Gabriel E. Lipkowitz

Email: gel19@stanford.edu | **Office**: James H. Clark Center E150 | **Tel**: (650) 441-7449
Portfolio | **Personal website** | **Scholar**

Research interests

Computational design, Multimaterial fabrication, Generative structural design, Architectural robotics, Spatial environmental design

Education

Stanford University — Stanford, CA
PhD in Mechanical Engineering — 2020 – Present
Research focus: Sustainable multimaterial design and fabrication
Teaching focus: Parametric structural design
Advisors: Professors Joseph DeSimone and Eric S.G. Shaqfeh
Anticipated graduation: June 2024

Imperial College London — London, UK
MSc in Applied Computational Science and Engineering — 2019 – 2020
Graduated with highest honors
Advisors: Professors J.P. Latham and Eleanor Schofield

Princeton University — Princeton, NJ
Bachelor of Arts in Biology — 2015 – 2019
Graduated summa cum laude

Awards and Fellowships

Fulbright Scholarship (US/UK Fulbright Commission)	2019-2020
NSF Graduate Research Fellowship	2020 - Present
Solid Freeform Fabrication Symposium NSF Student Award	2022, 2023
Data Science Institute Fellow (University of Virginia)	2019
Sigma Xi thesis award, Princeton University	2019

Research Publications (Conferences)

Palette-PrintAR: augmented reality design and simulation for multicolor resin 3D printing
Lipkowitz, G., Shaqfeh, E.S.G., and DeSimone, J.M.
Accepted: *Association for Computing Machinery, Conference on Human Factors in Computing Systems, Full Paper, 2024.*

Palette-PrintAR: an augmented reality fluidic design tool for multicolor resin 3D printing
Lipkowitz, G., Shaqfeh, E.S.G., and DeSimone, J.M.
Association for Computing Machinery, Symposium on User Interface Software and Technology, Late-Breaking Work, 2023.

Paraflow: A Computational Design Tool for Support-free Multimaterial 3D Printing
Lipkowitz, G., Shaqfeh, E.S.G. and DeSimone., J.M.
Association for Computing Machinery, Conference on Human Factors in Computing Systems, Late-Breaking Work, 2023.

Printing atom-efficiently: faster fabrication of farther unsupported overhangs by fluid dynamics simulation
Lipkowitz, G., Krishna, N. Coates, I., Shaqfeh, E.S.G., and DeSimone, J. M.
Association for Computing Machinery, Symposium on Computational Fabrication, Full paper, 2023.

Interactive Fluid Dynamics Simulation with Real-time Visualization for Augmented Resin 3D Printing
Lipkowitz, G., DeSimone, J.M.
International Solid Freeform Fabrication Symposium, Full Paper, 2023.

Generative co-design for microfluidics-accelerated 3D printing
Lipkowitz, G., Shaqfeh, E.S.G., DeSimone, J.M.
Association for Computing Machinery, Symposium on Computational Fabrication, Demonstration track, 2022.

Fluidics-Informed Fabrication: A Novel Co-design for Additive Manufacturing Framework
Lipkowitz, G., Shaqfeh, E.S.G. and DeSimone, J.M.
International Conference on Human-Computer Interaction, Full Paper, 2023.

Digital Microfluidic Design for Injection Continuous Liquid Interface Production of 3D Objects
Lipkowitz, G., ..., Shaqfeh, E.S.G., DeSimone, J.M.D
International Solid Freeform Fabrication Symposium, Full Paper, 2022.

Research Publications (Journals)

Injection continuous liquid interface production of 3D objects
Lipkowitz, G., Samuelsen, T., Hsiao, K., Lee, B., ... DeSimone, J. M.
Science Advances, 2022.

Growing three-dimensional objects with light
Lipkowitz, G.*, Saccone, M.*, ..., and DeSimone, J.M.
* Authors contributed equally to this work.
Accepted: *Proceedings of the National Academy of Sciences*

Bioinspired fluidic design for additive manufacturing
Lipkowitz, G., Krishna, N., Coates, I., Shaqfeh, E.S.G., and DeSimone, J.M.
Under review: *Nature*

Single-digit-micrometer-resolution continuous liquid interface production
Hsiao, K., Lee, B. J., Samuelsen, T., Lipkowitz, G., ..., DeSimone, J. M.
Science Advances, 2022.

Teaching

CEE 220C: Parametric Design and Optimization
Teaching assistant Spring 2022
Department of Civil and Environmental Engineering, Stanford University
This course explores tools and techniques for computational design and parametric modeling as a foundation for design optimization.

CEE 220A: Building Modeling for Design
Head teaching assistant Summer 2022
Department of Civil and Environmental Engineering, Stanford University
This course introduces techniques for creating, managing, and applying of building information models in the building design and construction process.

CS11SI: How to Build VR - An Introduction to Virtual Reality Design
Student-initiated course project advisor Fall 2023
Department of Computer Science, Stanford University
This course introduces students to development for virtual reality technologies.

Biodesign collaboratory teaching associate Spring 2022 - Present
Byers Center for Biodesign, Stanford University
Mentored post-graduate students in computer-aided design and digital fabrication workflows using 3D printers, laser cutters, and 3D scanners.

Graduate teaching assistant Spring 2023 - Present
Uytengsu Undergraduate Teaching Lab, Stanford University
Mentored undergraduates in CAD practices and installed 3D printers for use in undergraduate courses and extracurricular projects.

CS12SI: Spatial Computing Workshop Spring 2024
Student-initiated course instructor
Stanford University
Course to expose students to the basics of Apple Vision Pro development using principles of spatial design and visionOS, including using SwiftUI and Unity PolySpatial workflows.

Exhibits

G-code is my love language
San Jose State University November 2023 - February 2024
Fabrication lead
Fabricated and helped to design invited artists' pieces for 3D printing, and contributed augmented reality-based exhibit tool.

Industrial work

Stanford XR Project Incubator
Organizer (Winter 2023 - Present)
Mentored by members of Apple's Vision Products Group (VPG), translating XR design academic research conducted at Stanford into prototype visionOS application for deployment to Apple Vision Pro.

Immerse the Bay Hackathon
Organizer (Fall 2023)
With Stanford XR and external contributors, mentors, and judges from Apple, Unity, ShapesXR, Foundary, and other AR/VR companies, helped to organize a XR hackathon with 300 hackers (largest in Bay Area history).

Layer Construction
Chief Technology Officer (2022-Present)
Start-up (stealth mode) focusing on mobile 3D printing for concrete construction. My role focuses on developing computer vision machine learning models for robot navigation in unstructured environments.

Methods and Systems for Making Polymeric Microstructures
Patent issued (2023)
Lipkowitz, G. Dulay, M., Samuelsen, T. Shaqfeh, E.S.G., DeSimone, J.M.

Polymeric Structures having a Micro-void space and Methods for Making the Same
Patent pending
Coates, I. Lipkowitz, G. DeSimone, J.M.

External Talks & Presentations

Printing atom-efficiently: faster fabrication of farther unsupported overhangs by fluid dynamics simulation
Oral presentation
ACM Symposium on Computational Fabrication
New York City, NY USA, October 2023

Demonstrating Paraflow: Interactive fluid dynamics simulation with real-time visualization for augmented resin 3D printing
Oral presentation
International Solid Freeform Fabrication Symposium
Austin TX USA, August 2023

Designing data: Methods for 3D synthetic data generation for computer vision machine learning
Invited lecture
COMPSCI C8: Foundations of Data Science
UC Berkeley, August 2023

Multimaterial 3D printing by injection continuous liquid interface production
Oral presentation
eWEAR Annual Symposium
Stanford University, February 2023

Accelerated 3D printing with injection continuous liquid interface production
Presentation
Stanford Bio-X Symposium
Stanford University, August 2022

Injection continuous liquid interface production
Additive Manufacturing of Soft Materials, Gordon Research Conference
Ventura CA USA, August 2022

Digital Microfluidic Design for Injection continuous liquid interface production
Presentation at International Solid Freeform Fabrication Symposium
Austin TX USA, July 2022

Multimaterial printing by injection continuous liquid interface production
Presentation at 3D Printing-enabled Polymeric Composites and Hybrid Systems Session, American Chemical Society
San Diego CA USA, March 2022

3D Printed Buildings: Can it be green, affordable, and sustainable?
Discussion lead: CEE 132A Sustainable Architecture and Engineering Colloquium: Re:Defining Sustainability
Stanford CA USA, October 2023

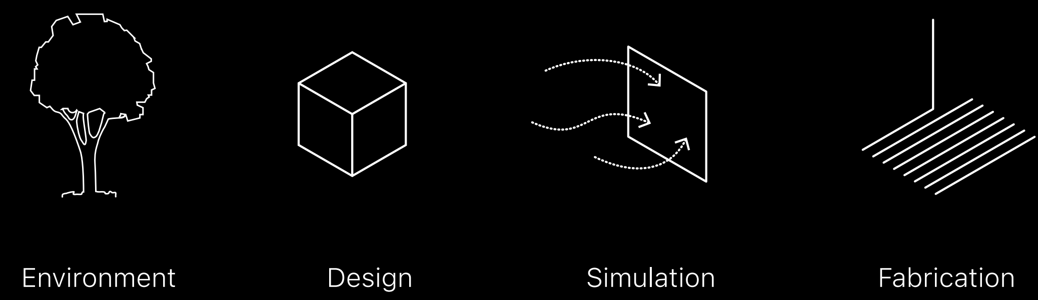
Paraflow: Generative Design for 3D Printing with Fewer Supports
Applied Artificial Intelligence, Big Data, and Data Analytics Session, American Institute for Chemical Engineers
Orlando FL USA, November 7, 2023

Academic Service

Session chair, Solid Freeform Fabrication Symposium (2023)
Peer reviewer, Nature (2023)
Peer reviewer, Nature Communications (2022)
Peer reviewer, Science Advances (2022-2023)
Peer reviewer, Solid Freeform Fabrication Symposium (2023)
Peer reviewer, ACM Symposium on Computational Fabrication (2023)
Peer reviewer, ACM Conference on Human Factors in Computing Systems (2023)

DESIGN RESEARCH PORTFOLIO

Gabriel Lipkowitz



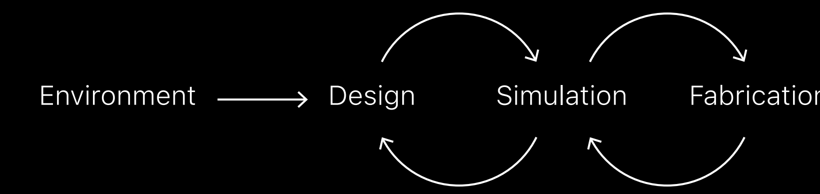
Linear CAD workflow

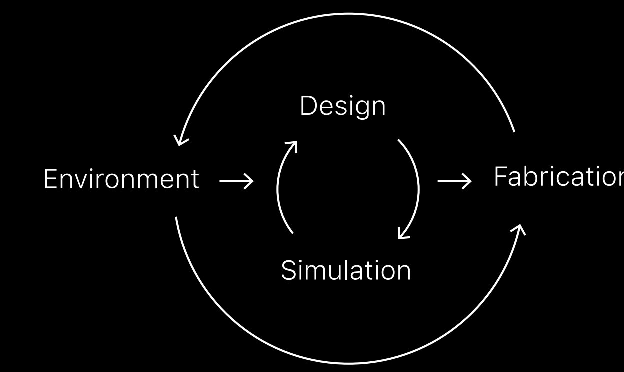
Environment ⟶ Design ⟶ Simulation ⟶ Fabrication

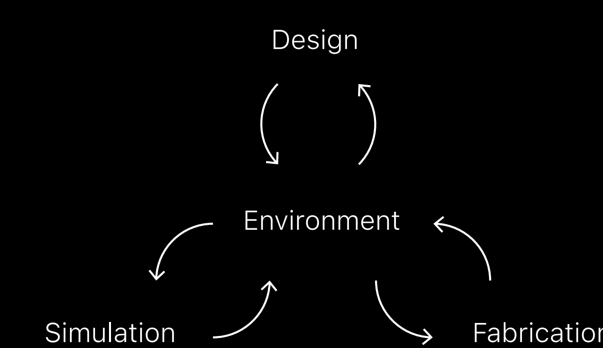
Computer-aided design (CAD), transformative when introduced in the 1960s, today demands reinvention to more holistically account for factors of **material** and **fabrication** in design, so as to better address burgeoning crises of **sustainability**, **accessibility**, and **affordability** now confronting built environments. Four projects described here propose alternative, more integrated approaches to **embodied design computation**. At differing length scales, with differing materials, and through differing fabrication processes, each attempts to more closely couple real-world materials and fabrication with computation through **design feedback loops**. Alluding to **software infrastructure** critical for application development, along with an aspiration to emulate how **Nature** designs, for each design scenario is developed a distinct **design ecosystem**.

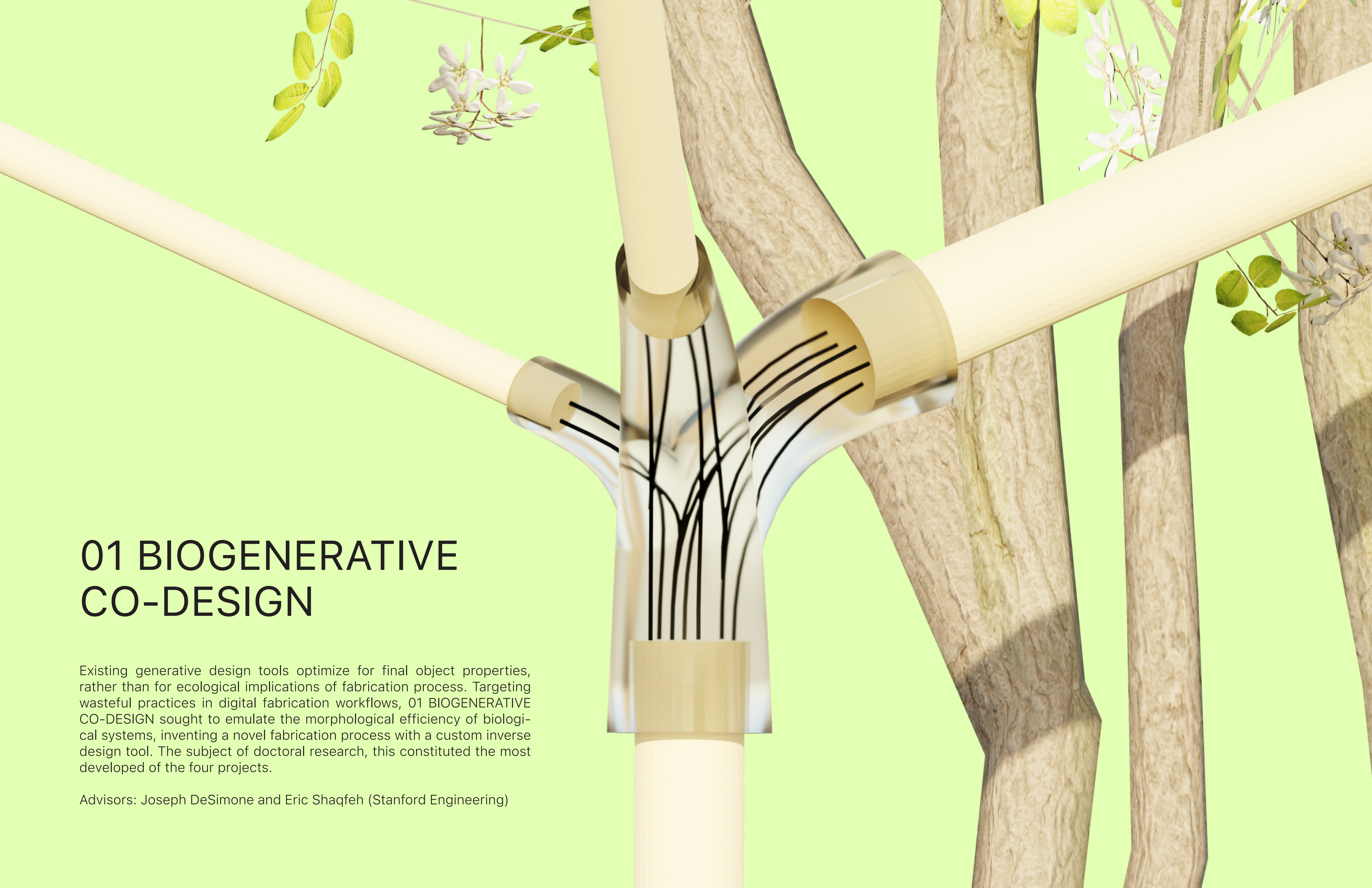
Contents

Design ecosystem





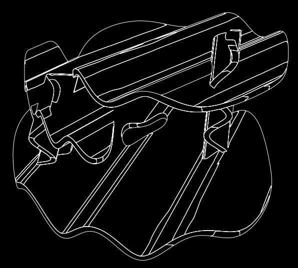




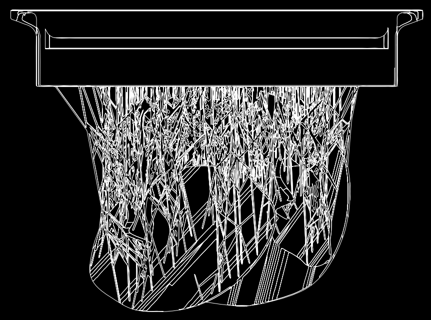
01 BIOGENERATIVE CO-DESIGN

Existing generative design tools optimize for final object properties, rather than for ecological implications of fabrication process. Targeting wasteful practices in digital fabrication workflows, 01 BIOGENERATIVE CO-DESIGN sought to emulate the morphological efficiency of biological systems, inventing a novel fabrication process with a custom inverse design tool. The subject of doctoral research, this constituted the most developed of the four projects.

Advisors: Joseph DeSimone and Eric Shaqfeh (Stanford Engineering)



3D model



3D model with supports

3D model

↓

Support structure design

↓

3D print ⟶ 3D object

↓

Manually cleave support structures

↓

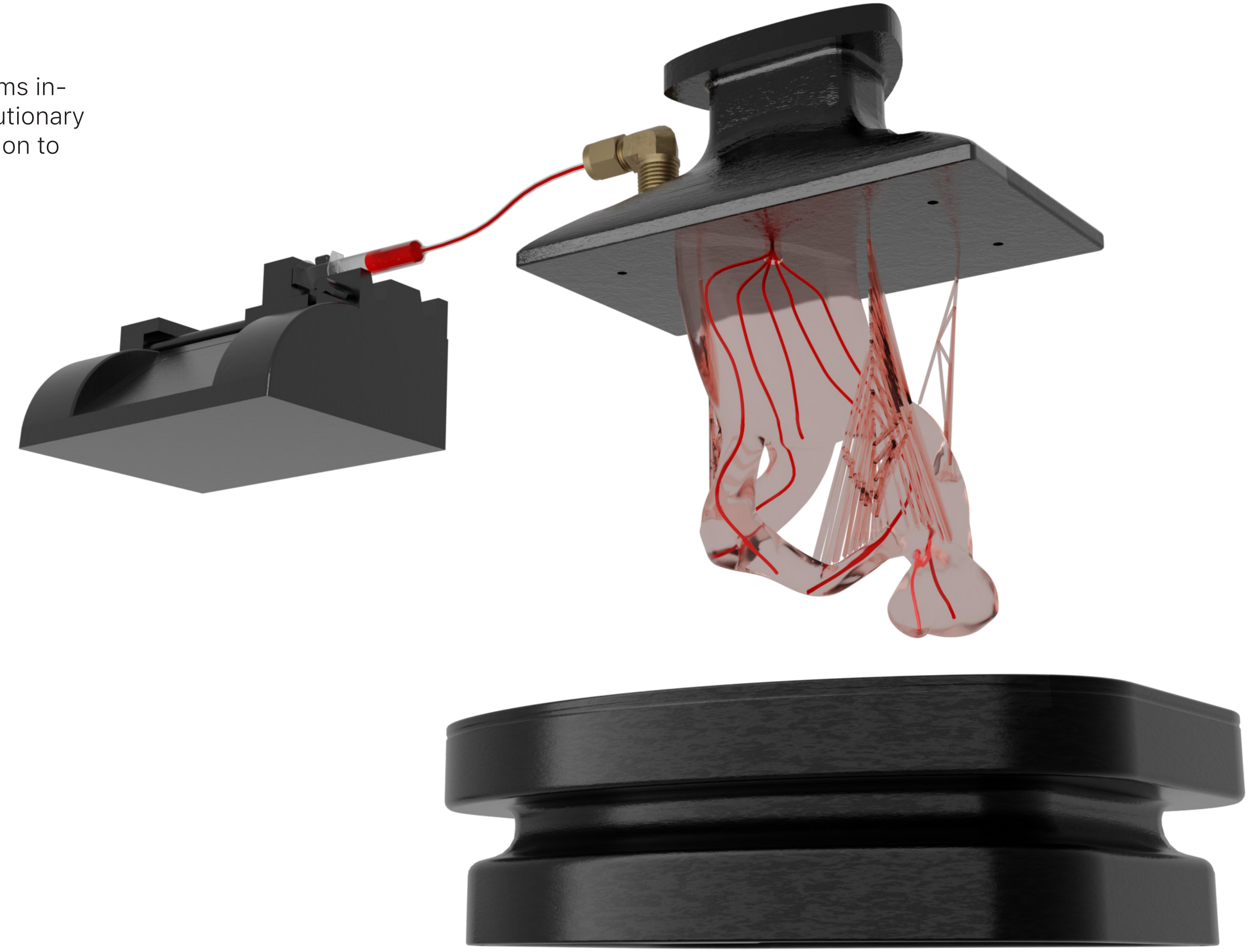
Discard support structure waste

Current 3D printing practices require significant waste as support structures. To right, a piece of the artist Jolie Ngo, for exhibition at "G-Code is my love language", San Jose State University (November 2023 - February 2024).

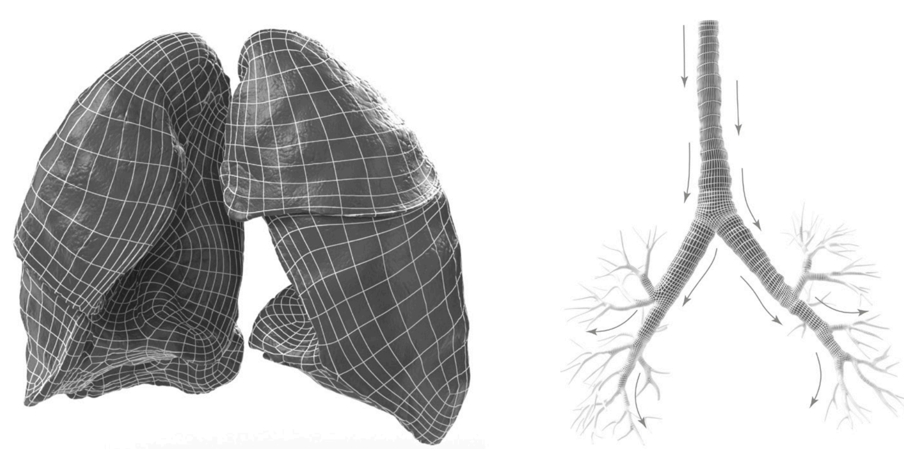
Fabrication and Photograph: Gabriel Lipkowitz

Photograph: Gabriel Lipkowitz

The project posed the question: could the fluidic control mechanisms of biological organisms inspire a more sustainable fabrication approach? For computational implementation, an evolutionary algorithm driven by particle swarm optimization (PSO) was combined with a hardware add-on to existing printers, optimally growing a fluidic network for any user mesh.

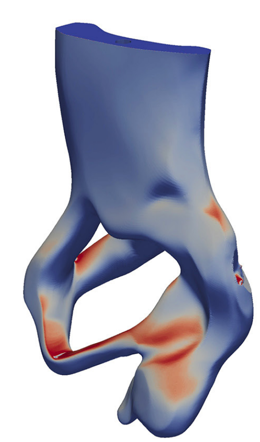


Bioinspiration and summary of mesh operations for inverse design approach



Human respiratory fluid mechanics

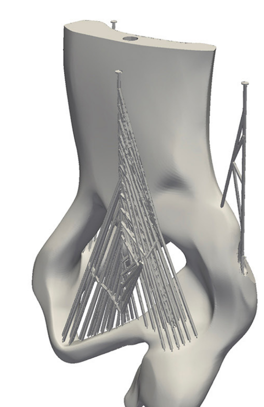
Input 3D model



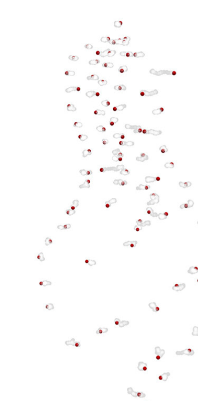
Surface normals extraction

Overhang analysis

Support requirements



Support inverse design

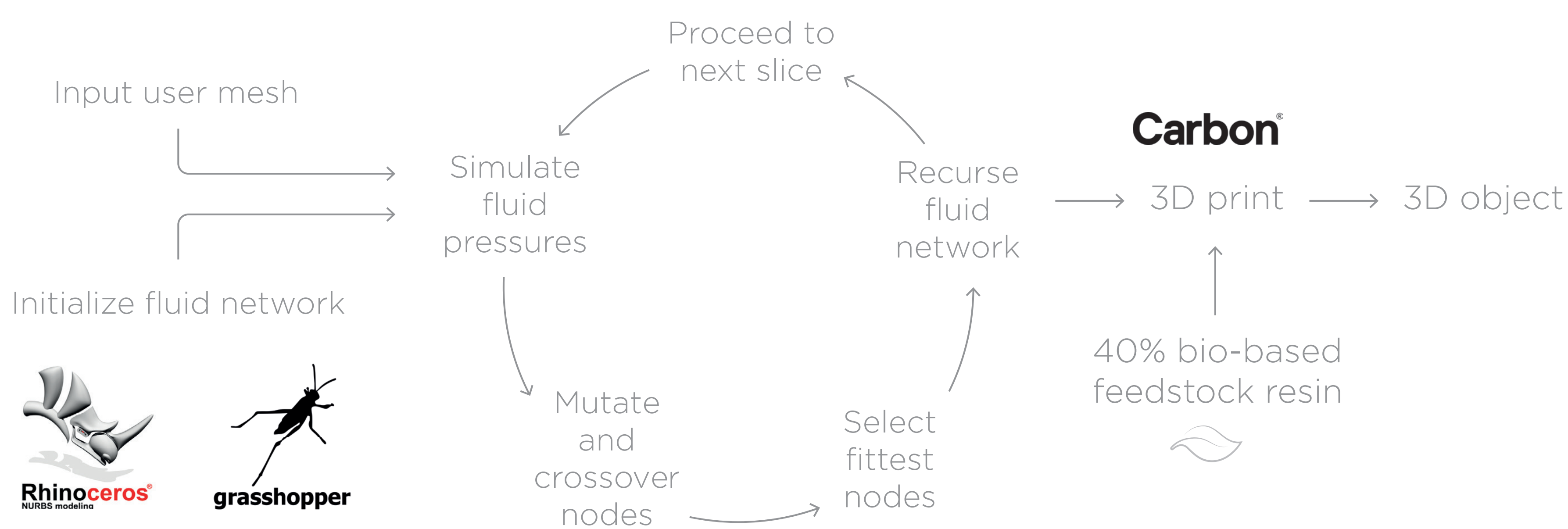


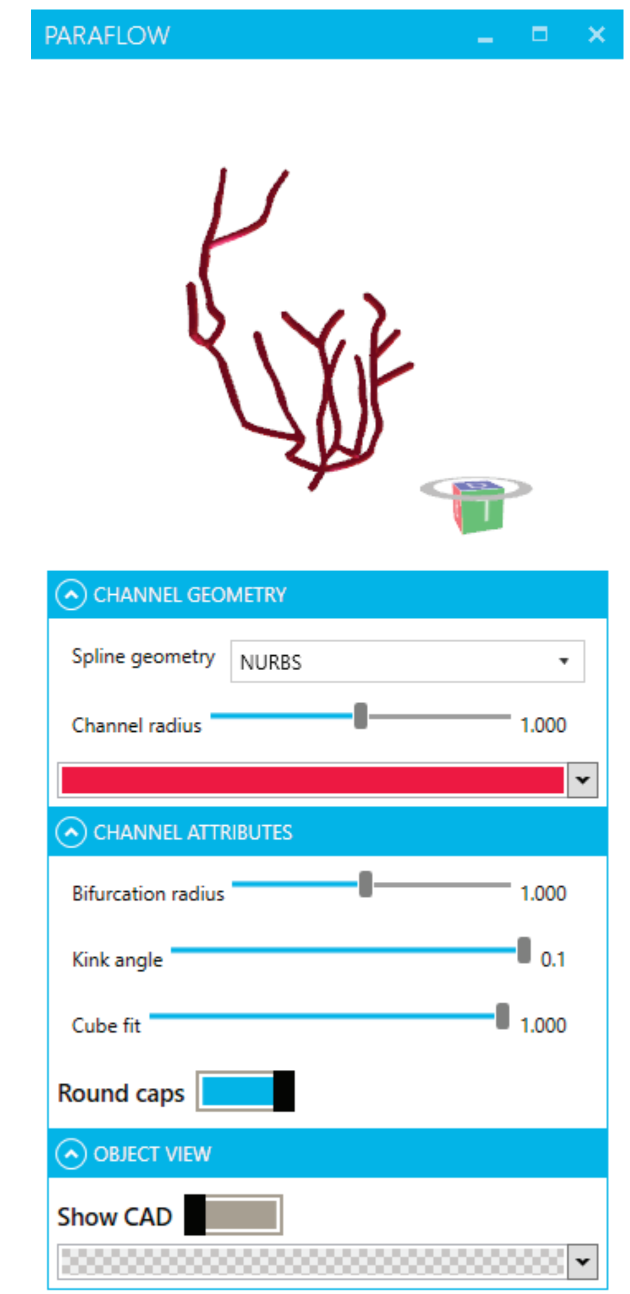
Evolutionary optimization

Fluid network inverse design

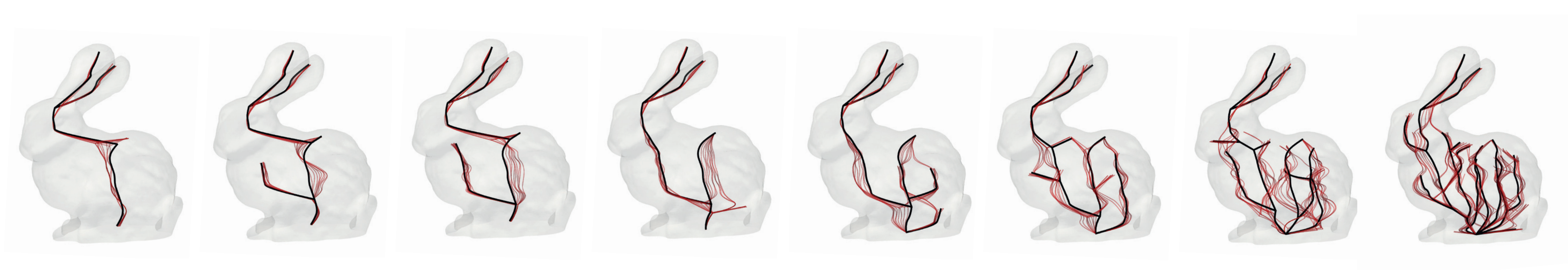
An inverse computational design algorithm was open-sourced as a Rhino/Grasshopper-based tool that wrapped complex physics-based fluid dynamics simulations into an intuitive and modifiable user interface, here shown for *Stanford bunny*, a canonical computer graphics model for testing 3D computational geometry algorithms.

State diagram of novel injection 3D printing design and fabrication process



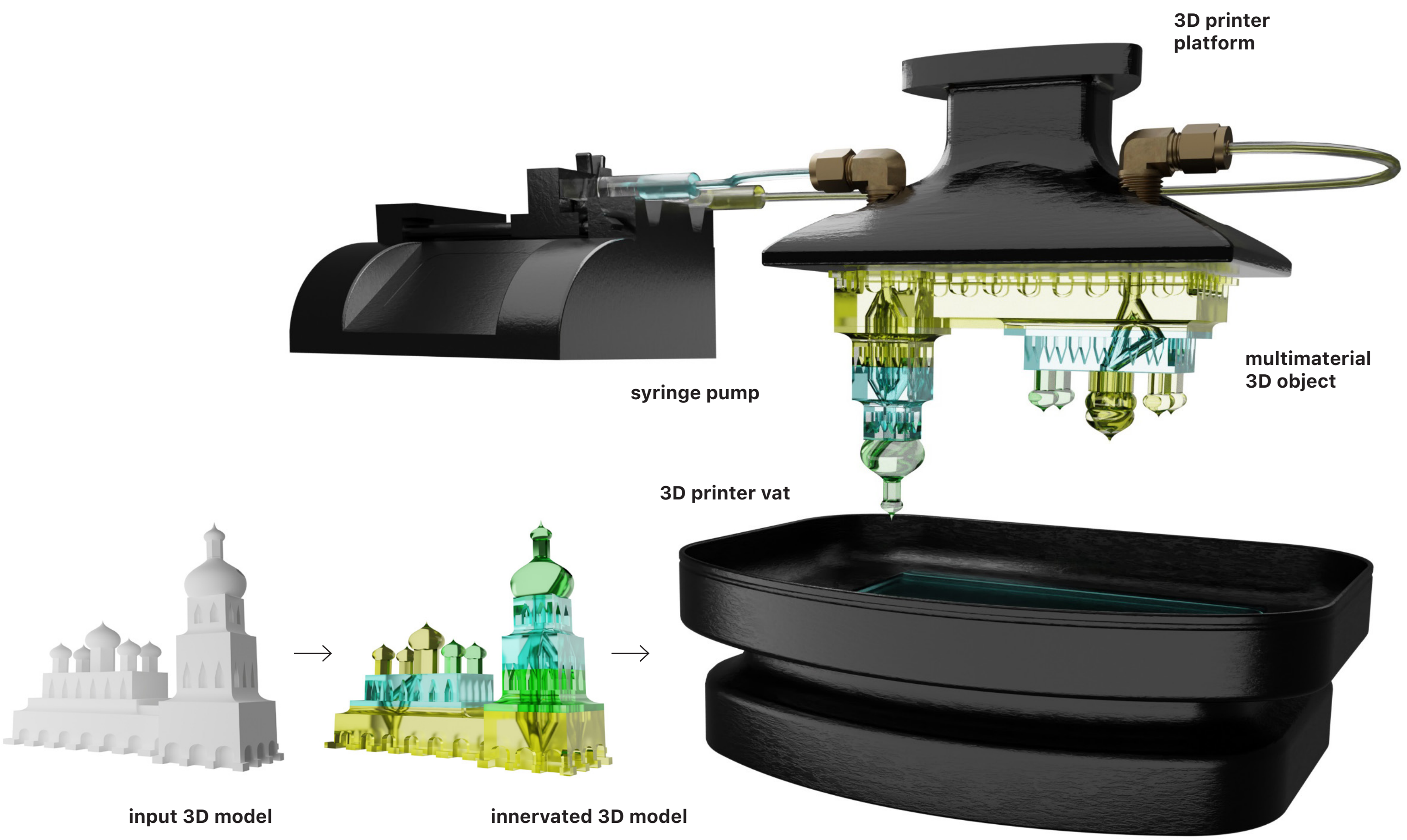


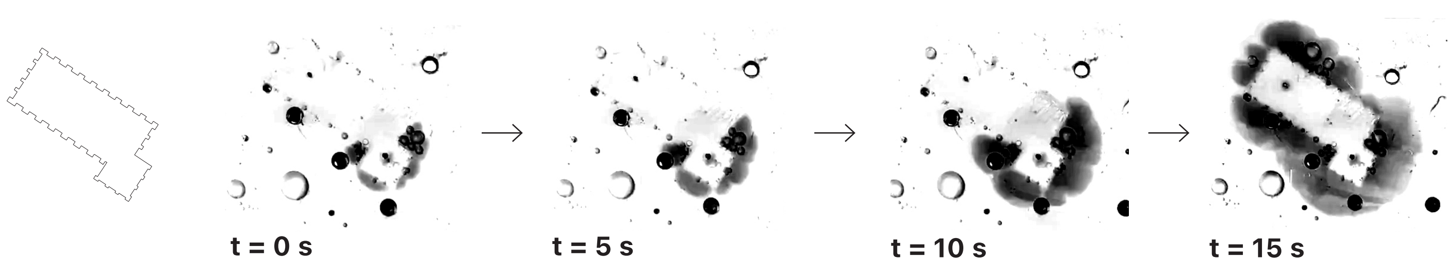
Summary of evolutionary algorithm for generating network geometry



Lipkowitz, Gabriel, Eric Shaqfeh, and Joseph Desimone. "Paraflow: A Computational Design Tool for Support-free Multimaterial 3D Printing." Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems. 2023.

Beyond alleviating need for supports, this approach rendered an otherwise single material computational fabrication process multimaterial, infusing multiple resins through fluidic channels into the 3D printer.

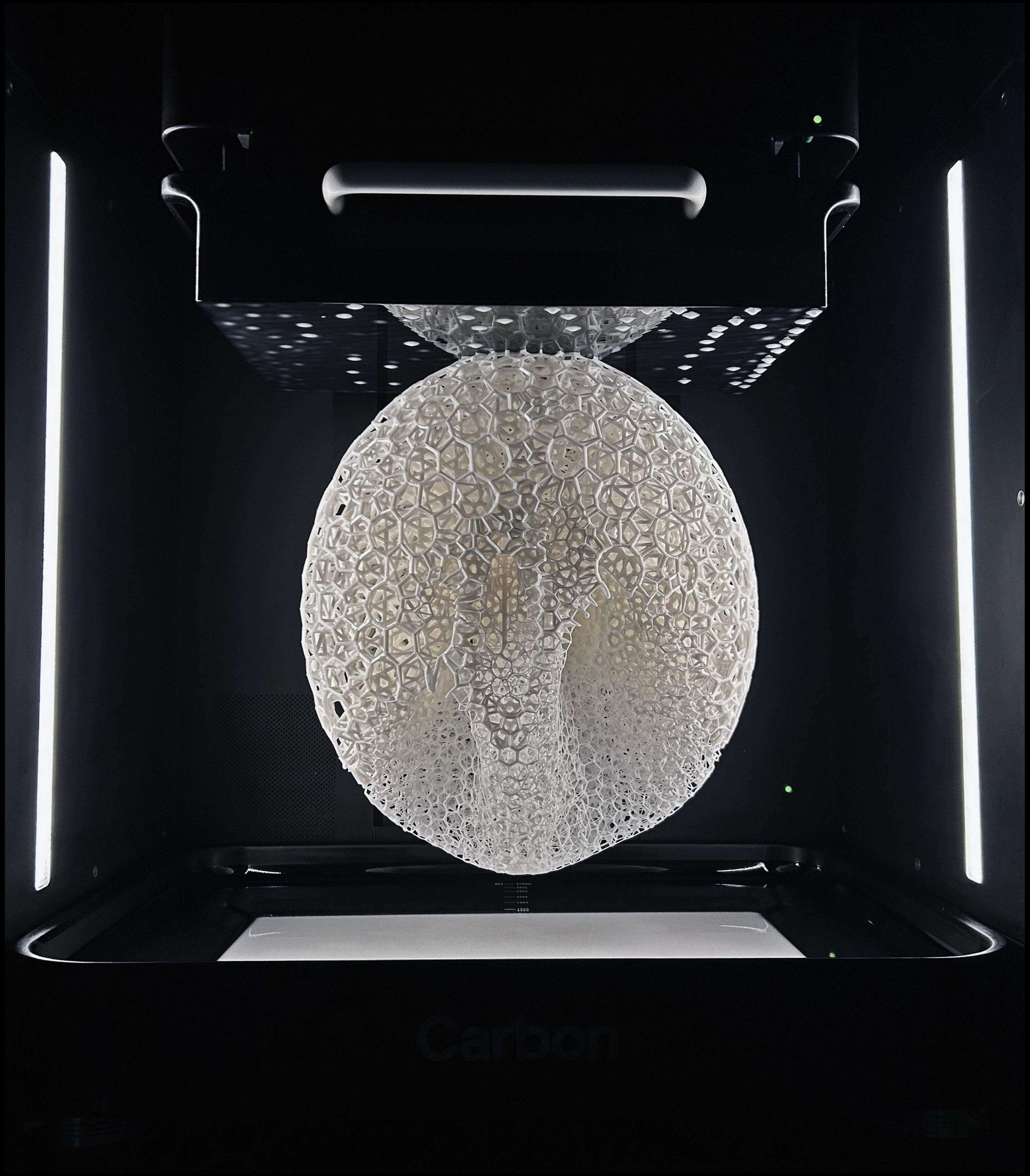




Real-time views of injection 3D printing (Fabrication and Photographs: Gabriel Lipkowitz)

Lipkowitz, G. Dulay, M. Samuelson, T. Shaqfeh, E. DeSimone J. (2023). Methods and systems for making polymeric structures (Patent No. WO2023177815A1). WIPO/PCT.

Lipkowitz, G., et al. “Injection continuous liquid interface production of 3D objects.” *Science Advances* 8.39 (2022): eabq3917.



With this computational design and fabrication approach, our goal is to realize architectural component-scale models as dematerealized objects with zero plastic waste.

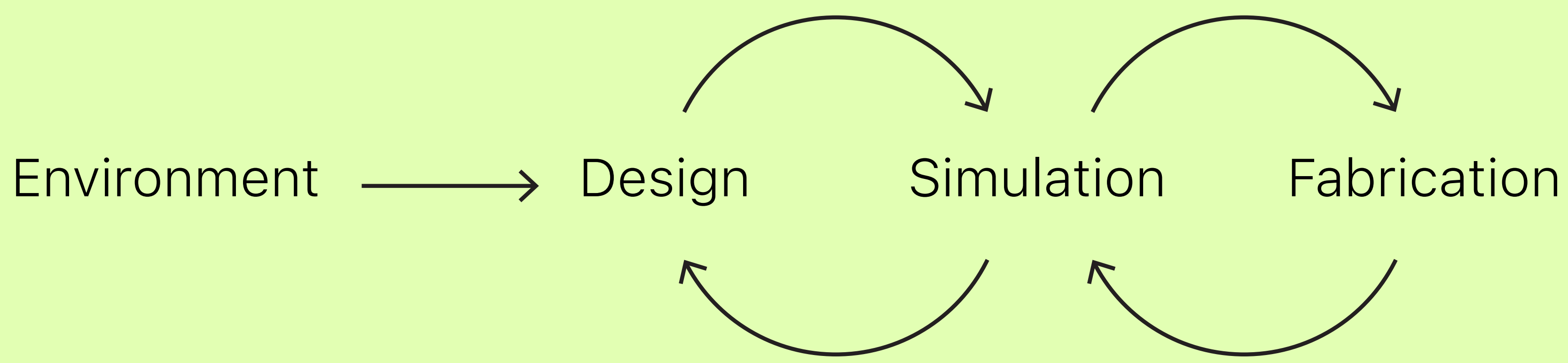
Design by Alvin Huang and fabricated at Stanford for exhibit at San Jose State University.
Fabrication and Photograph: Gabriel Lipkowitz.

For architectural-scale structures, we envision fabricating node-truss assemblies that interweave with, and respond to, their natural environmental context.

"Study nature, love nature, stay close to nature. It will never fail you."

- Frank Lloyd Wright

Design Ecosystem: 01 Biogenerative co-design

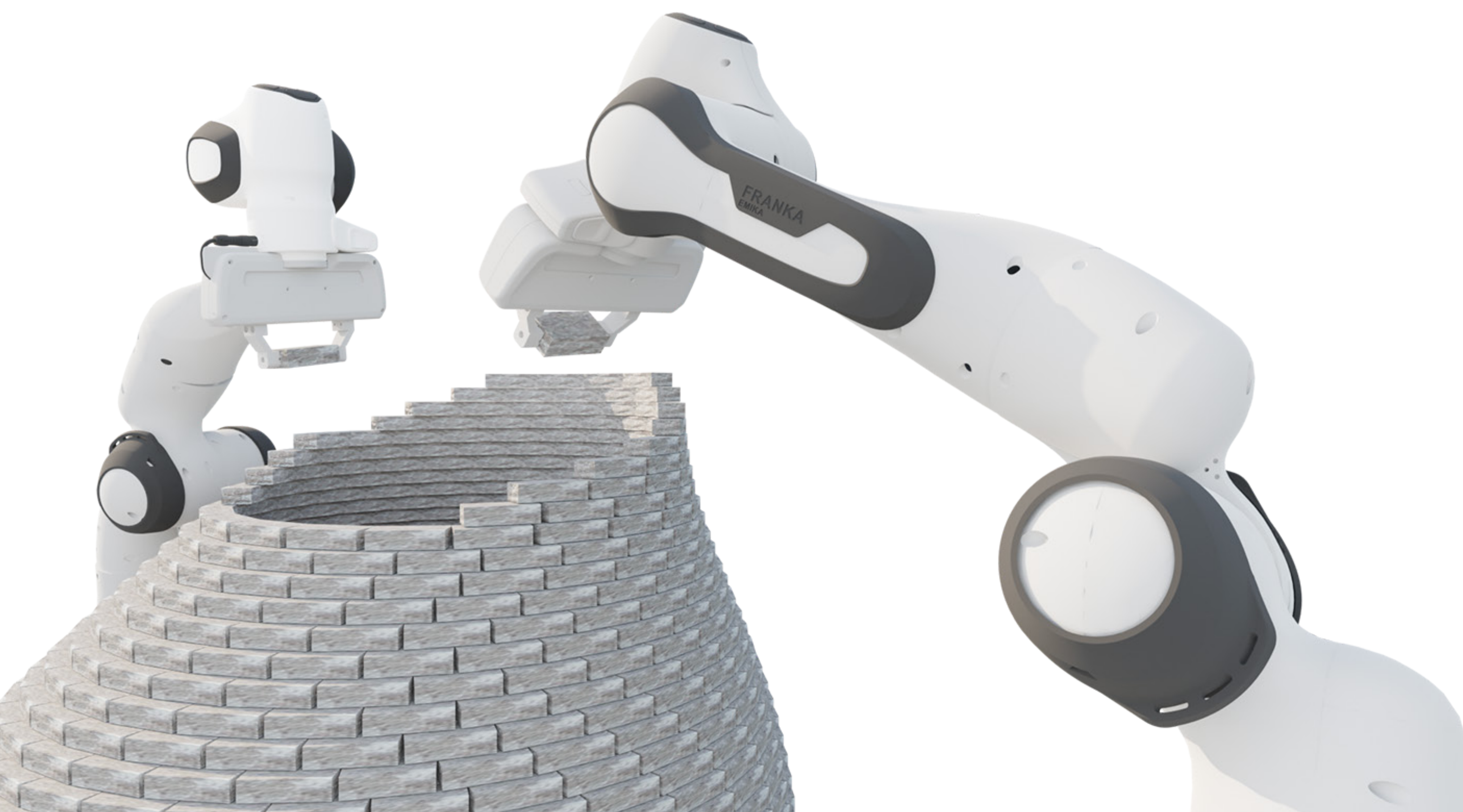


01 BIOGENERATIVE CO-DESIGN incorporated two feedback loops into traditional 3D printing design workflows, with the goal of emulating the efficiency of fluidic networks designed by natural systems. Simulation of fluid-structure interaction guided the novel multimaterial fabrication approach, which in turn directly informed the complementary co-design process.

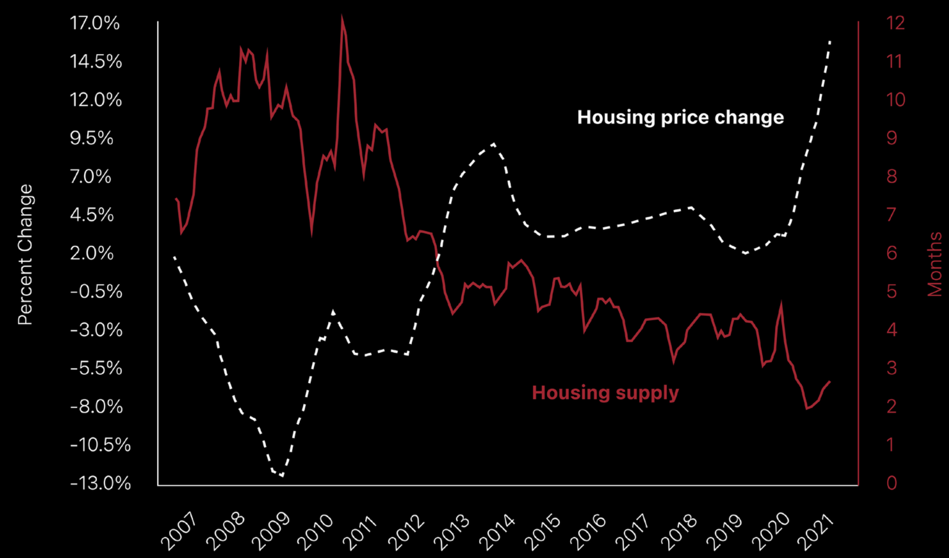
02 EMBODIED FABRICATION AGENTS

Motivated by a burgeoning need for affordable housing, 02 EMBODIED FABRICATION AGENTS, carried out through courses in the *Stanford Artificial Intelligence Laboratory* (SAIL), proposed architectural-scale robotic fabrication using a range of different materials, enabled by artificial intelligence, specifically computer vision machine learning (CVML) for *in situ* responsiveness to variable environmental conditions.

Professor: Oussama Khatib (Stanford Computer Science)



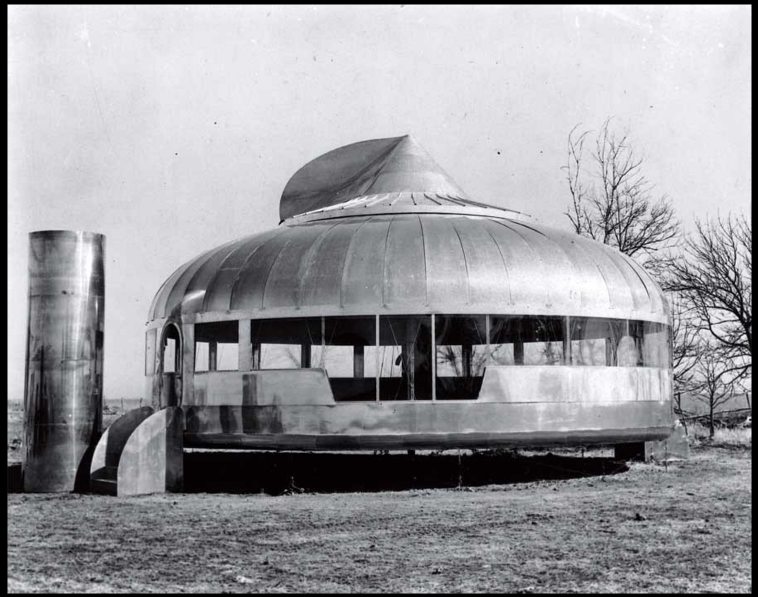
Housing prices and supply, 2007-2021



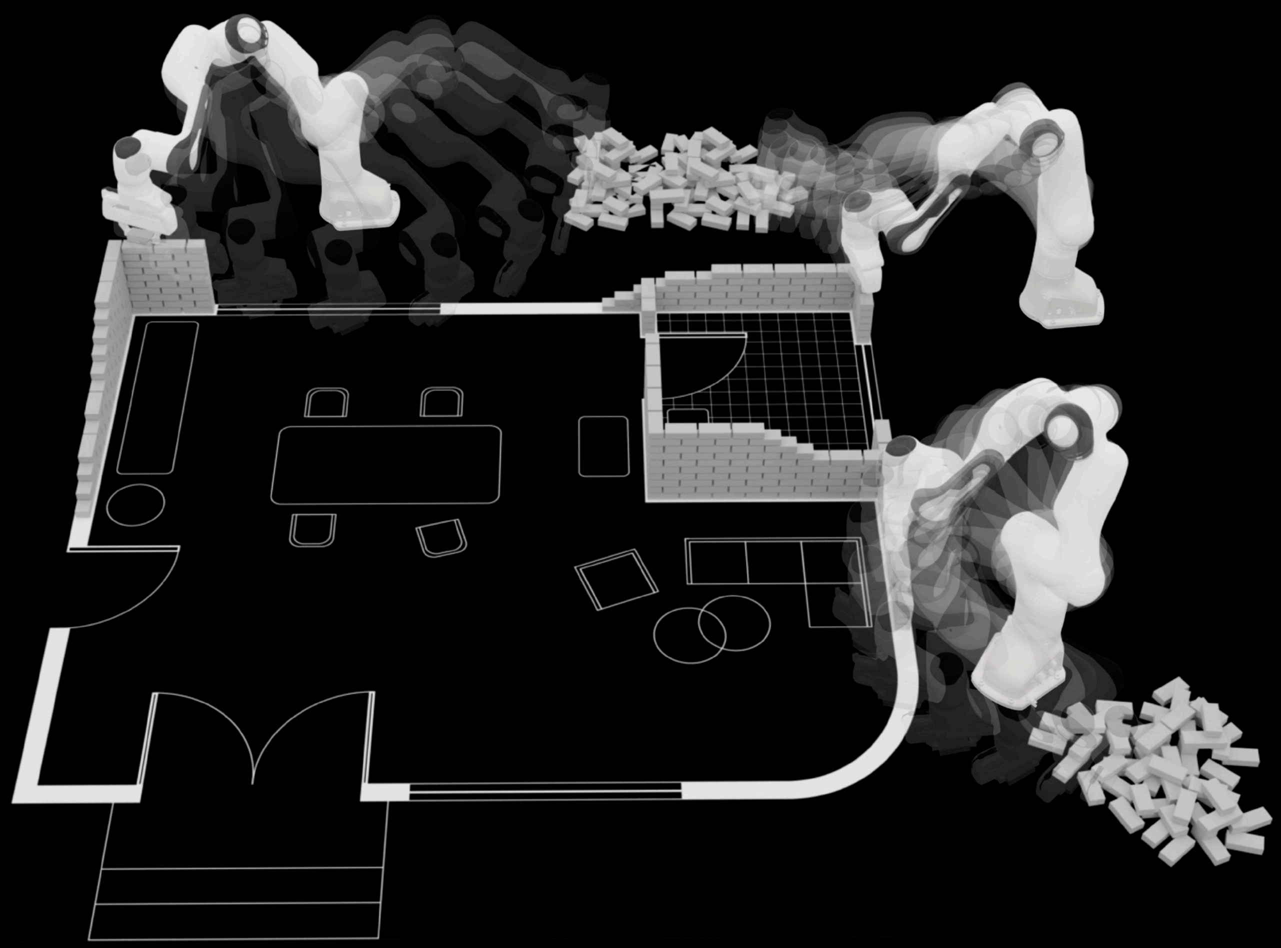
Source: Federal Reserve Economic Data; National Association of Realtors Monthly Supply Data

Wichita House, inspired by Dymaxion prototype.

R. Buckminser Fuller (1944)



Example unit placement kinematic trajectories



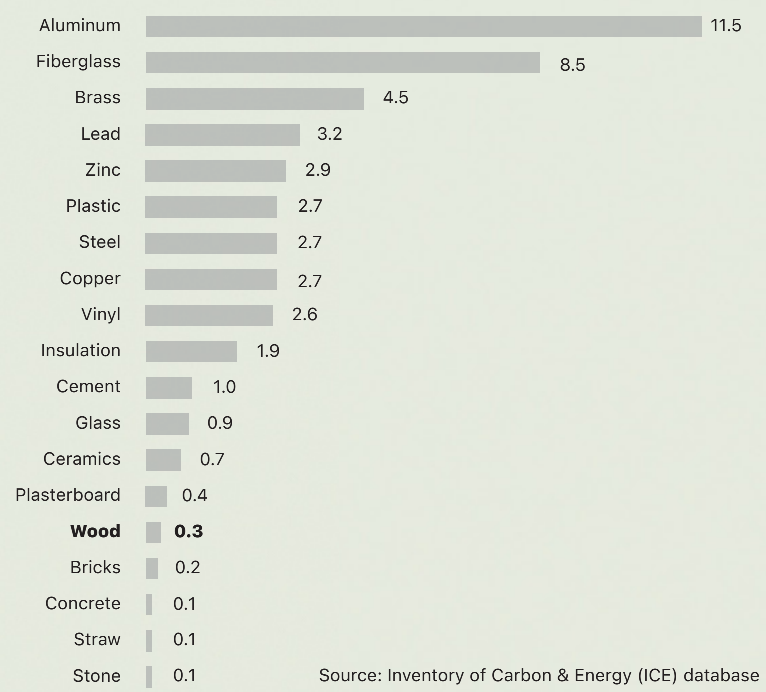
Frustrated by existing concrete 3D printers utilizing gantries larger than the house itself, this project sought to utilize more nimble, adaptive robotic manipulators. Aiming for a similarly rapid architectural (pre)fabrication as Fuller's historical vision, it developed a design tool translating an AutoCAD floor plan directly to 6 DOF Franka Panda manipulator joint torques for material deposition.

State Diagram of subunit deposition using 6 DOF robotic manipulator

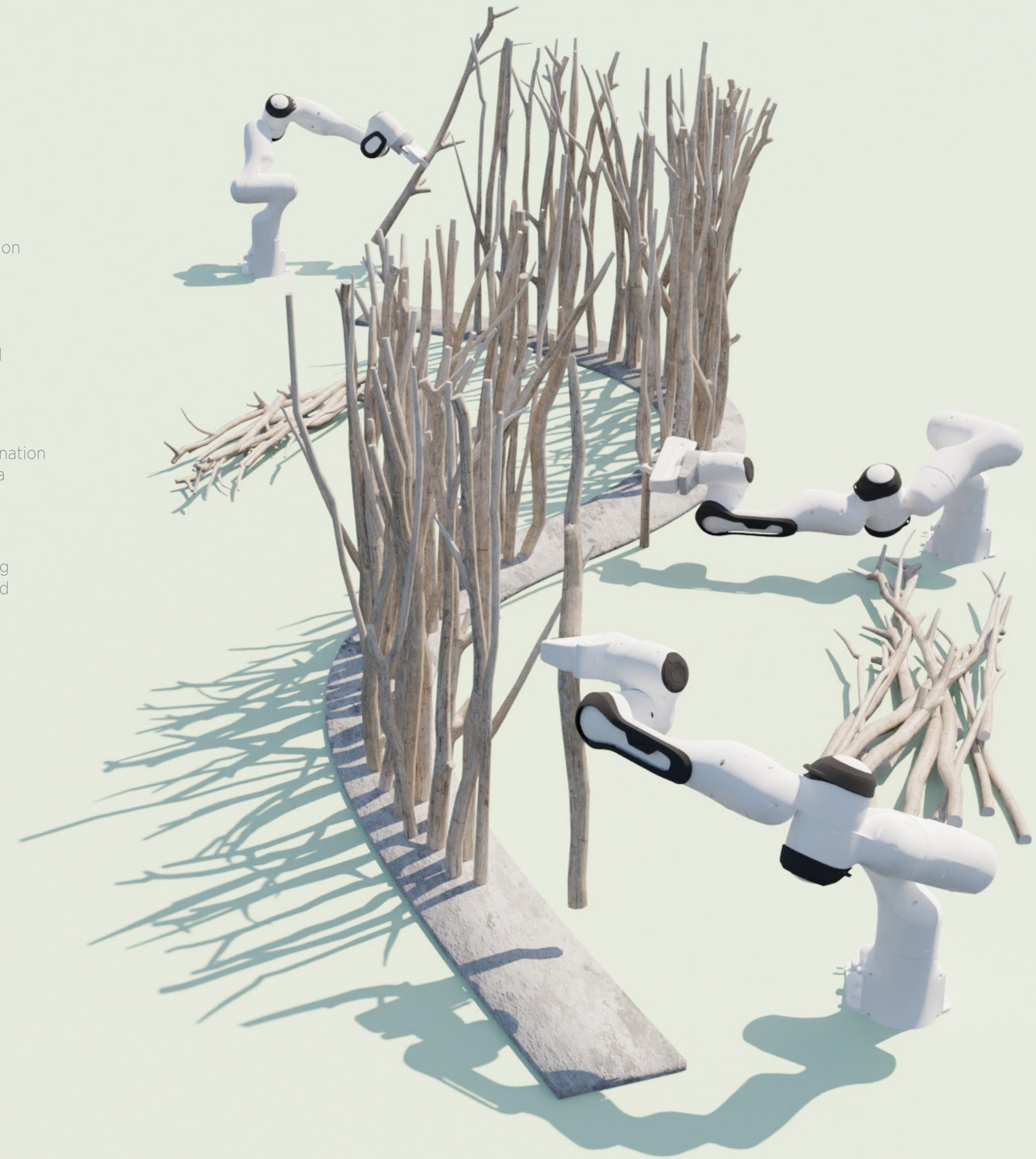
Initialize robot orientation
↓
Input unit position
↓
Inverse robot kinematics
↓
Execute joint torques
↓
Deposit → Check termination criteria
↓
Printing finished

Check termination criteria → Reload → Reposition → Input unit position

Embodied energy comparison of available building materials for subunit deposition by manipulators



Source: Inventory of Carbon & Energy (ICE) database



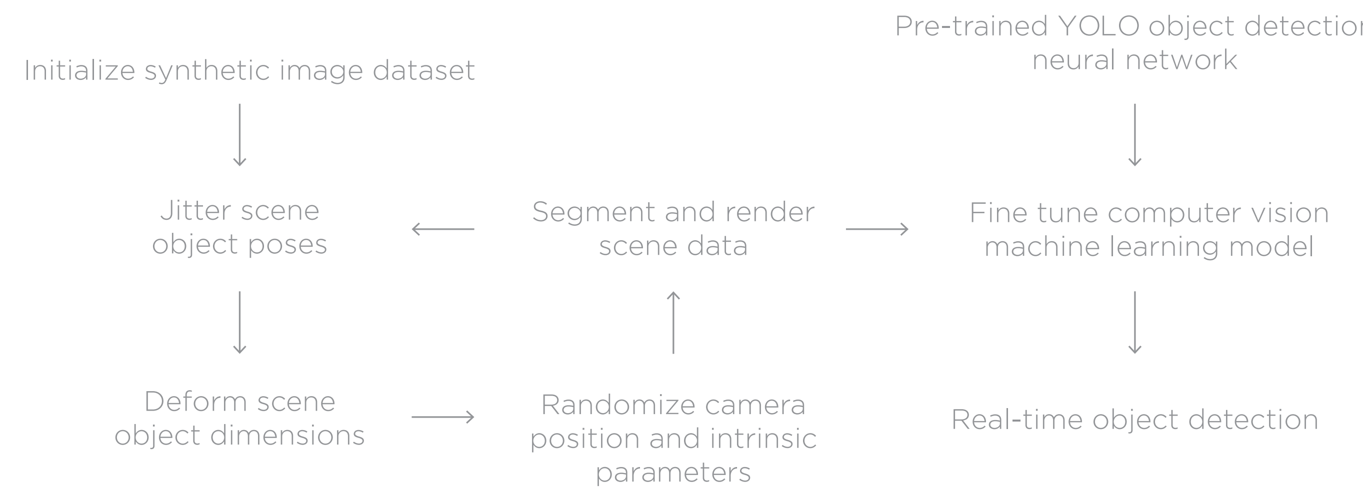
"There is a strong reciprocal relationship whereby our more ambitious design visions encourage the continuing development of the new digital technologies and fabrication techniques, and those new developments in turn inspire us to push the design envelope ever further."

– Zaha Hadid

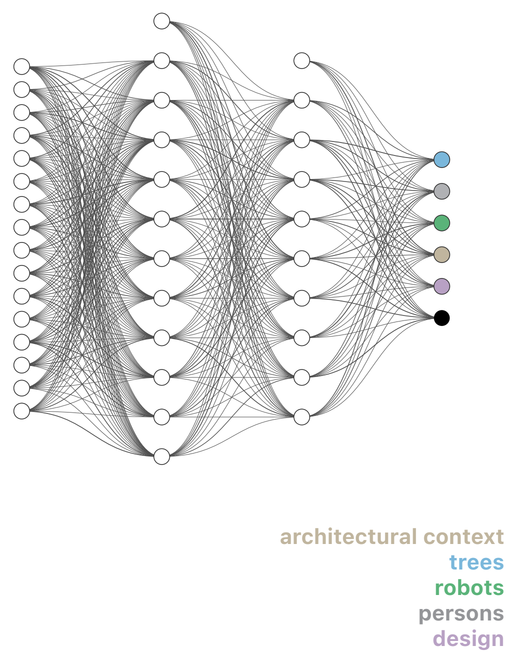
Beyond other robots, *in situ* implementation requires embodied fabrication agents to interact with complex, changing environments comprising existing built structures, natural contexts, and humans.

Such responsiveness to variable environmental conditions requires accurate scene understanding and object detection. For this, embodied fabrication agents can be programmed using computer vision machine learning (CVML) models trained using synthetic image data segmenting the scene into corresponding instances.

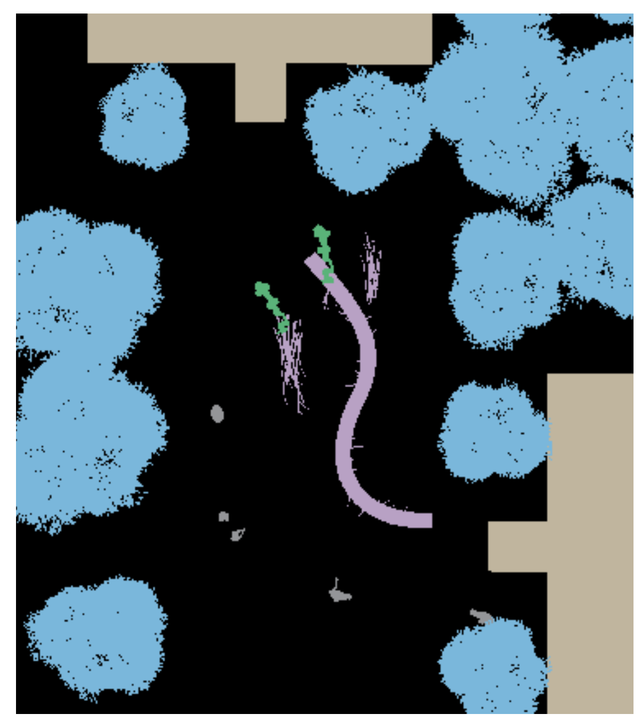
Algorithm for generating scene data for computer vision machine learning model training



Input RGB image

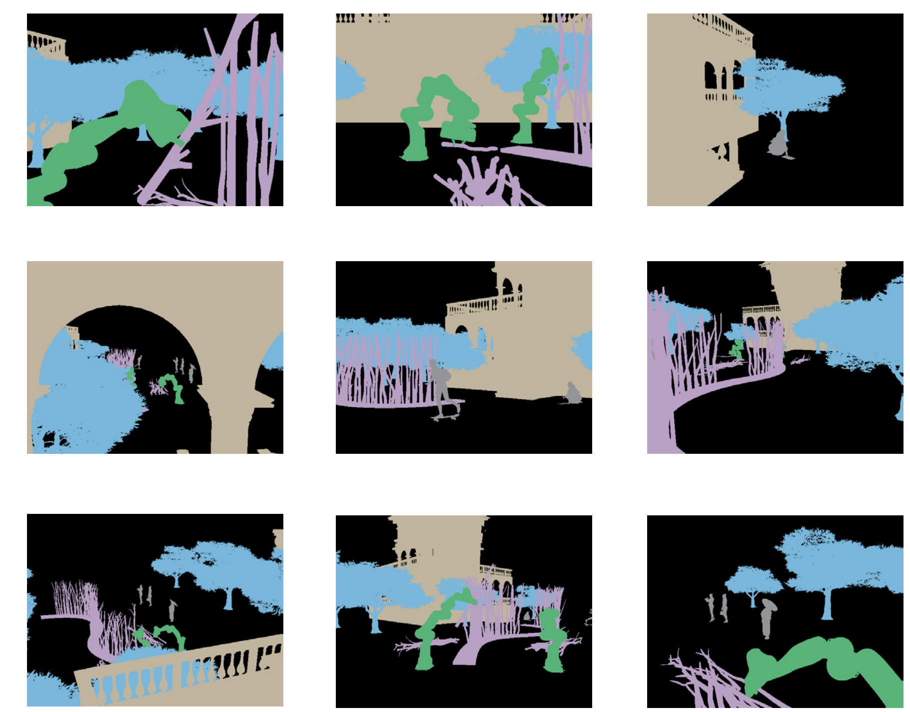


Semantic segmentation neural network



Output segmentation mask

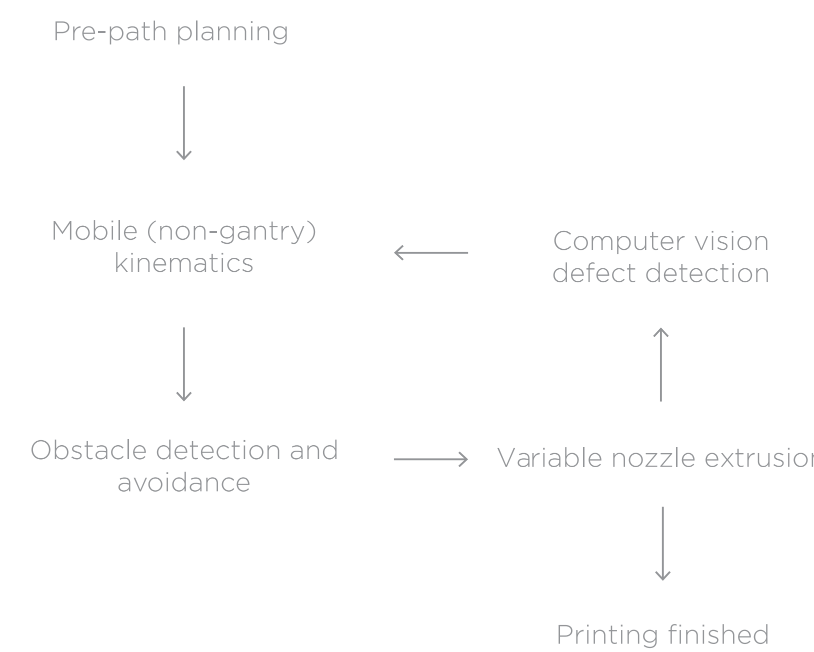
...



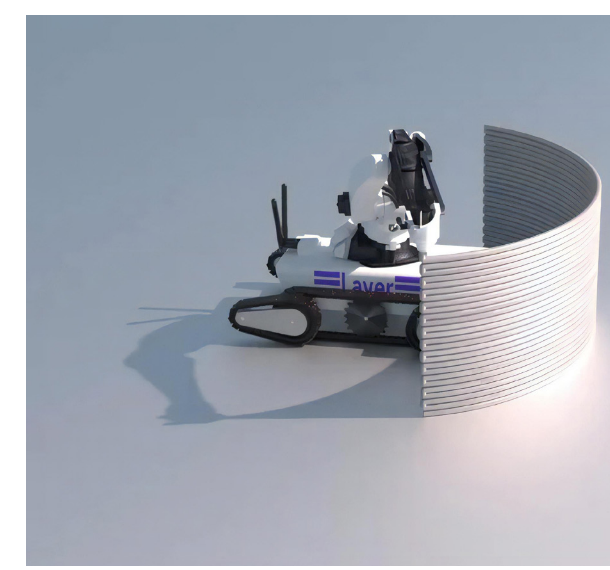
Such embodied fabrication approaches are being commercialized in a currently stealth-mode start-up, *Layer Construction*. Layer seeks to democratize 3D concrete printing with CVML-guided mobile robotic printing, a fundamentally different approach than traditional gantry style printing.

Photograph: Nors Li, co-founder

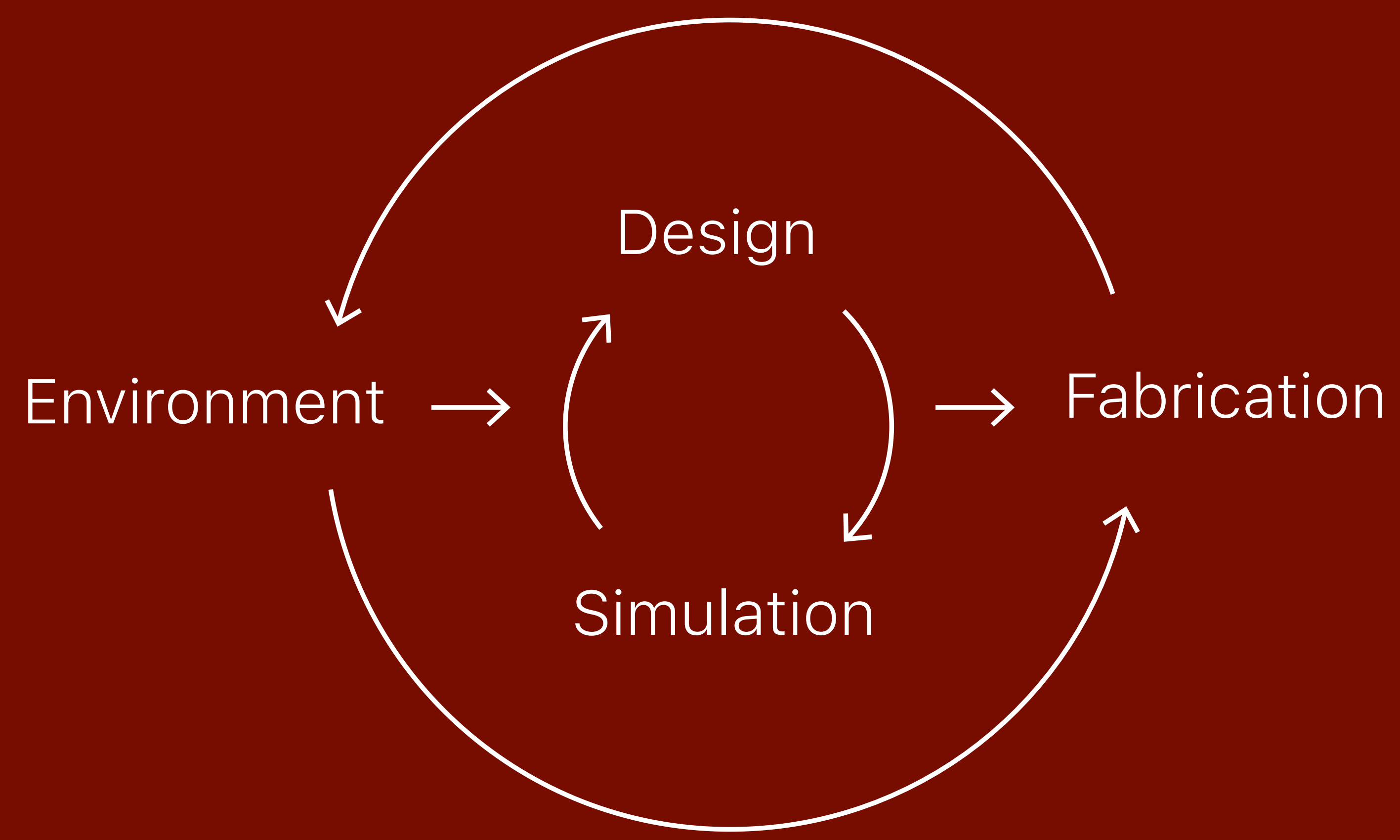
State diagram for robotic concrete 3D printer



Mobile robotic printer prototypes



Design Ecosystem: 02 Embodied Fabrication Agents

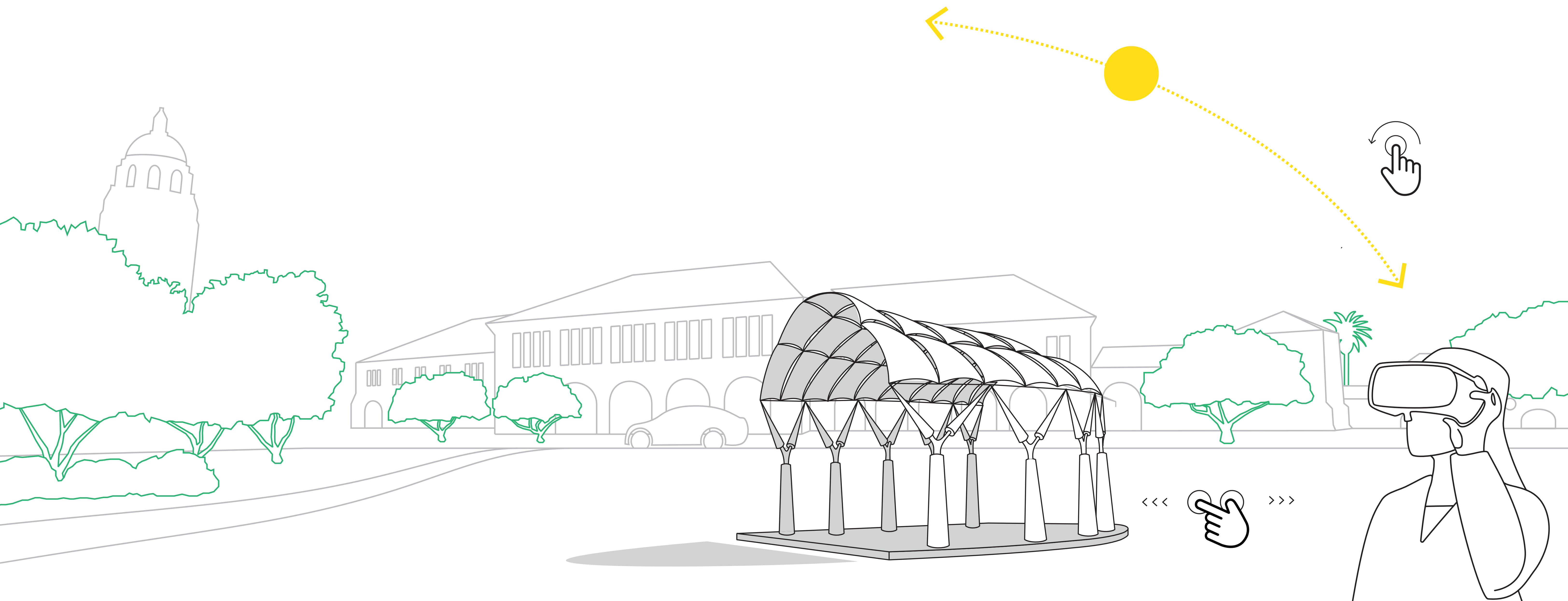


02 EMBODIED FABRICATION AGENTS sought to enable architectural robotic fabrication systems to account for real-time environmental conditions autonomously, developing computational pipelines for generating synthetic scene data for computer vision machine learning models. Two feedback loops hence linked design with process simulation, and environment with *in situ* fabrication.

03 AUGMENTED DESIGN COMPUTING

Motivated by the need to democratize increasingly specialized and specialist design workflows, 03 AUGMENTED DESIGN COMPUTING questioned the barrier between computational design and site context. Seeking to render design and fabrication workflows more intuitive to all users, of all audiences, this project proposed design ecosystems blending digital models, insolation simulation, and a real-world campus environment.

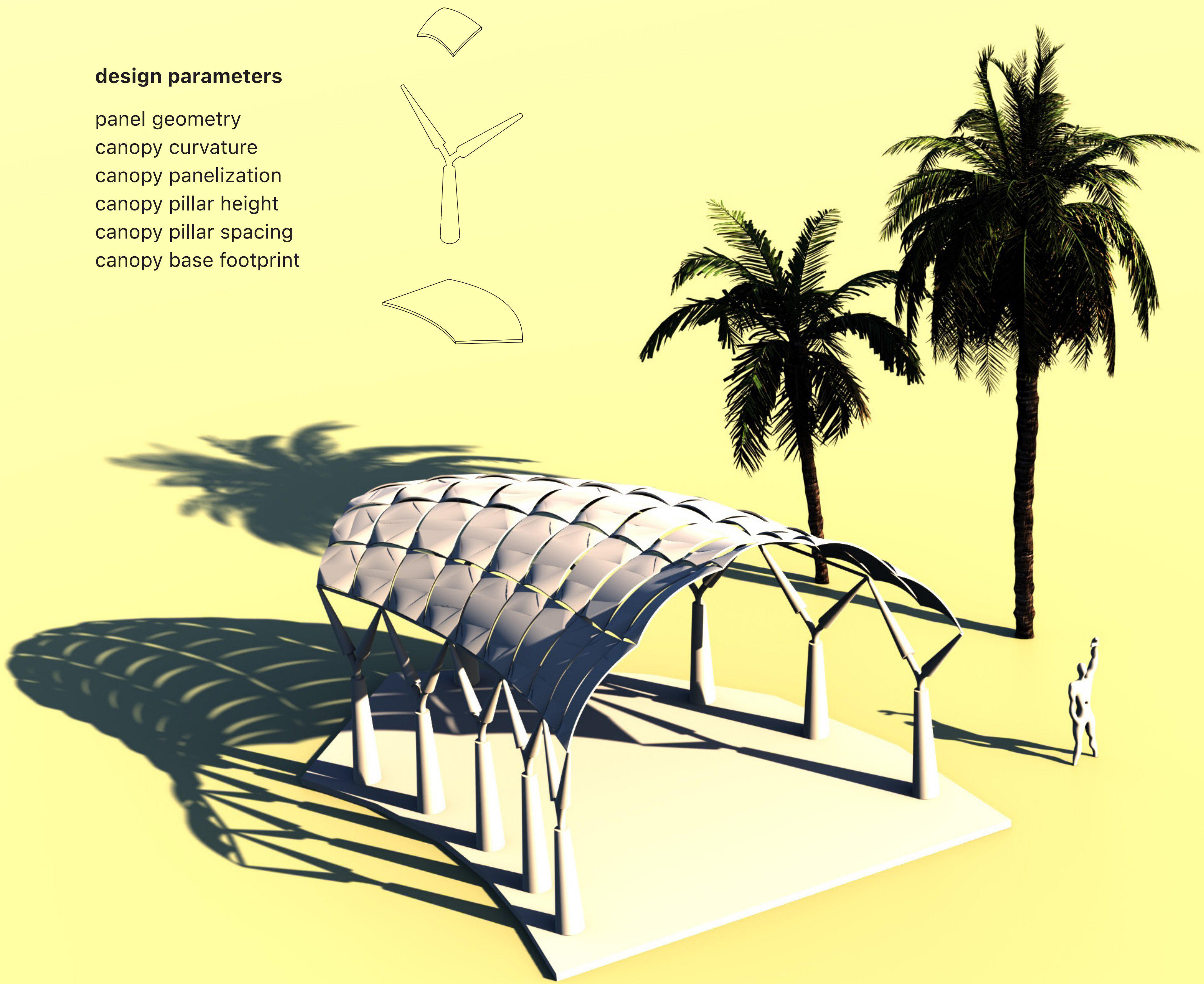
Advisor: Glenn Katz (Stanford Sustainable Architecture and Engineering)

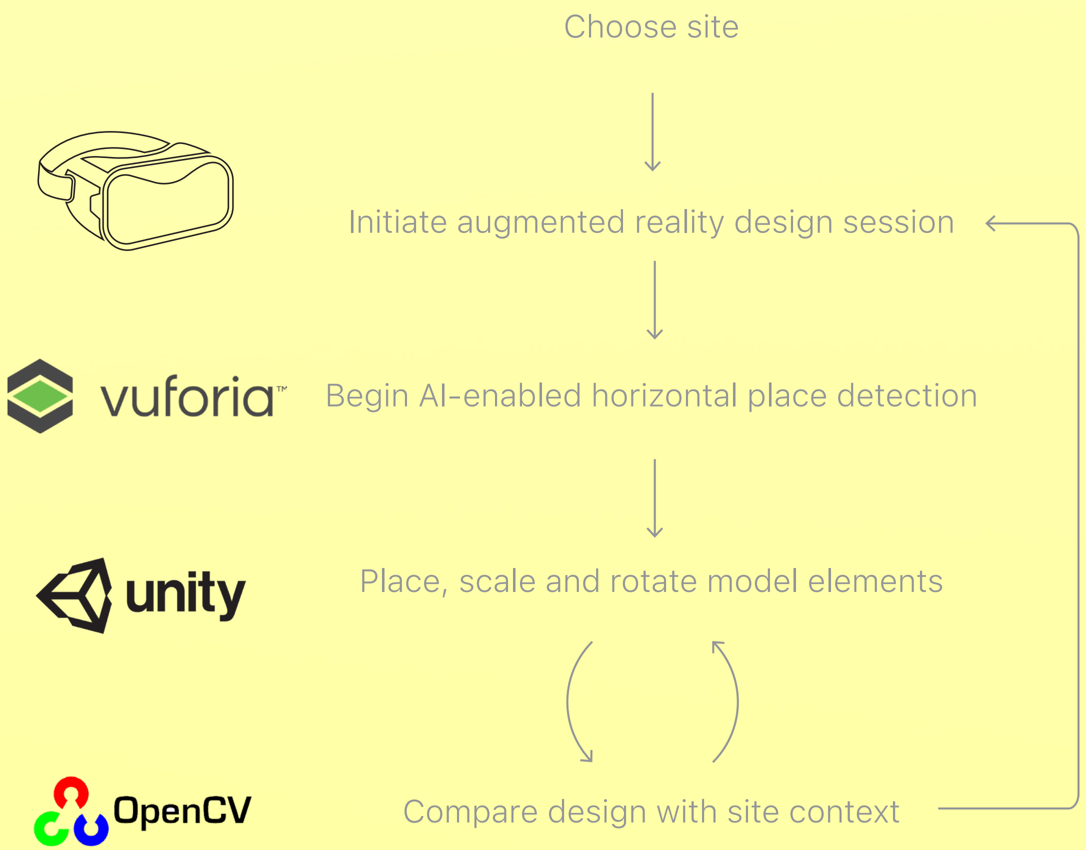


To achieve this aim, the project developed an extended reality (XR) framework for the visualization of a parametrically-designed adaptive panel canopy structure, combining 3D modeling in Rhino and Grasshopper, XR development in Unity, augmented reality (AR) integration via Vuforia, and computer vision analysis via OpenCV. A similar software stack was used for an interactive AR design tool for the 3D printing method in 01: BIOGENERATIVE CO-DESIGN; computational tools hence transferred across length scales.

design parameters

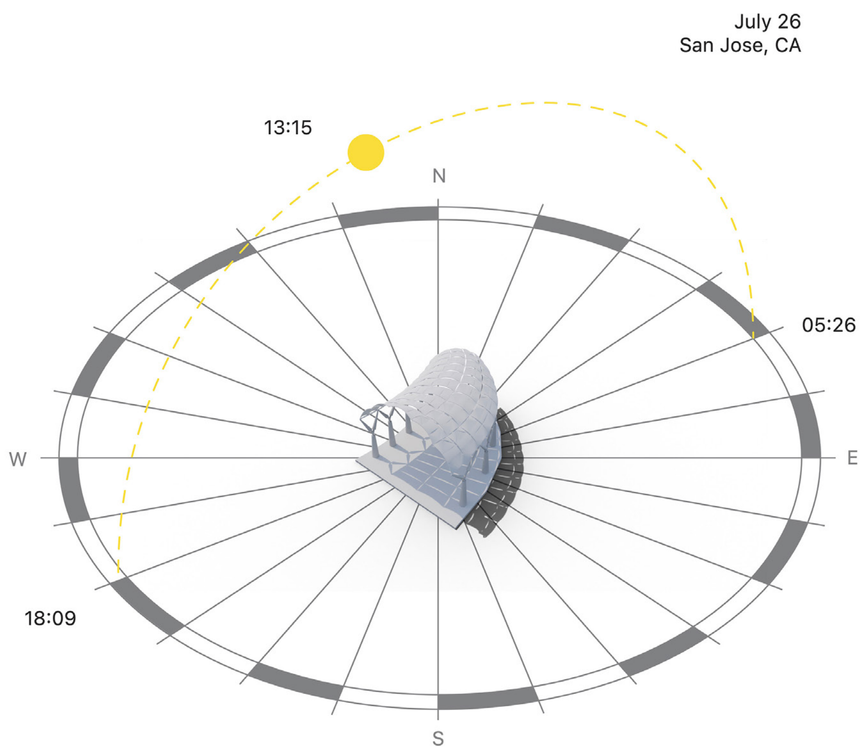
panel geometry
canopy curvature
canopy panelization
canopy pillar height
canopy pillar spacing
canopy base footprint

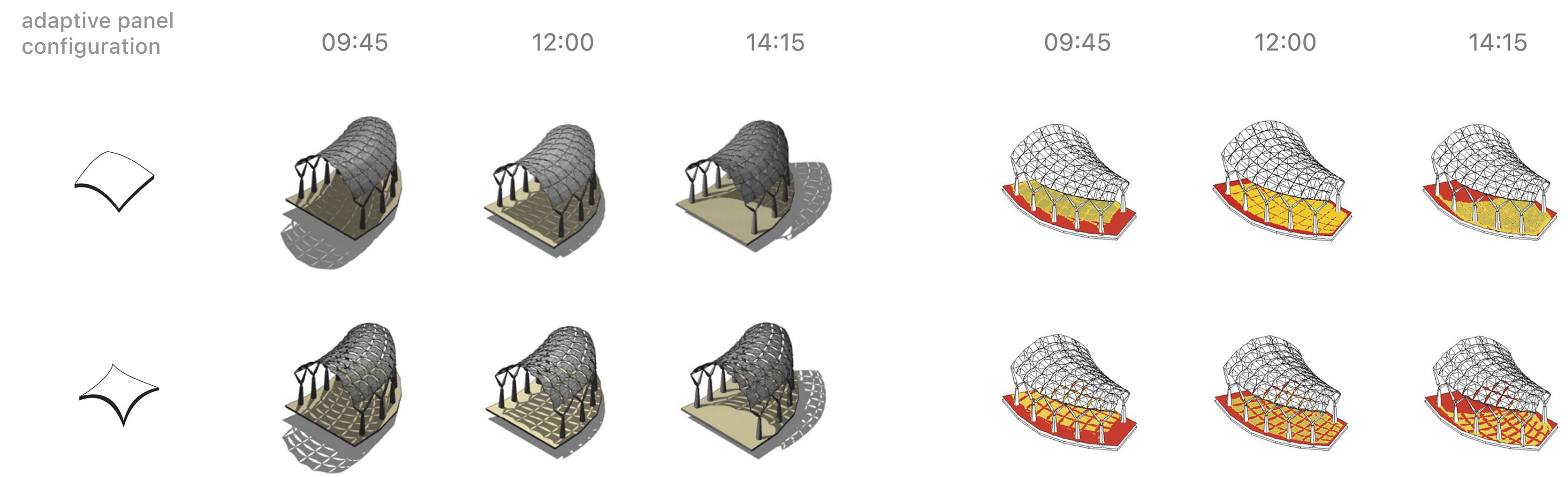




User workflow and enabling software libraries for augmented reality design visualization tool

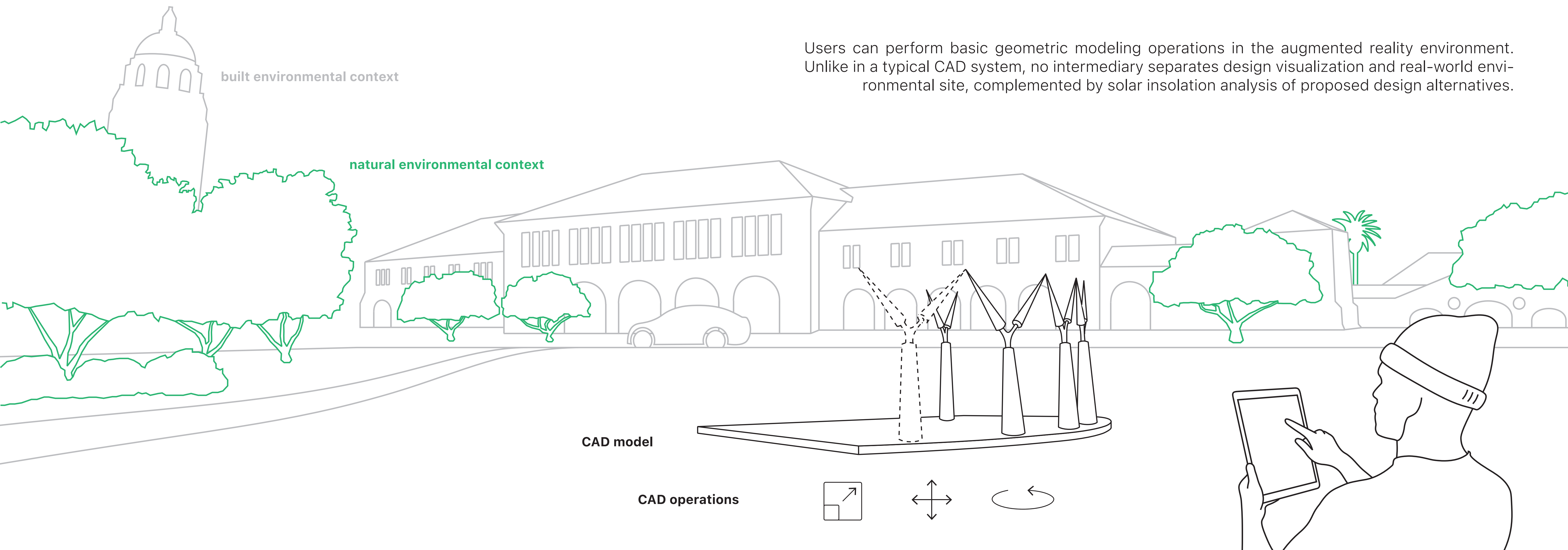
Lipkowitz, G., Shaqfeh, E.S.G., and DeSimone, J.M.D. "Palette-PrintAR: an augmented reality fluidic design tool for multicolor resin 3D printing." Association for Computing Machinery, Symposium on User Interface Software and Technology, 2023.





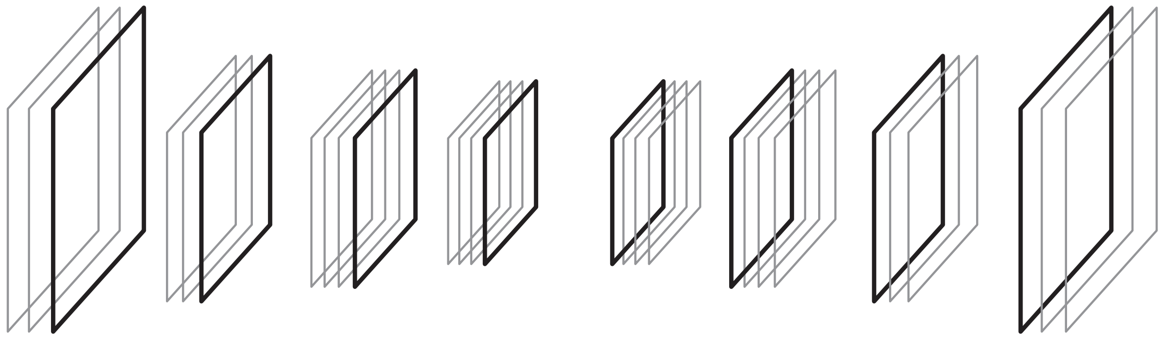
Solar insolation simulation of design orientation in context

Users can perform basic geometric modeling operations in the augmented reality environment. Unlike in a typical CAD system, no intermediary separates design visualization and real-world environmental site, complemented by solar insolation analysis of proposed design alternatives.



To detect features of the environmental context, similar CVML synthetic data generation pipelines were used as for 02: EMBODIED FABRICATION AGENTS. 3D modeling tools from typical 3D design workflows, including photorealistic modeling tools such as Blender, were used to produce pixel-perfect semantic segmentation datasets for training semantic segmentation neural networks.

Input RGB image

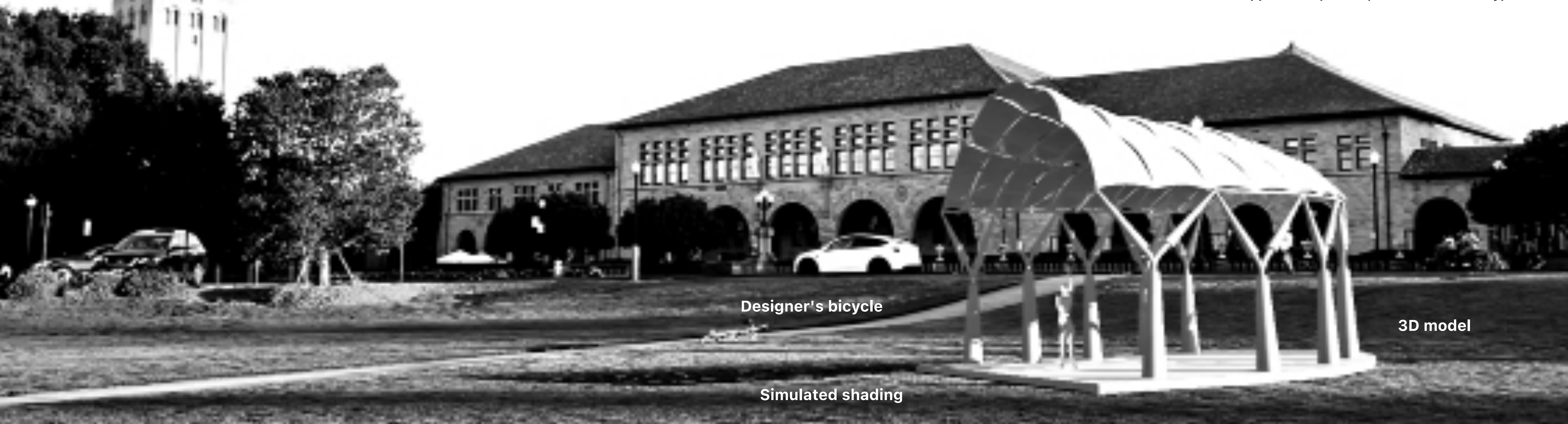


Convolutional encoder-decoder

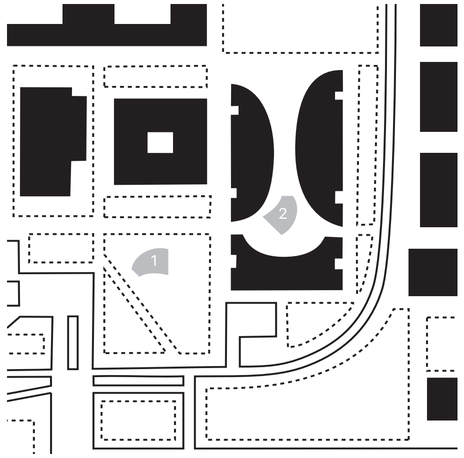
Output segmentation mask

trees + foliage
persons
architectural context
design

Static screenshot of mobile device running dynamic and interactive augmented reality visualization application (at Oval, Stanford University)

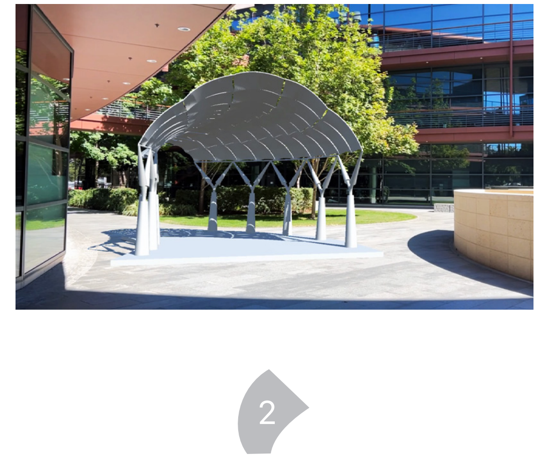


Stanford Medical School

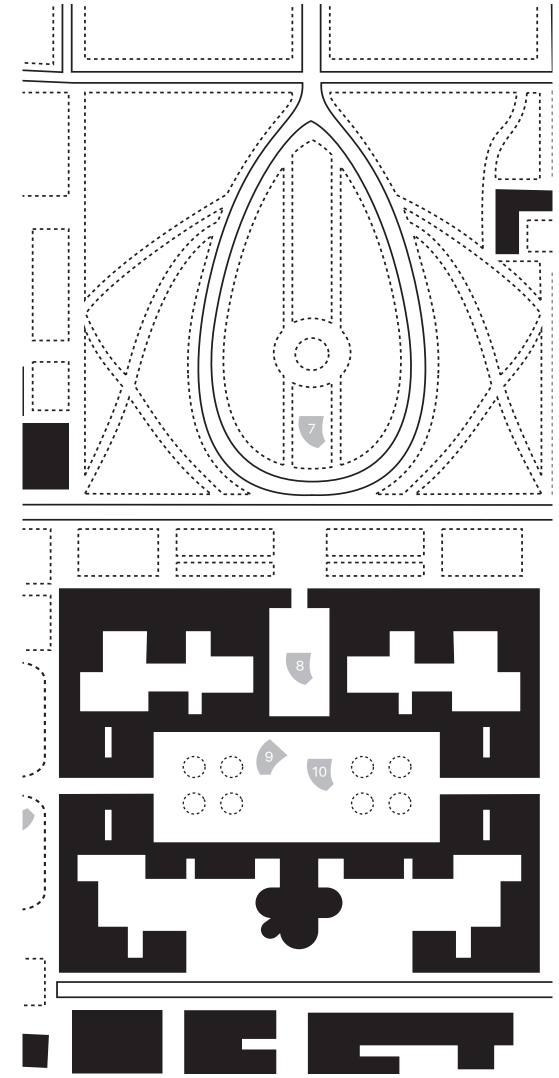


AR site viz 1

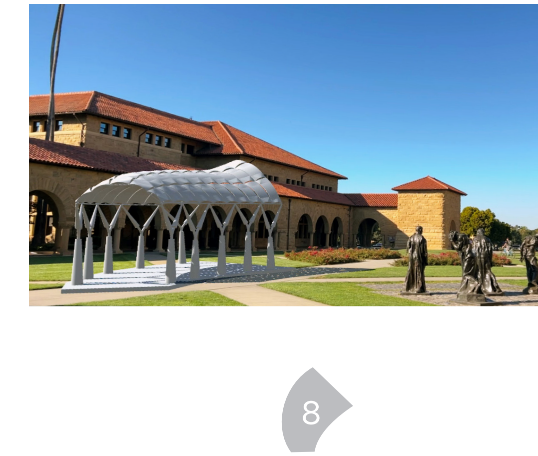
AR site viz 2



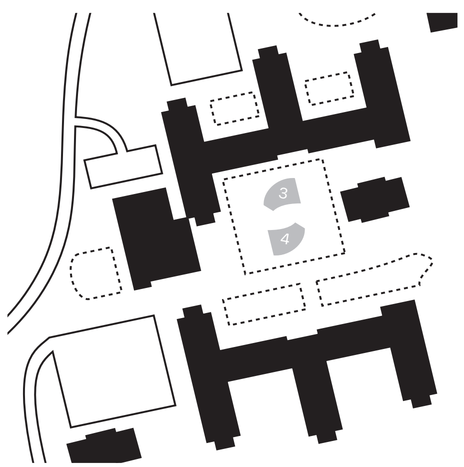
Palm Drive and Memorial Church



AR site viz 8



Escondido Village Graduate Residences

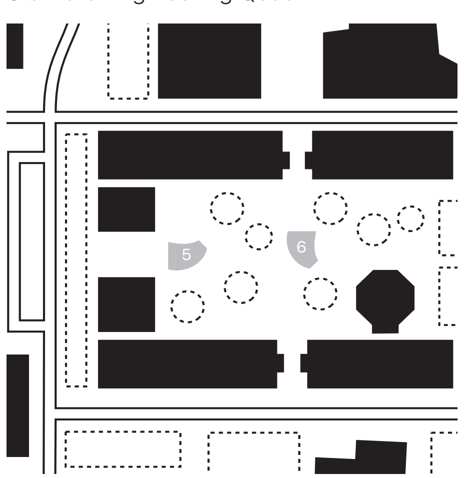


AR site viz 3

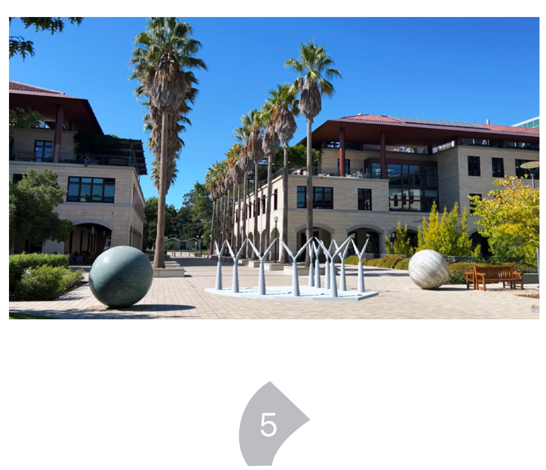
AR site viz 4

AR site viz 9

Stanford Engineering Quad

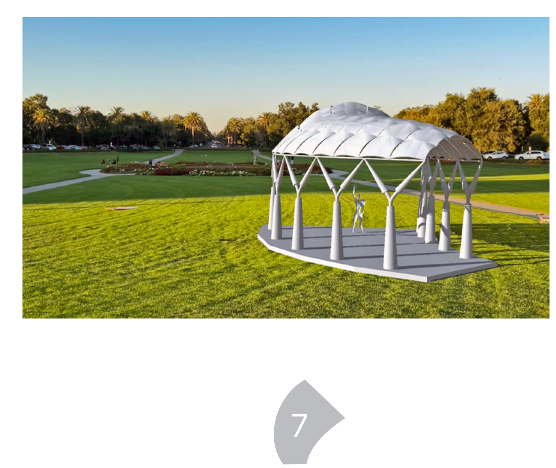


AR site viz 5



AR site viz 6

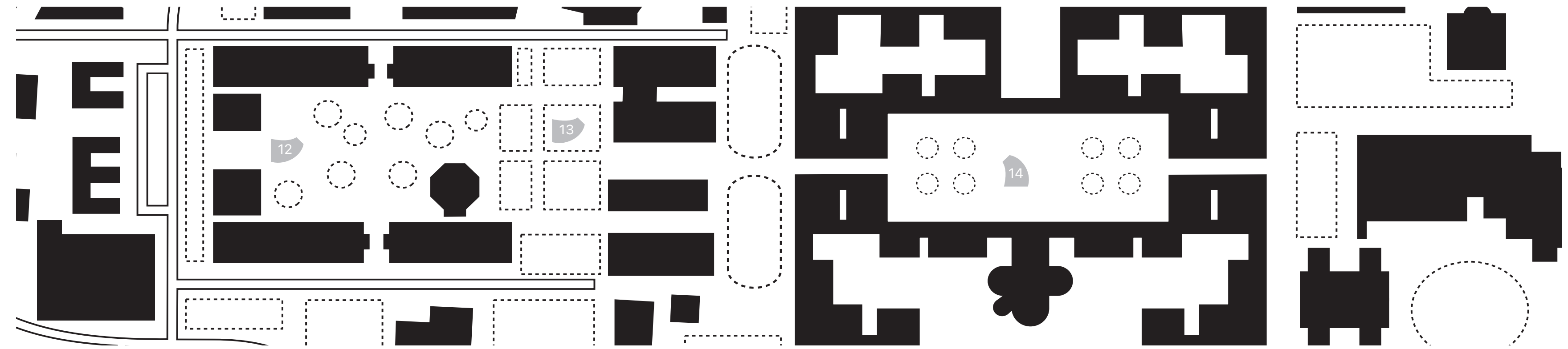
AR site viz 7

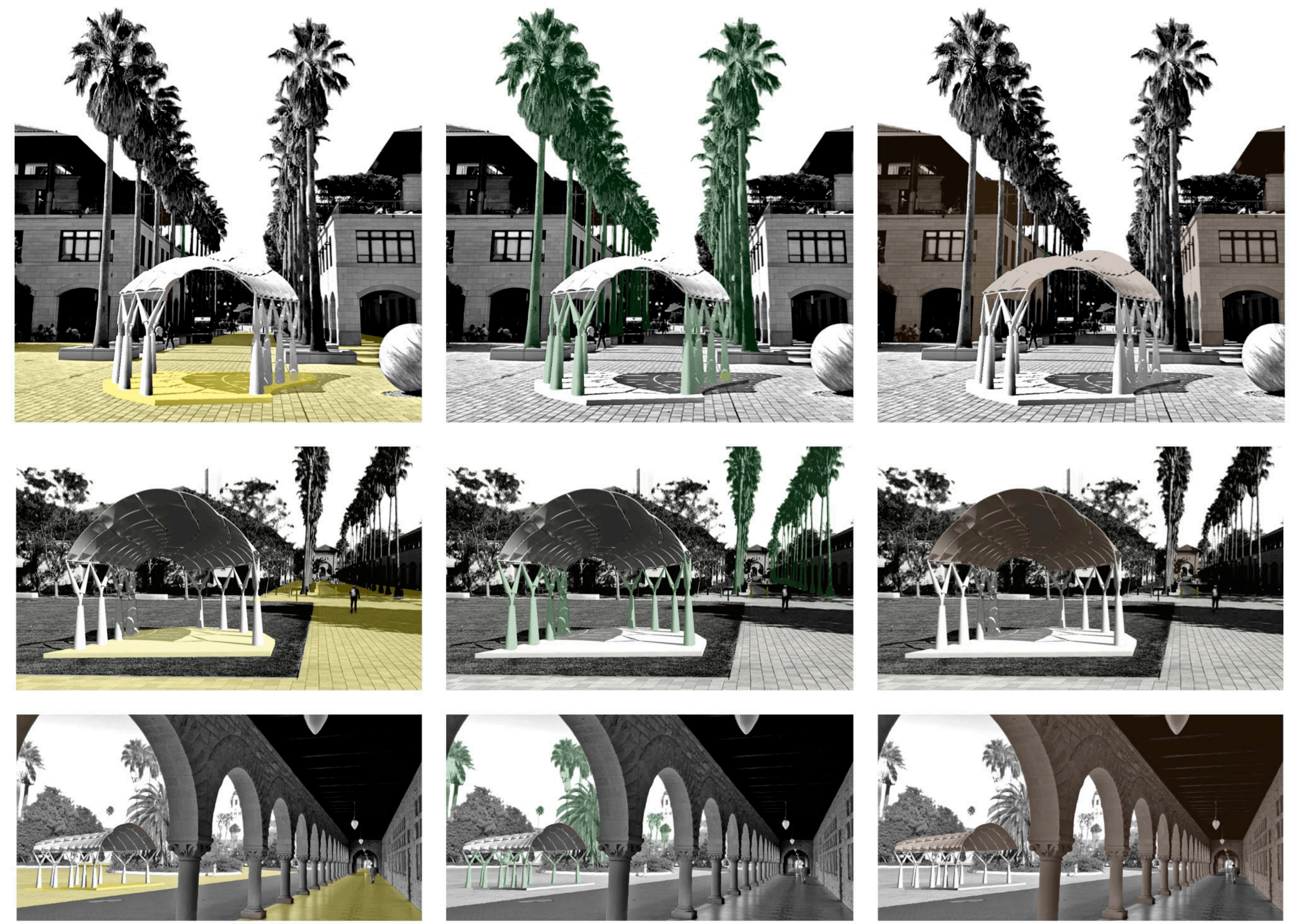


AR site viz 10

With the tool, users could physically walk around their 3D model visualization anchored on-site to evaluate different viewpoints; adjust scale, position, and orientation while remaining in context; and explore different campus locations, at different times of day.

Motivated by the importance of crafting formal relationships between structure and site, designers could also visualize connections between digital models and real-world existing architectural context and natural features.





Stanford Engineering Quad 12

Stanford North-South Axis 13

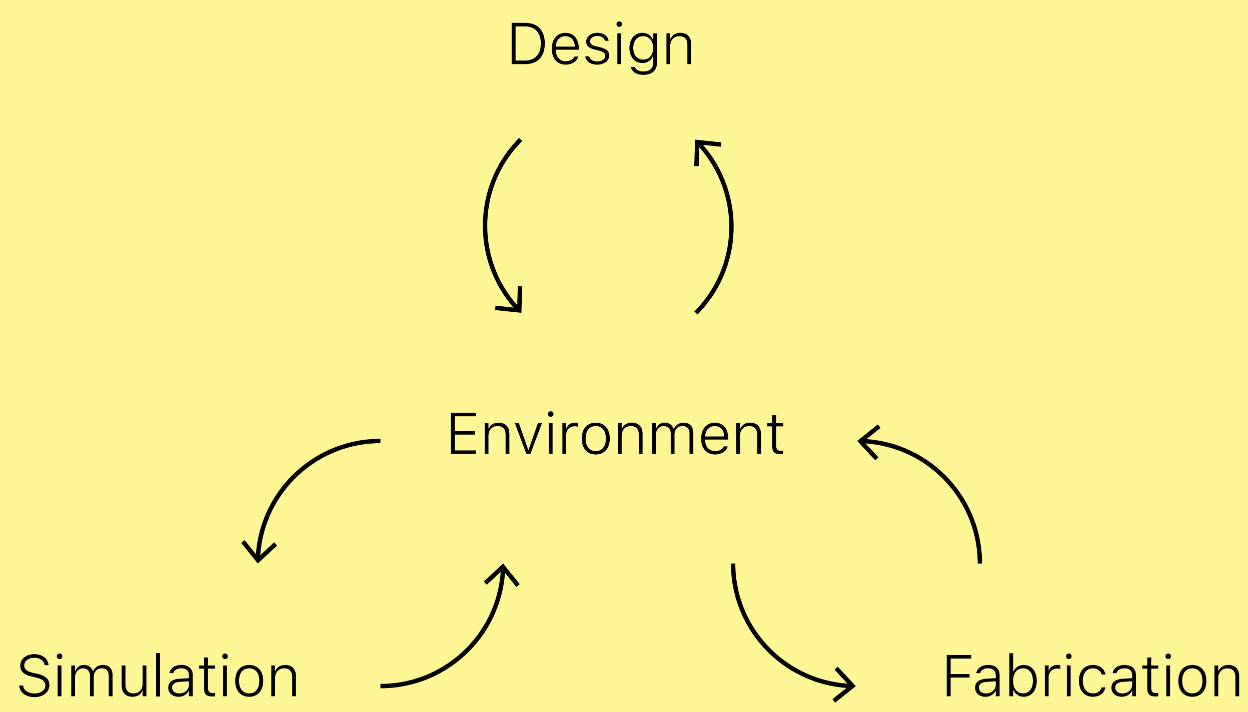
Stanford Main Quad 14

Horizontal planes

Vertical elements

Arched structures

Design Ecosystem: 03 Augmented design computing



03 AUGMENTED DESIGN COMPUTING explored extended reality (XR) technologies to assist designers in visualizing models and associated environmental simulations on-site. As XR technologies continue to advance, further integration with computational design workflows promises design ecosystems defined by feedback loops fully integrating simulation, design, and fabrication with environmental context.