# Symbiotic Futures: co-designing marine conservation efforts with intelligent aquatic agents in maritime Singapore


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**Figure 1: Leveraging emerging technologies from spatial computing and 3D generation models, Symbiotic Futures encourages participants to proactively engage with maritime conservation efforts through interactive experiences that immerse users in – and encourage them to critically reflect upon – past, present, and future maritime scenarios.**


## Abstract

As an island nation at the epicenter of marine geopolitics and climate change, Singapore provides the context for this research-through-design project that critically examines posthumanist design practices, aiming to rethink ocean conservation alongside non-human voices. This demonstration merges natural language-driven conversational AI, AI-based 3D model generation technologies, and spatial computing interactions. The system leverages spatial computing capabilities to transform natural language inputs into immersive 3D scenes and provide intuitive spatial interaction experiences. Participants become maritime planners of symbiotic futures, co-creating with non-human agents through voice dialogue and spatial gesture controls to address sea level rise, plastic pollution, and habitat collapse. The project combines advanced technologies with design fiction, local culture, and marine conservation to encourage multi-species thinking and interdependent futures.



## CCS Concepts

• **Human-centered computing → Spatial user interfaces, Mixed / augmented reality, Systems and tools for interaction design**.





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## Keywords

natural language interaction, spatial computing, 3D model generation, memory-driven, marine AI agents, posthumanism

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## 1 Introduction

Pollution, coral bleaching, and overfishing and broader climate-related problems contribute to the devastation of ocean habitats and loss of animal lives. This includes in areas local to Singapore, our context as a quintessential maritime city-state that relies on port economics, shipping, fishing, and land reclamation for its development, such as the Johor Strait and South China Sea. While populations may understand the need for marine life conservation, they are often not fully cognisant of the severity of the oceans' current state or truly understand the impacts of various conservation efforts. How they, as an individual and as a collective, can play an active part in those global efforts may often be abstract and hard to appreciate.

To address this gap, we developed "Symbiotic Futures", utilizing recently-introduced spatial computing technologies to propose new ways of communicating conservation media to users. Using

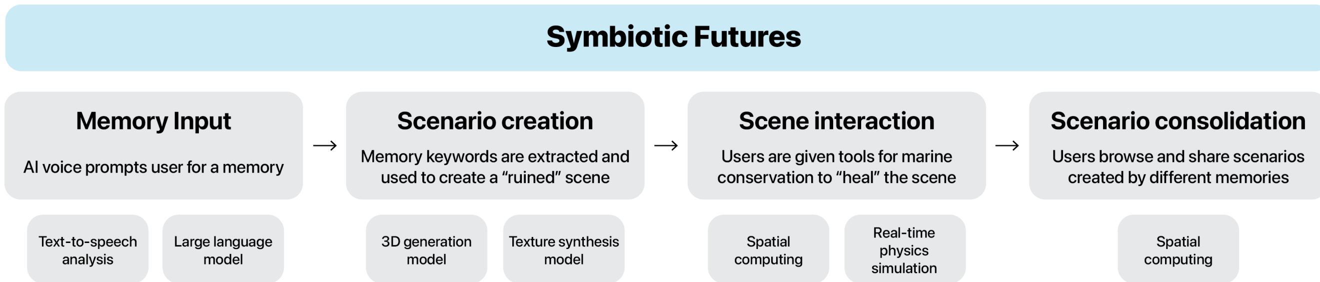


**Figure 2: Overview of *Symbiotic Futures* user interaction sequence and proposed technical architecture.**

voice input to drive 3D content generation, our system creates an immersive ocean environment and 3D interactive marine agents, which can be viewed as personified non-human agents capable of dialogue-based interactions with users to collaboratively consider sustainable solutions. Our system specifically proposes to utilize recently-introduced real-time 3D generation capabilities, including from natural language user input, to transform users' ocean memories into visualized scenes and interactive elements.

Symbiotic Futures in particular seeks to draw upon the traditional knowledge systems of the Malay, Chinese, Indian, and indigenous communities in Singapore, such as the Orang Laut, which contain extensive and undertapped wisdom with respect to co-existing with the ocean. These memories and wisdom will guide people to reconsider their relationship with the sea. Using real-time 3D generation methodologies in this manner, and for the specific purpose of ocean conservation, Symbiotic Futures breaks human-centrism in design methodologies by incorporating non-human life into co-design dialogues. Our system aims to impart a greater understanding and appreciation for both marine life and various conservation efforts, therefore motivating users to take genuine action in their daily lives.

## 2 Related Work

### 2.1 Posthumanist Design and Environmental Interaction

Posthumanist design challenges traditional human-centered design paradigms by viewing non-human entities (such as animals, plants, ecosystems) as active participants rather than passive objects in the design process. [9] This approach is particularly important in environmental interaction design as it encourages designers to consider broader ecological relationships and multi-species coexistence. [10]

Researchers have explored methods for integrating non-human perspectives into the design process, such as through data visualization, embodied simulation, or bio-inspired design. [4] These efforts reflect a growing recognition that effective environmental design must transcend human needs and embrace a more inclusive multi-species perspective. [8]

### 2.2 Spatial Computing and Natural Language-Driven 3D Generation

Spatial computing devices represent a new frontier in human-computer interaction, moving beyond traditional augmented reality (AR) and virtual reality (VR) to create computing environments that seamlessly blend physical and digital worlds. These devices enable users to intuitively interact with 3D digital content through gesture recognition, eye tracking, and spatial mapping technologies. Such technologies have been shown to offer significant advantage in environmental visualization, capable of immersively demonstrating complex ecosystems to users [13].

Simultaneously, advances in natural language-driven 3D content generation technologies have created new possibilities for environmental narratives. Large language models (LLMs) combined with 3D generative AI can use textual descriptions to create rich visual scenes [14], enabling non-technical users to create complex 3D content. This combination allows environmental educators to translate abstract ecological concepts into concrete, visible 3D representations and enables users to explore and modify these environments through natural language dialogue.

The combination of natural language as an interaction interface with spatial computing provides powerful tools for more intuitive, immersive environmental education, serving as a "time machine" that can display past environmental conditions or future climate scenarios [2], reinforcing the urgency of climate action.

## 3 Symbiotic Futures Working Principle

Symbiotic Futures is an interactive system based on natural language processing and spatial computing, combining large language models, real-time 3D generation technology, and spatial gesture recognition. The system uses an AI agent (named "Kaya") as a mediator between users and the ocean world. Our system is summarized in **Figure 2**. The system operates through four key technical stages:

### 3.1 Natural Language Memory Solicitation

The system first invites users to share personal ocean memories as an entry point for interaction through a voice interface. It proposes to utilize advanced speech recognition and natural language processing technologies to convert users' natural language into text and perform semantic analysis. This design choice is based on research showing that personal narratives can effectively connect with environmental care. [12] Users share brief ocean memories

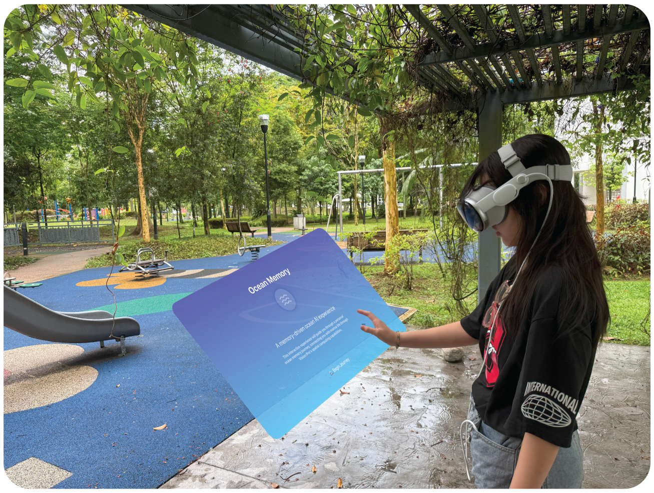


**Figure 3: Window-based user introduction to Symbiotic Futures, an application natively designed and developed for Apple Vision Pro.**

**Figure 4: User view of immersive maritime scene serving as the backdrop to the conservation-based content.**

through dialogue-based interaction (e.g., "As a child, I chased baby sea turtles on the beaches of Tioman Island"), from which the system's natural language processing module identifies key entities ("sea turtle"), emotional tones ("childhood memory"), and geographical locations ("Tioman Island") for subsequent content generation.

## 3.2 Natural Language-Driven 3D Model Generation

Once users share memories, the system's AI model analyzes key elements in the language input (such as "sea turtle") and triggers a 3D generation pipeline. The system uses text-to-3D generation technology to transform abstract language descriptions into concrete visual forms, generating Kaya's 3D model in real-time. [7]Kaya may appear as a sea turtle, coral, or other marine organism, adapting to the user's memory and materializing in the user's spatial environment. This text-to-3D conversion is completed in real-time, allowing the system to provide dynamic responses. [6]

Our approach aims to generate an interactive agent not merely as a static model but possessing skeletal animation and procedural actions, enabling natural movement and interaction in space. [11] Additionally, the natural language model generates dialogue responses expressed in the first person, establishing emotional connections e.g., "I remember the waves were gentle that day... but now, my children are often born among plastic." These responses are conveyed through speech synthesis technology while the 3D model performs corresponding animations, creating a multimodal communication experience.

## 3.3 Interactive Spatial Co-Creation Session

At the core of the system is a 3D co-creation session implemented using newly-introduced spatial computing capabilities, where users collaborate with AI agents in a mixed reality environment to design solutions addressing ocean challenges directly related to the user's memories. Through a combination of procedural generation and preset models, the system provides five basic interactive elements: biological filter strips (filtering microplastics), beach reinforcement strips (resisting erosion), light-shadow shields (blocking nighttime light), temperature-controlled incubation shells (helping regulate hatching temperature), and implantable directional totems (guiding hatchlings to sea).

In our implementation, users can directly grasp, rotate, scale, and combine these elements in 3D space through gesture tracking without additional hardware interfaces. The system leverages spatial computing's depth perception and environmental understanding capabilities to enable virtual objects to interact naturally with physical space, such as placement on tables or floors. [3] Such user interactions are visualized in **Figures 3-4**. Through this spatial interaction, users co-design interventions that address marine conservation problems.

# 4 System Implementation

## 4.1 Proposed Technical Architecture

The Symbiotic Futures system proposes four integrated technical modules:

*4.1.1 Natural Language Understanding and Generation:* Our system proposes to employ large language models for user input understanding, semantic analysis, and dialogue generation. This module processes multilingual inputs (English, Chinese, etc.), extracts key entities and relationships, and connects to a knowledge base containing local expertise in marine ecology, ocean pollution, and existing conservation efforts.

*4.1.2 Real-time 3D Generation Engine:* Combining text-to-3D generation technology with a preset model library, the system aims to transform natural language descriptions into 3D visual content. [1] This engine supports model deformation, material generation, and

**Figure 5: Introduction to aquatic agent, Kaya, guiding the user through the immersive experience.**

**Figure 6: User interacting with marine conservation 3D models in an immersive space.**

scene synthesis, enabling AI agents and environments to dynamically adapt to user input. The generation process is optimized to run with low latency on spatial computing devices.

*4.1.3 3D Asset Management and Physics Simulation:* The designed system proposes to employ a multi-level asset management architecture combining automatically generated and manually optimized 3D models. The asset database uses a distributed storage system indexed by semantic tags and physical properties, supporting real-time retrieval and dynamic loading. Core assets include basic environments (ocean base, beach topography), Kaya's various forms (turtle, coral, etc.), pollution elements (plastic waste, microplastics), and co-creation components (biological filters, directional totems, etc.). An implementation of our design would entail an intelligent asset generation pipeline that automatically generates low-polygon initial models based on semantic descriptions from user inputs and optimizes details and textures, dynamically adjusting rendering complexity based on viewing distance and system load through level of detail technology. User interactions with such 3D assets that would be generated by such a technical pipeline are described in **Figures 5-6**.

*4.1.4 Spatial Computing Interface:* Utilizing spatial computing capabilities, including high-precision gesture recognition, eye tracking, and environmental understanding, to create mixed reality experiences. This interface employs spatial anchoring technology to fix digital content to physical space while achieving physically realistic interaction feedback. The system supports multiple input modes: voice commands, gesture control, and gaze selection. The physics simulation engine, based on particle systems and constraint solving, would calculate water flow, buoyancy, and collisions, such that generated assets would have physical credibility in the virtual environment e.g. by simulating the effects of waves, tides, and water currents on marine life and artificial structures.

## 4.2 Interaction Design

The system's emotional design is based on establishing empathy between users and non-human AI agents. [5]Kaya's dialogue is carefully designed to balance information delivery with emotional expression, avoiding excessive anthropomorphism while remaining expressive. Sound design e.g., ocean waves and water ripples, further enhances emotional immersion, while visual aesthetics e.g., translucent materials and bioluminescent effects, emphasize the wonder and fragility of marine life. The interaction design follows three core principles of *spatiality*, *tangibility*, and *fluidity*, and are visualized in an example user experience flow in **Figure 7**.

*4.2.1 Spatiality.* The system utilizes spatial mapping capabilities to naturally integrate digital content into the user's physical environment. Generated ocean environments can appear on any surface around the user, while generated agents can move freely in 3D space.

*4.2.2 Tangibility.* Although a digital experience, the system emphasizes tangible interaction where users can "grasp," "rotate," and "combine" virtual elements, simulating physical making processes. This design choice aims to create a more substantial environmental crafting experience.

*4.2.3 Fluidity.* The entire interaction process is designed as a smooth narrative flow from memory elicitation to AI manifestation to co-creation to work preservation, forming a complete emotional journey. Water ripples, particle effects, and flowing transitions enhance this sensation.

# 5 Application Scenario

The following is a typical user interaction scenario. First a user shares a memory:

> *I remember seeing sea turtles hatching on Tioman Island, hundreds of baby turtles scrambling toward the ocean.*


**Figure 7: Symbiotic Futures user interaction sequence, beginning with (a) splash screen in an immersive space, (b) 3D avatar introduction, (c) natural language prompting, and (d) 3D marine content co-design.**

The system manifests Kaya in turtle form, explaining the challenges facing sea turtles today:

> *Our hatching grounds are shrinking, light pollution causes my children to lose their way, and plastics are mistaken for food.*

Then, various interactive tool models immersively surround the user—temperature-controlled incubation shells, light-shadow shields, biological filter strips, beach reinforcement strips, and implantable directional totems. Kaya encourages the user to create innovative combinations:

> *The BioFilter works well with temperature regulation systems.*

The user grasps, rotates, and combines these elements through gestures. When they successfully combine the temperature-controlled incubation shells with light-shadow shields, Kaya responds excitedly:

> *The perfect combination to guide young turtles safely from nest to ocean.*

When the user tries less suitable combinations, Kaya provides guidance:

> *An interesting combination! This could help address multiple challenges in our oceans.*

The user collaborates with Kaya to create a Turtle Nest Guardian, combining temperature-controlled incubation shells, light-shadow shields, and implantable directional totems to help sea turtles cope with climate change and human interference. Finally, Kaya provides feedback:

> *This design considers our complete life cycle, from eggs to hatchlings to adults. It not only protects our nesting grounds but also creates a safe path for our return home.*

The AI agent Kaya not only provides feedback and contextual information through voice but also actively moves and interacts in 3D space, demonstrating how to use the created tools or showing the impact of environmental problems, thereby visualizing how the design affects ocean systems. After completing the co-creation, users can save their work to the "Ocean Memory Wall" to share with other participants or download images of their creation and narrative cards. The AI provides a final response, reinforcing the emotional connection and encouraging the user to remember their experience and act upon it in their daily life.

## 6 Conclusion and Future Work

Symbiotic Futures demonstrates a novel approach using natural language-driven spatial computing and AI agents to promote empathy and understanding between humans and marine ecosystems. By connecting personal memories with environmental challenges, the system creates a unique design space that encourages posthumanist thinking and multi-species empathy. The system represents a new paradigm for marine environmental education, providing experiential learning through spatial computing and 3D interaction, making abstract environmental issues personally relevant and enhancing emotional investment. The system integrates traditional marine knowledge from Singapore's multicultural background with modern scientific understanding, enabling learners to understand ocean issues from non-human perspectives through Kaya's anthropomorphic expression, fostering cross-species empathy and ecocentric thinking, serving as an effective bridge connecting the public with marine science.

Future work will advance simultaneously in technological, educational, and application domains: we will focus on improving the efficiency and precision of natural language to 3D generation, exploring multimodal inputs; evaluating the long-term impact of immersive learning methods on environmental knowledge acquisition and behavior change; adding more marine ecosystem modules and AI agents; expanding the system into a multi-user platform to promote community involvement; and developing mechanisms to transform virtual designs into actual environmental protection actions. Symbiotic Futures is not merely a technological demonstration but a proof of concept showing how spatial computing, natural language interaction, and AI can reimagine human relationships with the ocean, nurturing a new generation of ocean stewards, promoting multi-species symbiotic design thinking, and pioneering new pathways for sustainable marine education.

In future, we plan to evaluate the effectiveness of the system through the following methods:

(1) *User Experience Evaluation:* Collecting user feedback on system usability, emotional responses, and engagement levels.
(2) *Environmental Attitude Assessment:* Measuring the system's impact on users' environmental attitudes and behavioral intentions.
(3) *Design Outcome Analysis:* Analyzing solutions created by users to assess their innovation and ecological awareness.

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