et al. 2018). However, physical biophilic interventions, such as gardens, water features, or daylighting, are costly, require substantial space, and may not be feasible to retrofit into existing facilities.

Augmented reality (AR) offers a potential solution by overlaying naturalistic elements into indoor spaces, providing seniors with immersive, customizable, and low-cost access to biophilic experiences. Recent studies have shown that AR-based interventions can effectively improve well-being among older adults. For example, Chandrasekera et al. 2017 highlight AR's role in assisting older adults with mild cognitive impairments in locating objects and retrieving information, thereby promoting their independence. AR can also aid in exercise rehabilitation by allowing participants to monitor their physical activity, which is particularly beneficial for older adults with conditions like sarcopenia (Jeon and Kim 2020). Despite this promise, AR applications for biophilic senior living remain underexplored – an important question remains about how to capture diverse design principles and address safety and usability needs in real-world contexts.

Recent advances in generative artificial intelligence (AI) provide new opportunities to develop dynamic and personalized AR biophilic experiences. By leveraging prompting-based generative modeling, researchers can rapidly create diverse and adaptive natural scenes, moving beyond the limitations of individual designers' knowledge and experience. (Zhang and Zhang. 2024) Integrating these generative capabilities with AR systems enables investigation of an important second question: the cognitive and emotional effects of exposure to virtual biophilic environments compared to real natural environments remain unclear and require systematic evaluation.

This study presents a generative AI–supported AR application for biophilic design in senior living, guided by two research questions. Our methodology includes: (1) prompt engineering based on biophilic design principles to generate 3D biophilic models using generative AI, (2) development and deployment of an AR system on tablet devices to deliver these models in senior living contexts, and (3) experimental testing of cognitive and emotional outcomes through pre- and post-intervention assessments with older adult participants. The results provide insights into the feasibility of integrating generative AI and AR and highlight their potential to enhance well-being in senior living environments.

RELATED WORK

AR for Older Adults. AR has been increasingly explored as a tool to support health and well-being in older adult populations. Recent studies show that AR-based interventions can improve physical outcomes by promoting activity, rehabilitation, and physiological monitoring. For example, Budzevski et al. 2024 developed an AR application that recreated biophilic environments in senior housing by overlaying natural elements such as plants and water features. Their study incorporated wearable devices, including the Fitbit Charge 5, to collect real-time physiological data such as heart rate variability, demonstrating AR's potential to augment physical well-being. Beyond physical health, AR has also been associated with psychological and social benefits. Frameworks for smart-home services that integrate AR with biophilic design principles emphasize its role in reducing loneliness and fostering connection with nature, thereby supporting "Aging in Place" (AIP) initiatives (Boffi et al. 2021). AR-based reminiscence and life review interventions have further shown promise in enhancing mood, meaning, and emotional resilience in older adults (Chan et al. 2019). Building on these findings, biophilic AR applications offer a particularly promising direction for enriching daily environments in senior housing.

Generative AI for AR Experiences and Built Environments. Generative AI techniques, particularly prompting-based large foundation models, have emerged as powerful tools for designing both virtual environments and built environments. In augmented and virtual reality (AR/VR), generative approaches enable the real-time synthesis of objects and environments (Gao et al. 2022). Within the built environment, generative AI has been applied to automate indoor scene generation, optimize spatial layouts, and support early-stage design exploration, providing designers with rapid alternatives that balance multiple requirements (Zhang and Zhang 2024). These methods extend beyond static or pre-rendered templates by incorporating contextual data and user preferences, making design workflows more adaptive and scalable. For senior living, generative AI offers a pathway to create personalized AR biophilic environments that address individual needs while remaining feasible for real-world deployment.

PROPOSED APPROACH

To create an interactive biophilic application for senior living, we proposed an integrated approach that combines prompting-based generative AI with AR. The outcome is a Unity-based AR application that enables senior users to enhance their immediate surroundings with diverse biophilic objects generated through AI-assisted modeling.

Generative AI Pipeline for Biophilic Model Generation. To standardize and scale the creation of biophilic 3D objects, we designed a generative AI pipeline to assist in studying the principles of biophilic design, conceptualizing themes, and constructing the AR-ready assets. We applied prompt engineering techniques such as Chain-of-Thought, Self-Evaluation, and Few-Shot Prompting **(Shulhoff et al. 2025)** to ensure both diversity and consistency with biophilic design principles. The four-stage pipeline is explained below and summarized in **Figure 2**:

Step 1: Knowledge grounding. The initial stage involved priming a multimodal large language model (LLM) with biophilic design knowledge and the context of senior living. In this study, we used GPT-4 as the LLM for its strong performance in prompt alignment and multimodal capacity to process both text and image data. We included the three key frameworks of biophilic design as conceptualized in **Figure 1** as reference material for types and attributes of biophilic design. Because our preliminary tests indicated that LLMs may drift or deviate, every 5–10 iterations of conceptualization (Step 2) the LLM was prompted to recall previously defined knowledge and context (as well as earlier generated biophilic object concepts). This strategy helped refresh the LLM's "memory" and encouraged proactive self-evaluation of its design outputs to maintain fidelity to biophilic principles.

2 Dimensions, 6 Elements, and 72 Attributes of Biophilic Design (Kellert, 2008b)					
I. Organic or Naturalistic				**II. Place-based or Vernacular**	
1. Environmental features	**2. Natural shapes and forms**	**3. Natural patterns and processes**	**4. Light and space**	**5. Place-based relationships**	**6. Evolved human-nature relationships**
• Color • Water • Air • Sunlight • Plants • Animals • Natural materials • Views and vistas • Façade greening • Geology and landscape • Habitats and ecosystems • Fire	• Botanical motifs • Tree and columnar supports • Animal (mainly vertebrate) motifs • Shells and spirals • Egg, oval, and tubular forms • Arches, vaults, domes • Shapes resisting straight lines and right angles • Simulation of natural features • Biomorphy • Geomorphology • Biomimicry	• Sensory variability • Information richness • Age, change, and the patina of time • Growth and efflorescence • Central focal point • Patterned wholes • Bounded spaces • Transitional spaces • Linked series and chains • Integration of parts to wholes • Complementary contrasts • Dynamic balance and tension • Fractals • Hierarchically organized ratios and scales	• Natural light • Filtered and diffused light • Light and shadow • Reflected light • Light pools • Warm light • Light as shape and form • Spaciousness • Spatial variability • Space as shape and form • Spatial harmony • Inside-outside spaces	• Geographic connection to place • Historic connection to place • Ecological connection to place • Cultural connection to place • Indigenous materials • Landscape orientation • Landscape features that define building form • Landscape ecology • Integration of culture and ecology • Spirit of place • Avoiding placelessness	• Prospect and refuge • Order and complexity • Curiosity and enticement • Change and metamorphosis • Security and protection • Mastery and control • Affection and attachment • Attraction and beauty • Exploration and discovery • Information and cognition • Fear and awe • Reverence and spirituality

3 Experiences and 25 Attributes of Biophilic Design (Kellert, 2018)		
1. Direct Experience of Nature	**2. Indirect Experience of Nature**	**3. Experience of Space and Place**
• Light • Air • Water • Plants • Animals • Landscapes • Weather • Views • Fire	• Images • Materials • Texture • Color • Shapes and forms • Information richness • Change, age and the patina of time • Natural geometries • Simulated natural light and air • Biomimicry	• Prospect and refuge • Organized complexity • Mobility • Transitional spaces • Place • Integrating parts to create wholes

3 Categories and 15 Patterns of Biophilic Design (Browning and Ryan, 2020)		
1. Nature in the Space	**2. Natural Analogues**	**3. Nature of the Space**
• Visual Connection with Nature • Non-Visual Connection with Nature • Non-Rhythmic Sensory Stimuli • Thermal & Airflow Variability • Presence of Water • Dynamic & Diffuse Light • Connection with Natural Systems	• Biomorphic Forms & Patterns • Material Connection with Nature • Complexity & Order	• Prospect • Refuge • Mystery • Risk/Peril • Awe

Figure 1. Principles of Biophilic Design (Zhong et al., 2022)

Step 2: Conceptualization. Using few-shot prompting techniques, the LLM was then asked to generate sets of five biophilic object concepts per iteration. A structured template guided the process, requiring outputs that varied across natural inspirations (e.g., aquatic terrains, stone formations, deserts), materiality, form, textures, and functional affordances. To implement the few-shot technique, example biophilic object concepts curated by the researchers were included within the prompt as reference outputs. approach emphasized diversity beyond commonly used “nature-in-the-space” type (e.g., indoor greenery), by incorporating "natural analogues” and “nature of the space” types, such as lattices or geometric patterns.

Step 3: 2D Image Generation. The LLM was next tasked with producing precise text prompts for image-based rendering. These prompts instructed image generators to create single-object, studio-style 2D image outputs with neutral backgrounds. When higher-resolution results were needed, the LLM was also prompted to generate images of the same object from multiple perspectives, enabling more detailed downstream 3D modeling. Examples are shown in **Figure 3**.

Step 4: 3D Model Generative Rendering. The rendered images were subsequently processed through an AI-based 3D model generator. In this study, we used MeshyAI, which is widely adopted for its ability to convert text or images into textured, low-poly 3D assets suitable for real-time applications such as AR and VR. The resulting 3D assets were imported into the AR application.

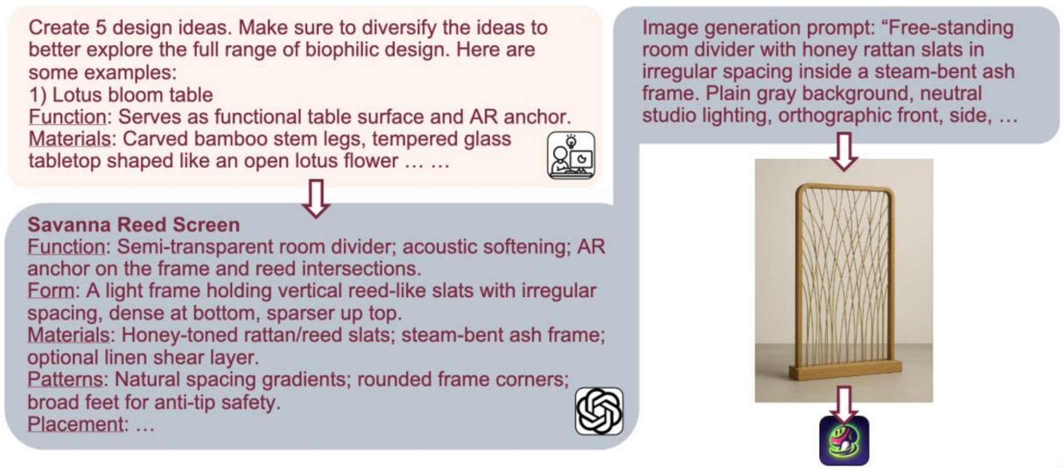

Figure 2. Prompting Pipeline for Ideation and Image Generation

Figure 3. AI-generated Biophilic Object Images

AR Application Development. The application was developed with Unity and the AR Foundation toolkit with plane detection, enabling the placement of 3D models on real-world horizontal surfaces. Our AR development was guided by two key rationales: (1) device choice and (2) interface design.

Device. We selected mobile devices as the platform because they are widely accessible, relatively low-cost compared to head-mounted AR systems, and familiar to older adults, making deployment in senior living facilities more feasible. Both smartphone and tablet versions of the application were created. However, the following experiments focused on tablets because their larger screens improve visibility, reduce interaction errors, and are easier for older adults to operate than smaller smartphones.

Interface. The AR application brings together AI-generated biophilic 3D models into an interactable user interface overlayed onto the visible physical environment on a mobile or tablet screen via its camera. The objects are available to the user via a scrollable menu from which they can drag and drop objects of choice onto the detected planes in the field of view as shown in **Figure 3** and **Figure 4**. The user can move, rotate, and scale objects as they create an augmented biophilic environment onto their living space. The interface design decision was made to provide intuitive interactions that are familiar from everyday touchscreen use (e.g., pinch-to-zoom, drag-and-drop), lowering the barrier for older adults who may be less experienced with AR.

EXPERIMENTS AND RESULTS

Experiment Setting. To test the quality and impact of the proposed application, we conducted a two-part experiment. Each participant experienced both a non-biophilic AR task and a biophilic AR task:

- Part 1 (Control – non-biophilic AR): Participant is asked to create a study space of choice using the neutral, non-biophilic virtual objects provided in the AR application (**Figure 3a and Figure 3b**).
- Part 2 (Biophilic AR): Participant is asked to create a meditation space with biophilic objects using the biophilic virtual objects in the AR application (**Figure 4a and Figure 4b**).

To measure the change in cognitive function and user emotion state condition, the participants took a Stroop test and a short PANAS survey at three points: before Part 1, after Part 1 (and before Part 2), and after Part 2. The Stroop test measures attention and executive function by evaluating reaction times and accuracy in color-word interference tasks. The Stroop effect is calculated as the difference between incongruent and congruent reaction times, with positive values indicating slower responses under interference and negative values reflecting faster responses on incongruent trials. PANAS survey assesses positive and negative effects to capture mood changes across conditions. For feasibility in a pilot setting, a shortened 4-item PANAS was used focusing on calmness, alertness, tension, and fatigue. After Part 2, an exit survey is conducted to gauge the participants' overall impression of the AR experiences. Both PANAS and exit surveys were registered on a 1-5 Likert scale, where 1 indicated "strongly disagree" or the lowest intensity of the item, and 5 indicated "strongly agree" or the highest intensity.

As a preliminary case study, we conducted this experiment on two participants of varying demographics in two different public spaces (a busy corridor and a more secluded lounge area) selected to resemble common gathering and passage areas in assisted living facilities.

Figure 3a. Participant 1 Study Space

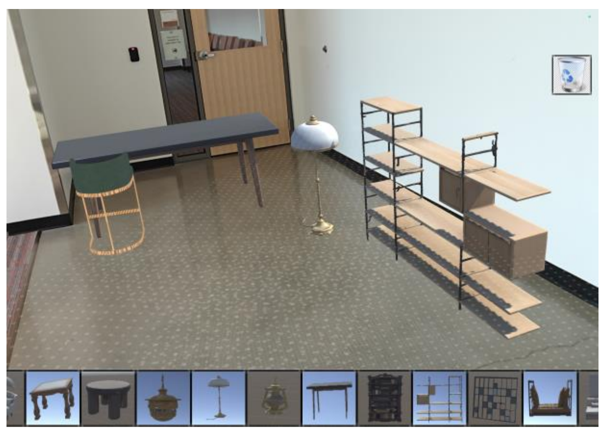

Figure 3b. Participant 2 Study Space

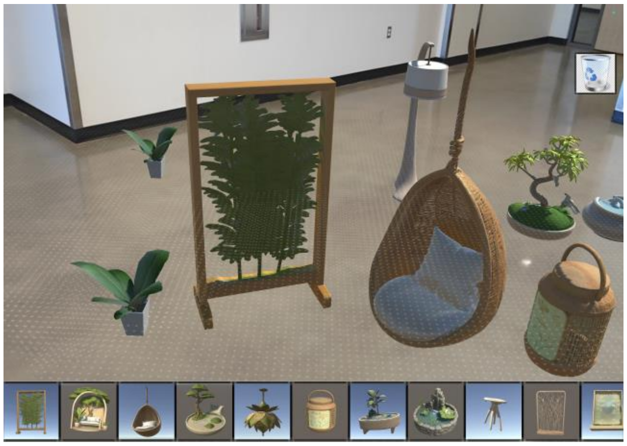

Figure 4a. Participant 1 Meditation Space **Figure 4b. Participant 2 Meditation Space**

Results and Analysis. Stroop test results (**Table 1**) showed different trends across the two participants. Participant 1's Stroop effect increased after both the non-biophilic and biophilic AR conditions (−40 ms at baseline, 198 ms after non-biophilic AR, 222 ms after biophilic AR), indicating greater interference relative to baseline. Participant 2 showed the opposite pattern, with a reduction from 252 ms at baseline to 72 ms after non-biophilic AR and 81 ms after biophilic AR, suggesting improved performance. These contrasting outcomes highlight individual variability in cognitive responses to AR exposure.

PANAS results (**Table 2**) indicated stable affective states across conditions. Both participants reported consistently high alertness and low negative affect. Participant 1's tension increased slightly after the non-biophilic condition but decreased after the biophilic condition.

Exit survey responses (**Table 3**) indicated that both participants found the biophilic environments pleasant and restorative and expressed willingness to spend more time in them. One participant reported low ease of use, while the other reported high ease of use, pointing to differences in usability perception.

Table 1. Stroop Test Results

Participant	Test time point	Congruent (ms)	Incongruent (ms)	Stroop Effect (ms)
1	Before Part 1 (Baseline 1)	1206	1166	-40
	Before Part 2 (Baseline 2)	974	1172	198
	After Part 2 (Proposed AR)	998	1220	222
2	Before Part 1 (Baseline 1)	947	1199	252
	Before Part 2 (Baseline 2)	1034	1106	72
	After Part 2 (Proposed AR)	780	869	81

Table 2. PANAS Survey Results

Participant	Stage	Calm	Alert	Tense	Fatigued
1	Before Part 1 (Baseline 1)	4	5	2	1
	Before Part 2 (Baseline 2)	5	5	3	1
	After Part 2 (Proposed AR)	4	4	2	3
2	Before Part 1 (Baseline 1)	4	5	2	2
	Before Part 2 (Baseline 2)	5	5	2	2
	After Part 2 (Proposed AR)	5	5	2	2

Table 3. Exit Survey Results

Question	Participant 1		Participant 2	Participant 2
	Part 1	Part 2	Part 1	Part 2
1.Biophilic objects do not feel artificial	3	3	5	4
2. Environment felt pleasant	3	3	4	5
3. Would like to spend more time	4	4	3	4
4. Environment felt restoring	4	4	3	4
5. App was easy to use	2	2	5	5
6. Experience was mentally demanding	1	1	2	2

CONTRIBUTIONS

This study makes three contributions. First, it introduces a prompting-based generative AI pipeline for biophilic model creation, which formalizes biophilic design principles into a reproducible process for generating diverse AR-ready assets. Second, it presents a mobile-based biophilic AR application that enables users to assemble naturalistic environments on mobile and tablet devices, demonstrating a practical platform for delivering biophilic experiences in senior living contexts. Third, it reports a preliminary experimental evaluation using cognitive and affective measures, providing initial evidence on the potential effects of virtual biophilic environments compared to non-biophilic conditions.

CONCLUSION

This paper presented a generative AI–supported AR approach for biophilic design in senior living. A four-stage prompting pipeline was developed to generate AR-ready biophilic objects, which were integrated into an AR application for deployment on mobile devices. A preliminary experiment tested cognitive and emotional outcomes using Stroop and PANAS measures, along with overall user perceptions. Results indicated individual differences in cognitive responses, stable affective states across sessions, and generally positive perceptions of biophilic AR environments.

Future work will expand the participant pool to enable systematic evaluation across diverse demographics. We will also refine the AR interface to improve accessibility and ease of use for older adults, as suggested by the preliminary study. Finally, we will extend testing to real senior living settings, including both independent and assisted living, and examine broader impacts on well-being, such as social and physical outcomes. These directions will build toward a scalable and accessible framework for integrating biophilic AR into everyday senior living environments.

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