

Artificial Intelligence-Assisted Ideation and Digital Fabrication for Adaptive Living Shoreline Infrastructure

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Abstract: Living shorelines offer adaptive, ecological alternatives to grey coastal infrastructure, yet translating ecological intent into fabricable 3D forms remains a key bottleneck. This study presents an AI-assisted concept-to-prototype workflow tested in a landscape architecture ecology course, integrating generative AI for 2D ideation, AI-driven 3D modelling, and digital fabrication. Qualitative thematic analysis of 52 student reflections indicates that AI significantly accelerates design exploration and prototyping while requiring careful prompt construction, ecological verification, and human oversight. The findings demonstrate that AI functions as a supportive and mediating tool, positioning designers as essential “human-in-the-loop” collaborators and reinforcing the importance of ecological expertise and ethical responsibility in design.

Keywords: Artificial intelligence, living shorelines, AI-assisted workflow, digital fabrication

1 Introduction

One of the significant obstacles for modern landscape architecture is the escalating impact of climate change on coastal regions (IPCC 2022, WANG & ZHANG 2023). Rising sea levels, coupled with the increased frequency of storm surge and erosion, threaten both human settlements and critical ecosystems (TEBALDI et al. 2021). Although grey engineering-based solutions (e. g., concrete seawalls) have been implemented to reduce coastal hazards, they are often costly, ecologically disruptive, and lack the flexibility required for dynamic environments (TIWARI et al. 2025). It is necessary to develop cost-effective strategies that provide tangible ecological benefits for climate adaptation.

Living shorelines have gained increasing attention for their ability to build upon natural features and adaptive infrastructure to reduce erosion, buffer wave energy, and sustain coastal ecosystems (MORRIS et al. 2022, SLOYE et al. 2025). For example, marsh plants, sediment nourishment, shellfish reefs, and hybrid “soft” infrastructure provide more resilient alternatives. Meanwhile, the field of digital landscape architecture has evolved from basic visualization and analysis into a comprehensive pipeline linking geospatial data, simulation, artificial intelligence (AI), and design interventions (CLINGEN & BOOZ 2025, HUANG 2025, VOGLER et al. 2025).

In this broader evolution, a gap persists between high-level environmental analysis and the design of small-to-medium-scale physical elements, such as reef modules and ecological concrete units, that constitute living shoreline systems. Many of these components are currently manufactured in standardized forms, often overlooking local hydrodynamics, habitat goals, or the potential for community co-design. Industry precedents, such as Natrx’s modular living shoreline system, demonstrate how data-driven design and repeatable units can form flexible coastal protection networks (NATRX 2025). However, the design workflow that translates

ecological performance goals to manufacturable and deployable 3D models remains a major bottleneck for both practitioners and students. Therefore, this research addresses a central question: How can designers efficiently explore the vast solution space of complex forms, embed ecological intelligence, and validate designs through physical prototypes?

This research builds on prior work at the intersection of digital landscape architecture and coastal resilience. It showcases an AI-assisted concept-to-prototype workflow which links conceptual sketching, generative visualization, 3D modelling, and digital fabrication. The process was piloted within a third-year Bachelor of Landscape Architecture (BLA) advanced ecology course focused on “adaptive infrastructure for living shorelines.” Final outputs included conceptual posters, physical 3D models, and animated videos to demonstrate how adaptive infrastructure can conceptually address erosion and storm surge challenges while enhancing ecological performance climate-vulnerable coastal environments.

The findings suggest that an AI-assisted design workflow significantly reduces the time required for model generation. However, AI remains a supportive and mediating tool and still requires ecological verification and sustained human oversight. The contributions of this study include integrating Large Language Models (LLMs)-based prompting, generative image tools, AI-driven 3D modelling, and physical fabrication into a continuous workflow rather than focusing solely on visualization. This study also situates AI experimentation within the ecological framework of living shoreline infrastructure, which embeds habitat logic and modular aggregation into each stage. Since this study restricted AI use during the initial sketch phase, it establishes a pedagogical control that clarifies AI’s cognitive and translational roles in later phases. The integration of generative AI for ideation with 3D printing for fabrication represents a transformative paradigm for landscape architecture education.

2 AI-Assisted Design Workflow Methods

The core of this research is a five-stage workflow that guides students from abstract problems to physical prototypes (Figure 1). This framework was implemented in the Resilience Lab at the College of Environment and Design, the University of Georgia (UGA). Using a project as a detailed case study, we documented the complete workflow from hand-drawn sketches to fabricated physical prototypes. This process was tested in the third-year BLA’s Advanced Ecology course, where focused on designing adaptive infrastructure for living shorelines. A cohort of 27 students participated in the study and submitted 52 reflections (two reflections per student, with one submission missing).

The design workflow comprised the following stages: (1) Conceptual Hand-Drawing: Students developed initial modular shoreline unit concepts through traditional sketching, focusing on biological and structural forms. (2) AI-Assisted 2D Concept Generation: Based on their manual sketches, students employed iterative prompting in generative AI tools (such as Adobe Firefly) to refine and visualize their modular concepts; (3) AI-Assisted 3D Modelling: Students utilized AI-powered modelling platforms (such as Tripo AI) to translate their 2D concept images into fabricable 3D digital models; (4) Digital Fabrication (3D printing): Physical prototypes were produced using 3D printers, including the Bambu Lab H2D printer and Original Prusa MK4S 3D printers at the Lab; (5) Critical Reflection: At the conclusion of the project, the students submitted qualitative reflections on the AI-assisted workflow in both 2D concept and 3D modelling. We used thematic analysis to analyze the qualitative data.

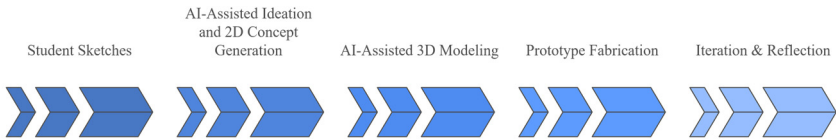


Fig. 1: AI-Assisted Living Shoreline Prototype Workflow

2.1 Student Sketches

In the fall semester of 2025, 27 students spent half of the term establishing a foundational understanding of ecological design principles and living shoreline systems through instructor-led lectures, assigned readings, and guest presentations (e. g., NATRX). Then, each of them developed hand-drawn concepts for adaptive infrastructure, focusing on a “singular modular living shoreline unit.” These units were required to be sculptural, repeatable, and capable of both shoreline stabilization and habitat provision for aquatic life. Students submitted three of their most viable and creative concepts (Figure 2). They were not allowed to use external assistance during this initial phase, including search engines or AI tools. This restriction ensured that all concepts were generated independently, based solely on students’ existing knowledge and ecological understanding.

2.2 AI-Assisted Ideation and 2D Concept Generation

In the second phase, students independently utilized LLMs to translate their hand-drawn sketches into descriptive prompts (Figure 2). They described the target forms in natural language, iteratively moving from concise prompts to more detailed narratives of form, structure, and ecological function. The refined prompts along with the scanned sketches were then processed through generative AI tools (e. g., Adobe Firefly) (Figure 2). Its purpose was not to replace students’ original concepts but to rapidly generate diverse visual iterations rooted in the initial hand-drawn geometry. This AI-assisted ideation stage was indispensable for breaking away from standard forms and exploring complex geometry shapes that are beneficial for biological colonization and wave energy dissipation. This process was similar to other applications in landscape analysis, where models are trained to interpret complex patterns but apply them in a generative, forward-looking manner (CLINGEN & BOOZ 2025). This stage demonstrates how AI shifts early design cognition from visual intuition to semantic precision.

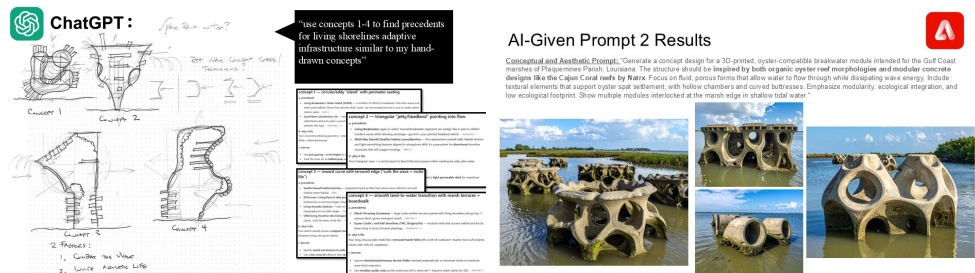


Fig. 2: Student sketches and AI-assisted ideation

2.3 AI-Assisted 3D Digital Modelling

The third stage involved translating the most viable 2D AI-generated concepts into 3D-printable digital models. This is a crucial step in design explanation and refinement, where students played a connecting role between the AI-generated “visions” and the demands of ecological performance. Utilizing AI-driven 3D modelling platforms (e. g., Tripo AI), students were divided into nine groups to develop digital models (two models per group) and embed design logic centred on ecological functions and coastal resilience. This ecological design logic included four components. Students uploaded the final concept images to Tripo AI, which generated volumetric 3D models (e. g., STL file) within minutes, bypassing traditional manual modelling constraints (Figure 3). To prepare for fabrication, the STL files were audited and refined in standard slicing software (e. g., PrusaSlicer). Models were scaled to representative dimensions and prepared for high-fidelity output. The transition from 2D imagery to volumetric modelling exposed a representational gap between visual plausibility and structural feasibility. Finally, while students did not perform hydrodynamic simulations, they were required to justify how specific formal features would conceptually contribute to wave attenuation, promote the recruitment of oysters and vegetation, or facilitate interlocking in modular arrays.

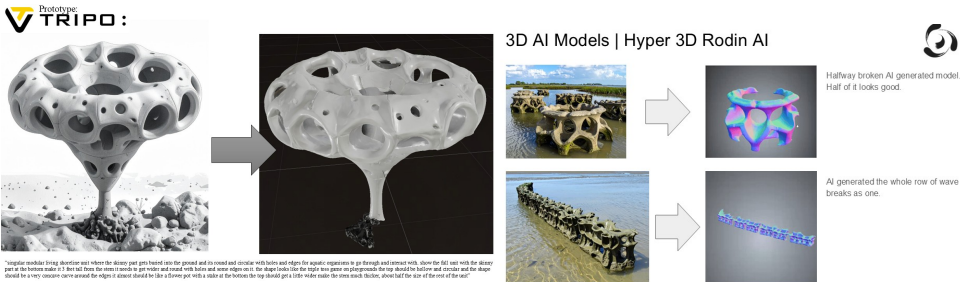


Fig. 3: AI-Assisted 3D digital modelling

2.4 Digital Fabrication & Prototyping

With refined 3D models, the workflow transitioned from virtual design to physical prototyping. Physical prototyping translates the abstract design concepts into tangible forms in order to make them more accessible and comprehensible, particularly for non-expert audiences (WANG & WANG 2023). Students fabricated their designs using 3D printers, including Bambu Lab H2D and Original Prusa MK4S 3D printers in the Resilience Lab. This hands-on prototyping phase exemplified research through making approach. The translation of digital files into a tangible object promptly revealed critical design flaws and fabrication issues, such as inadequate support structures or weak connections. Through iterative cycles of designing, printing, testing, and redesigning, students refined their modular prototypes to improve structural integrity and fabrication efficiency. Common refinement steps included thickening fragile elements, repairing mesh errors, resolving non-manifold geometry, and adjusting overhang angles to ensure printability, underscoring continued human oversight. In professional practice, fabrication restrictions are as important as the design intent. Therefore, this iterative physical testing was essential for developing viable, executable solutions (Figure 4). All prototypes were fabricated using standard polylactic acid (PLA) filament with a

layer height of 0.2 millimetres. A single one-kilogram spool of PLA, priced at 32.99 United States dollars (USD), could produce between one and five or more models, depending on model size and print settings. Overall, material costs were low.

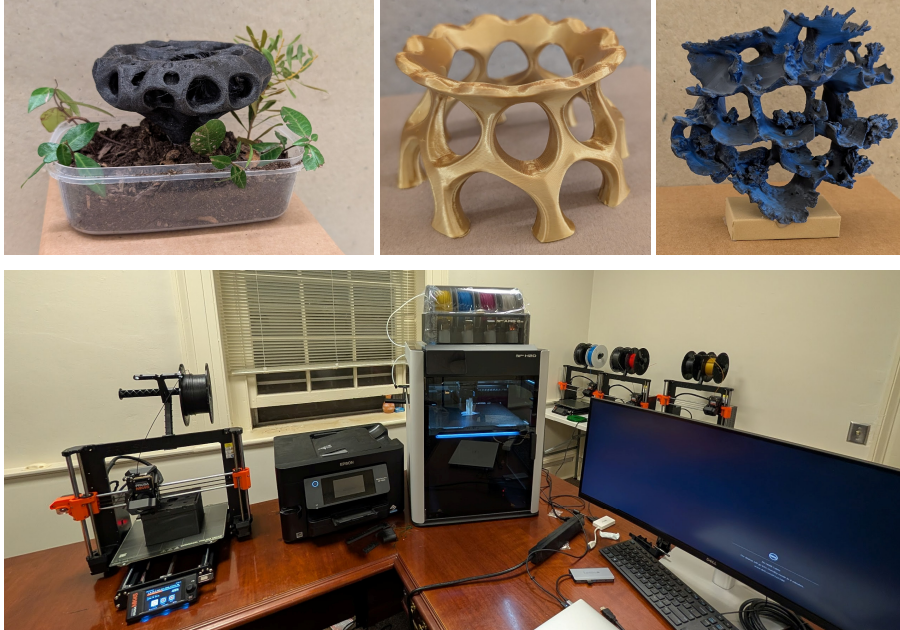


Fig. 4: Printed 3D models and 3D printers

2.5 Reflection and Evaluation

A primary outcome of this study was the evaluation of student reflections and perception. A qualitative thematic analysis was conducted on 52 reflections on AI-assisted concept ideation and 3D modelling submitted by 26 students. This analysis aimed to synthesize student experiences regarding the utility of AI to assist the design process. Following an inductive protocol, reflections were anonymized and iteratively coded. Initial open coding identified recurring concepts related to AI use, ecological reasoning, workflow challenges, and ethics. Codes were then grouped into broader themes through axial coding, resulting in stabilized thematic categories. Coding was conducted by the first author and reviewed through peer discussion with the co-author to strengthen analytical consistency. Themes were finalized when no new categories emerged, and a codebook was developed. The analysis captures pedagogical perception rather than objective performance metrics, but the structured coding process enhances transparency and credibility.

The initial phase of AI-assisted concept ideation transformed the design process from manual sketching to linguistic iteration by LLMs and Generative AIs. There were four dominant themes characterized the student experience and thoughts, including temporal compression, designing through language, the need for ecological verification, and ethical concerns. Most students believed that AI-assisted ideation shortened the timeframe for early design exploration. The rapid generation of visual alternatives enabled students to survey of a broad “design

landscape” in minutes. This speed encouraged non-traditional ideas due to the low cost of iteration. One student reflected, “The main benefits of using AI for concept generation are time, efficiency, and the ability to rapidly explore multiple design directions without the usual limitations of hand drawing or 3D modelling. I didn’t have to spend hours sketching or rendering every idea that came to mind; instead, AI could instantly visualize a wide range of concepts, which I could then refine and adjust based on my goals (Student 19 [S19]).” A major finding was the realization that AI required linguistic precision. It became a form of design labour for the AI-assisted design workflow. Students emphasized that small changes in wording, such as substituting “artificial reef” with “reef-like form shaped by natural erosion (S7),” produced different visual outcomes. This led to a shift in how students conceptualized design authorship, moving from drawing and modelling toward iterative prompt construction.

Although students reported that AI-generated images introduced forms or spatial ideas they did not initially envision, they were concerned that these AI products focused on visual aesthetics while lacking an inherent understanding of ecological processes and site conditions. As a result, students described a recurring need to verify AI outputs against ecological knowledge. As students noted, “AI can generate shapes and surfaces, but it doesn’t understand ecology, culture, or the purpose behind a design (S6).” “I had to constantly verify the outputs with real ecological principles and case studies (S13).” Students also discussed ethical questions regarding AI use, with a focus on originality and authorship. They considered AI as a supportive ideation tool rather than a creative designer. While many acknowledged AI’s value for rapid brainstorming and visualization, students argued that authorship resided in human decision-making, including selecting prompts, rejecting outputs, validating ecological logic, and translating concepts into fabricable forms. For instance, “It is tricky ethically... I don’t think image generation models are advanced enough to ‘do our projects for us,’ and even if they were, they shouldn’t (S1).”

In reflections on AI-assisted 3D modelling, students consistently described the transition from 2D imagery to 3D geometry as the most challenging and revealing stage of the workflow. In addition to previous themes, cognitive bottleneck emerged another significant theme. While AI-generated images appeared visually convincing, their translation into volumetric form exposed gaps in scale, thickness, structural logic, and spatial completeness. 3D modelling shifted students from aesthetic evaluation to constructive reasoning. As digital models were prepared for 3D printing, students reported a critical shift in their understanding of the design. Forms that appeared plausible on screen often lacked volumetric integrity when materialized (e. g., weak connections). “The software automatically created a 3D version of it, and while it looked impressive at first, the model needed a lot of cleaning up. Some parts didn’t make sense structurally; there were problems getting the model to have spaces in between the roots so at first it looked more like a big blob (S9).” Furthermore, 3D printing process revealed physical constraints that AI could not anticipate, such as gravity and fabrication tolerances. This reinforced the role of physical prototyping as a validation step rather than a mere representational exercise. “It also exposed some of the limitations of AI-generated models. Certain forms that looked fine on screen didn’t translate well into 3D printing; they were too thin, too fragile, or not structurally sound. These challenges showed me how important it is to bridge digital design with real-world testing (S6).”

3 Discussion

The findings indicate that AI functions as an accelerant and mediator in the design process. In the 2D concept generation phase, AI enables rapid visual ideation. This introduces a shift from intuitive visual thinking to linguistically mediated reasoning. Students learned that AI interprets design intent literally rather than intuitively, which requires precise prompts that are often refined through large language models. Beyond procedural acceleration, the workflow reveals a cognitive shift in ecological design reasoning. Prompt-based iteration externalizes design intent into language. As a result, ecological logic must be articulated explicitly. Although AI occasionally acted as a creative provocateur, it also presented risks of ecological misrepresentation. Therefore, students emphasized the necessity of human oversight to verify ecological credibility. During 3D modelling and prototyping, AI played a translational role, converting images into volumetric geometry. The transition from 2D imagery to 3D form functioned as a critical verification stage, revealing issues of scale, thickness, negative space, and structural feasibility that were obscured in two-dimensional representations. Although AI tools lowered the technical barriers to early prototyping, they lacked an intrinsic understanding of hydrology, habitat connectivity, and material performance.

Regarding ethics and authorship, the study suggests that designers perceive AI as a supportive, translational instrument rather than a creative authority. The retention of authorship is fundamentally tied to human judgment, ecological reasoning, and transparent workflow documentation. The limitations of this research include its reliance on student-authored reflective writing, which captures qualitative perceptions and pedagogical experiences. No hydrodynamic simulations or field validation were conducted. Therefore, performance-related statements reflect design intent rather than empirically tested outcomes.

4 Conclusion and Outlook

Overall, the study demonstrates that AI-assisted 2D ideation and 3D modelling workflows effectively compress the distance between concept and prototype. However, this acceleration intensifies the necessity for human ecological literacy, linguistic precision, spatial reasoning, and ethical responsibility. In the context of living shoreline infrastructure, while AI expands conceptual capacity and accelerates iteration, the translation of ecological intent into resilient, fabricable systems remains fundamentally dependent on human expertise. This is positioning designers as essential “human-in-the-loop” collaborators.

The transition from 2D imagery to 3D geometry emerges as a critical pedagogical moment, where visual imagination is confronted by spatial and material reality. Physical prototyping further grounds this process, reinforcing the limits of automation and the necessity of ecological verification. For landscape architecture education, these findings suggest that AI is most effective when positioned as a mediating tool within a structured concept-to-prototype pipeline. Such workflows can expand students’ capacity to imagine, test, and refine resilient systems while preserving the human expertise required to ensure ecological performance and ethical responsibility. Future research should examine how AI can be responsibly and productively embedded within ecological design processes through advanced simulation, such as linking generative forms with real-time hydrodynamic and habitat-connectivity data. As these tools evolve, the goal remains to embed them critically within the design process, en-

sureing that the next generation of landscape architects can navigate the complexities of climate adaptation with both technological fluency and ecological responsibility.

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