Forensics in Process: A Heuristic Approach Combining Topology Optimization and Computational Fluid Dynamics

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Forensics generally involves the application of scientific methods to investigate crimes or other legal matters. However, the term forensics is metaphorically coopted here to provoke new lines of inquiry regarding the process of design, specifically in the context of emerging double-curved shell architectures. Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) can be conceived of as new interactive lenses that assist in revealing hidden potentials in the forces and flows at work within structures and spaces. These tools aid in identifying and developing potential architectural microclimates and climatic efficiencies that coincide with double-curved shell structural-spatial syntaxes and their expanding ontologies. Working with CFD and FEA infuses the design process with iterative cognitive feedback capabilities for designers, expanding actionable knowledge and intuition during the design process. Computational simulation makes legible invisible stresses and strains in structures/materials—in the case of FEA—and patterns of airflow and ventilation, humidity, and temperature dynamics in spaces and through construction assemblies—in the case of CFD.

While considered innovative in terms of marrying expressive sculptural form with effective structural form, shell structures have traditionally been canonized as “structural art” However, the doubly curved geometries intrinsic in shell structures hold yet to be fully developed promises for multiple simultaneous, passive building systems optimizations, including simultaneous monocoque integrations of natural light direction and delivery, precipitation control, and acoustic conditioning (Knippers and Cremers 2019). The intersection of computational simulation modalities is particularly promising. FEA-enabled topology optimization can identify “lazy material”—a concept introduced by Pier Luigi Nervi, referring to unnecessary material that can be subtracted from shell-structured envelopes and components—creating porosity for the transference of forces and flows, including light, air, temperature, humidity, sentient beings, and vehicles.

Forensics in Process postulates that the pursuit of optimization during the design process need not be overtly deterministic. Rather, a heuristic approach to designing with computational simulation can effectively leverage the “forensic” capacities to produce architectures that satisfy corporeal needs while uplifting the human spirit (Benvenuto 2012). This approach is intrinsic to the non-linear, free associative, inductive, and recursive nature of design processes. Forensics in Process proposes a new relationship between the qualitative and phenomenological pursuits of design—desire, belief, delight in color and form—and objective knowledge, critical assessment, identifying failure, identifying yet-to-be-known potential, and analytic quantification.

Although CFD and FEA are advanced technologies relative to traditional manual techniques (pencil and ink on paper), they are still in their infancy, with much of their potential yet to be realized (Shou and Sun 2022). Normalizing computational simulation in practice and academia could address deficiencies in conventional architectural practice, where structural, material, and environmental performance are often ignored or notionally conceived by designers who outsource difficult problems to consulting engineers. This hardens disciplinary boundaries, limits the built environment’s full potential, and often results in engineering as an afterthought rather than comprehensive integration (Anderson, Tannehill, and Pletcher 2016). The conceptual framing of Forensics in Process seeks to bridge the rifts between architects and engineers, unlocking the built environment’s full potential. By subverting conventional architectural practices and assumptions, which often see structural, material, and environmental performance as secondary concerns outsourced to consulting engineers, this approach emphasizes that the polarity between formal, sculpturally expressive architecture and high-performance architecture is a false dilemma.

Keywords: Material Design Thinking, Topology Optimization, Computational Fluid Dynamics

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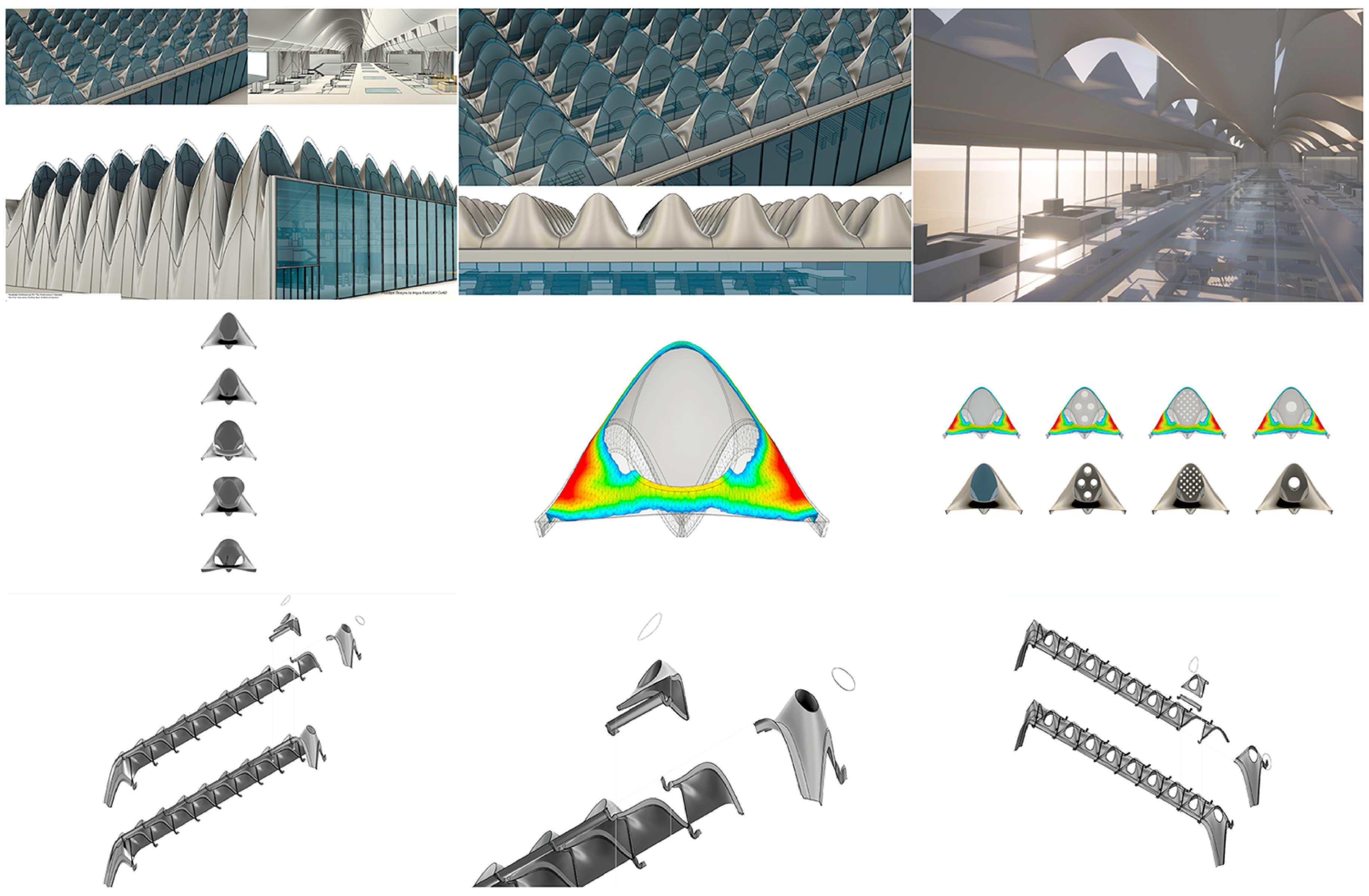

Figure 1. Skylight/Heat Chimney Design : Topology Optimization Yielding Vent Location Scenarios

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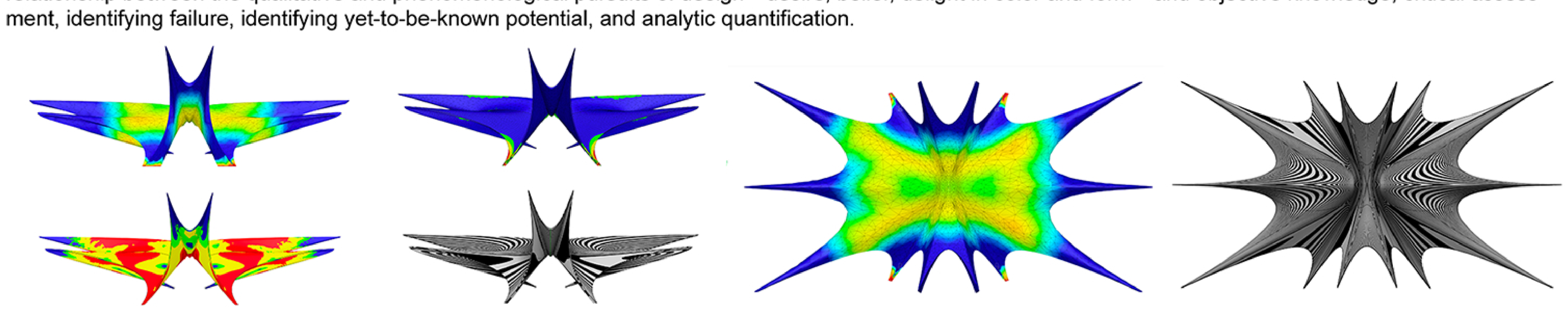
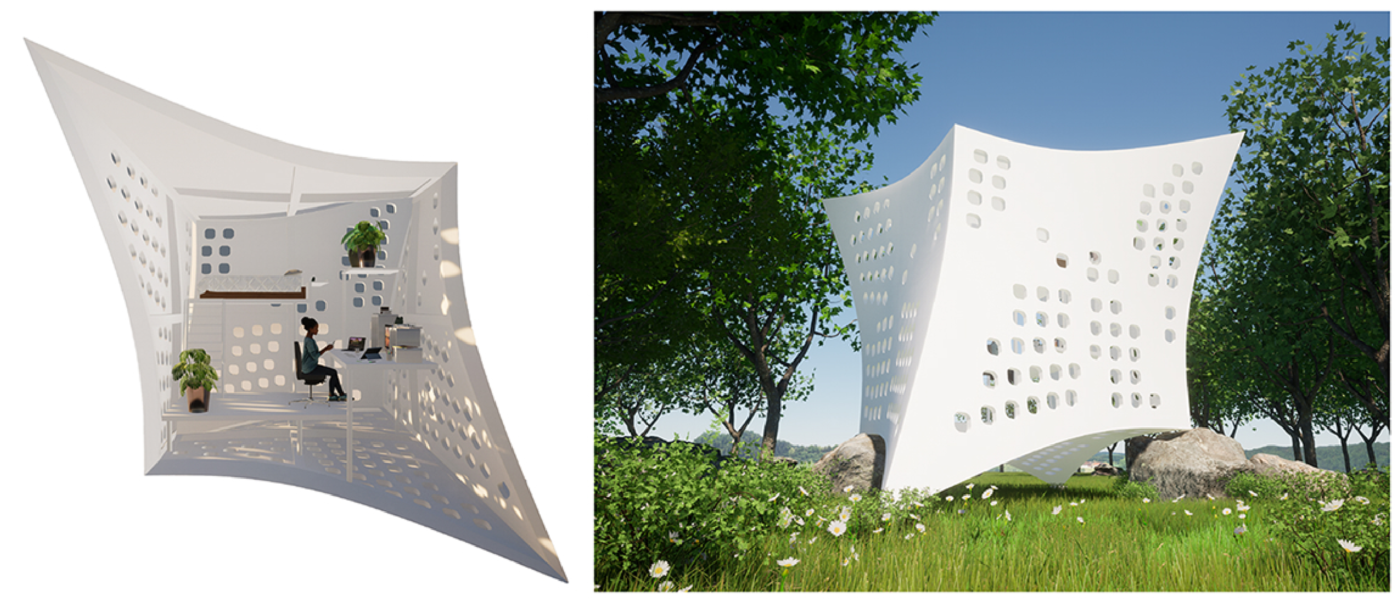


Figure 2. Test Subject Structural Stress Scans Across Material Variants and Curvature Analysis



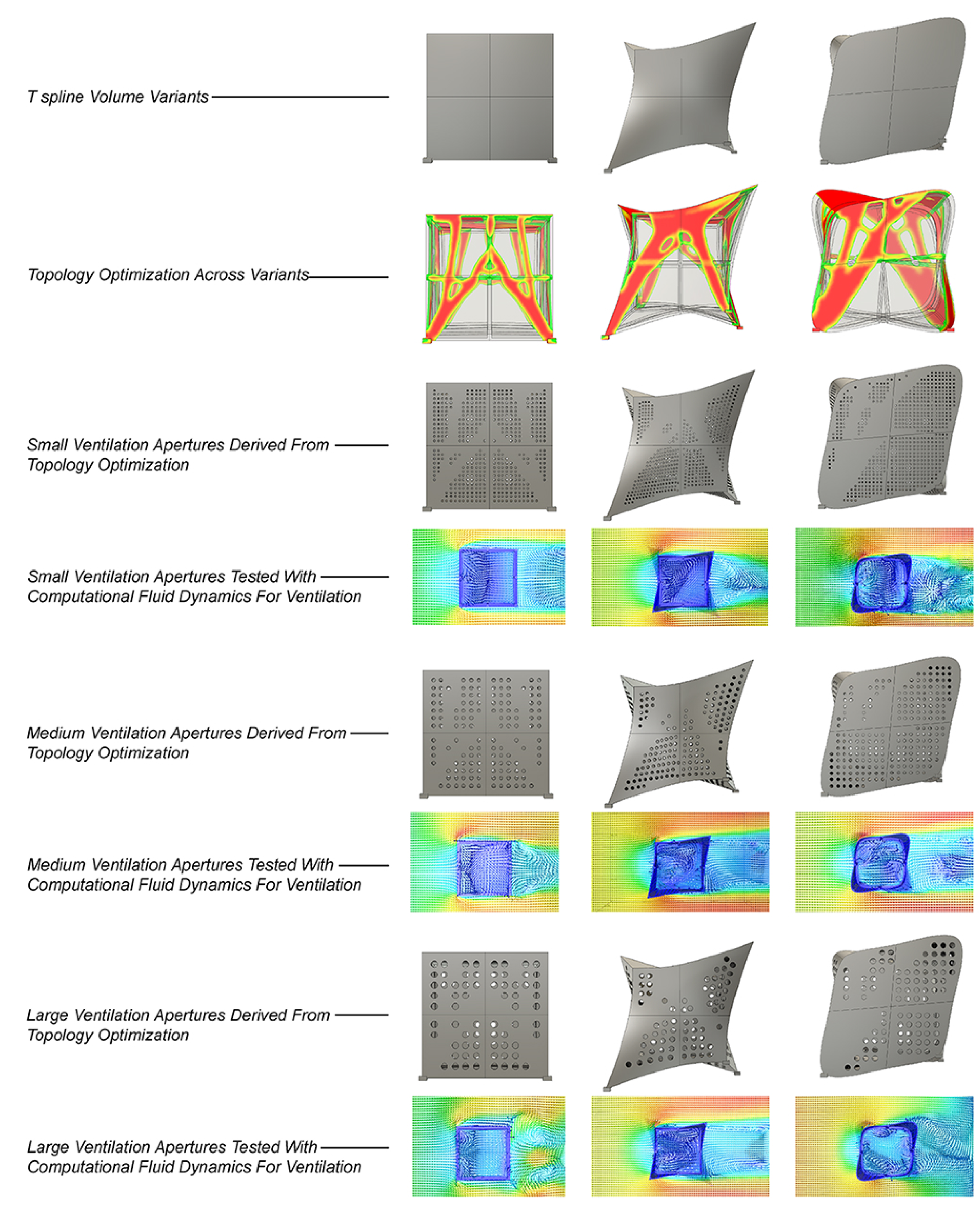


Figure 3. Study Combining to determine Ventilation Schematics Combining Topology Optimization and Computational Fluid Dynamics

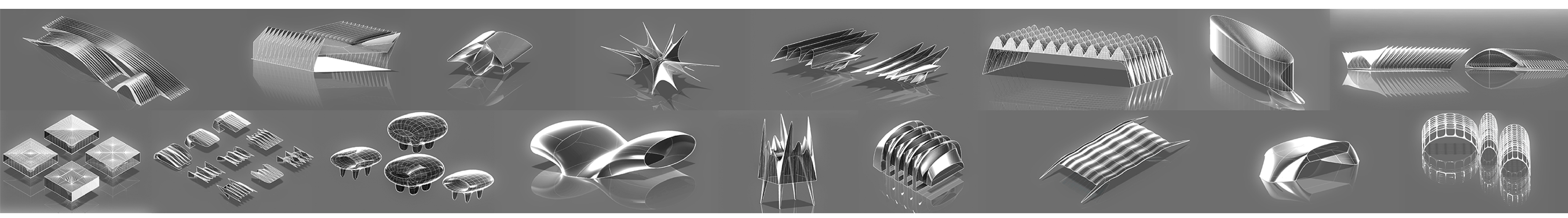


Figure 4. Taxonomy of Topological Permutations with Cursory Discretization

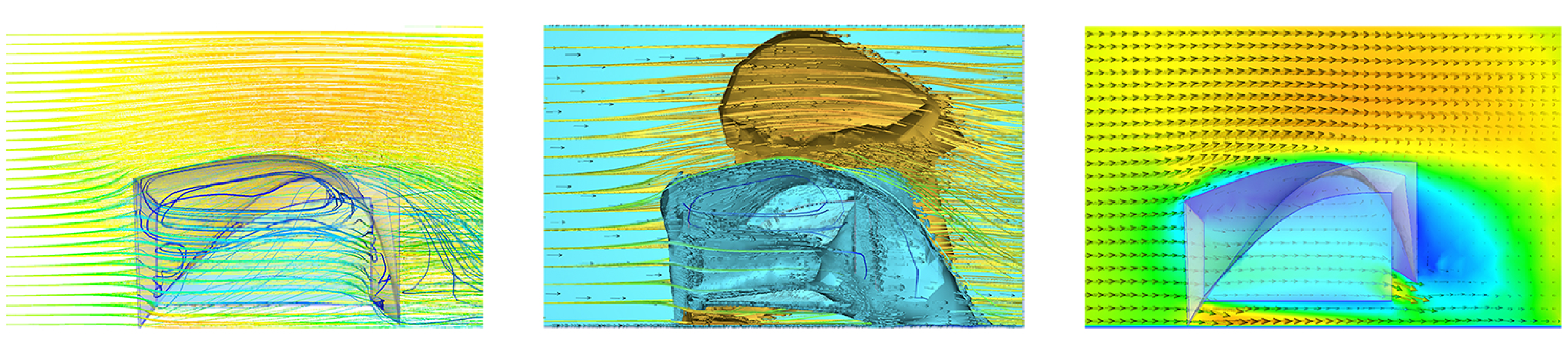


Figure 5. Computational Fluid Dynamic Analysis of Archetypal Hyperboloid Volumes

Left: Particle Tracing,
Middle: Turbulence Zones,
Right: Air Flow Velocity, Location, Direction

Although CFD and FEA are advanced technologies relative to traditional manual techniques (pencil and ink on paper), they are still in their infancy, with much of their potential yet to be realized. Normalizing computational simulation in practice and academia could address deficiencies in conventional architectural practice, where structural, material, and environmental performance are often ignored or notionally conceived by designers who outsource difficult problems to consulting engineers. This hardens disciplinary boundaries, limits the built environment's full potential, and often results in engineering as an afterthought rather than comprehensive integration. The conceptual framing of Forensics in Process seeks to bridge the rifts between architects and engineers, unlocking the built environment's full potential. By subverting conventional architectural practices and assumptions, which often see structural, material, and environmental performance as secondary concerns outsourced to consulting engineers, this approach emphasizes that the polarity between formal, sculpturally expressive architecture and high-performance architecture is a false dilemma.

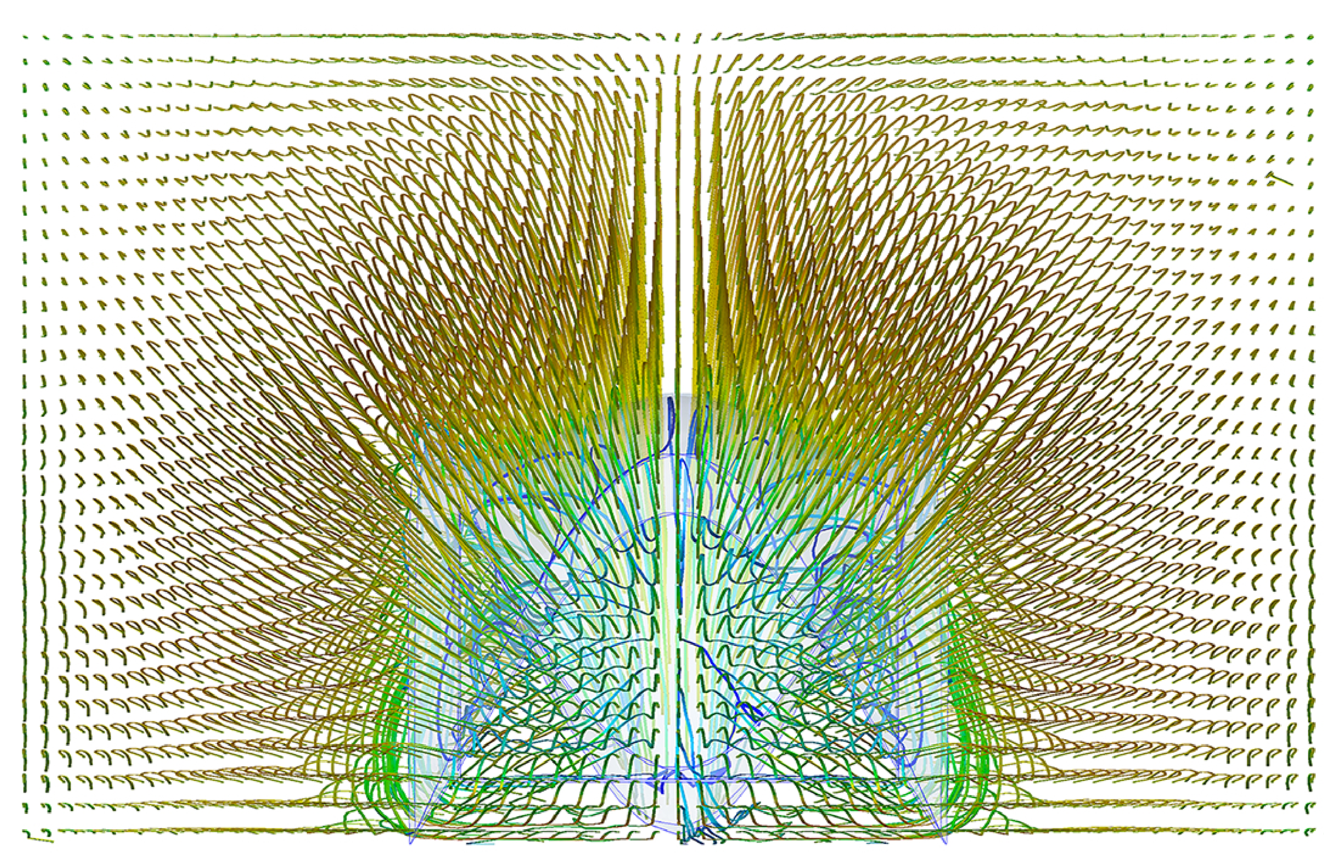


Figure 6. Computational Fluid Dynamic Analysis of Archetypal Hyperboloid Volumes - Particle Tracing

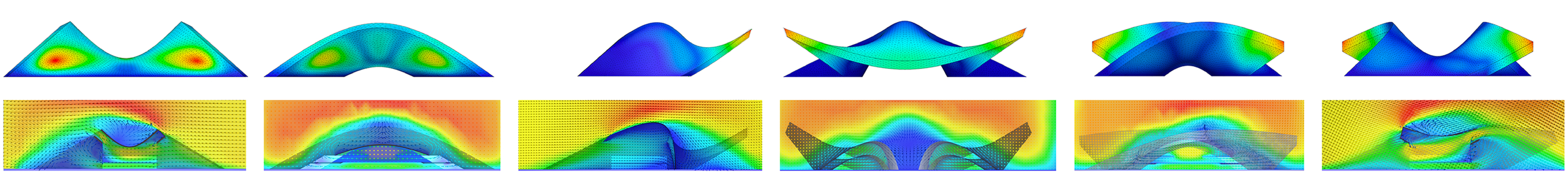


Figure 7. Computational Fluid Dynamics + Finite Element Analysis Comparative Analysis of Archetypal Hyperboloid Volumes Modified to Double Shell Thermal Plenum + Occupied Long-span.

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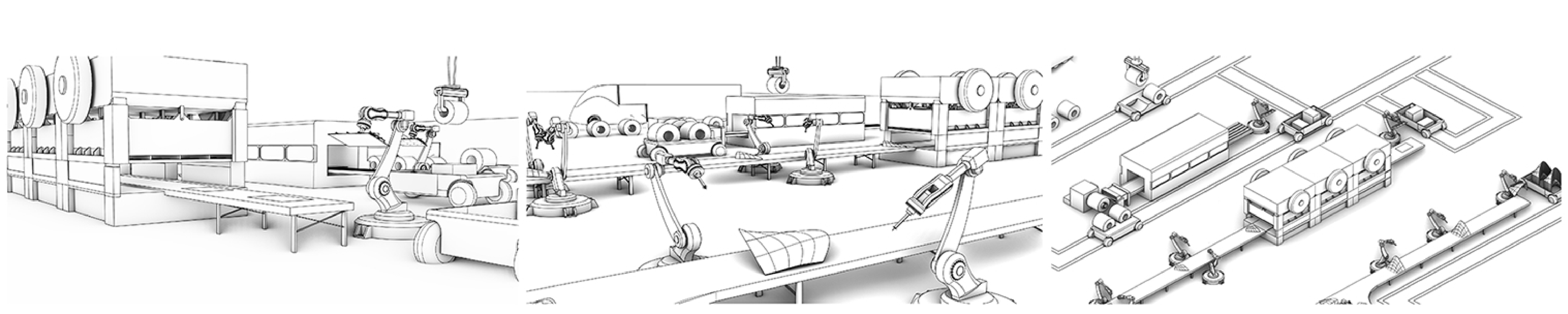

Figure 8. Emerging Manufacturing For Modular Rib Shell Modules: Robotic Stamp Pressing

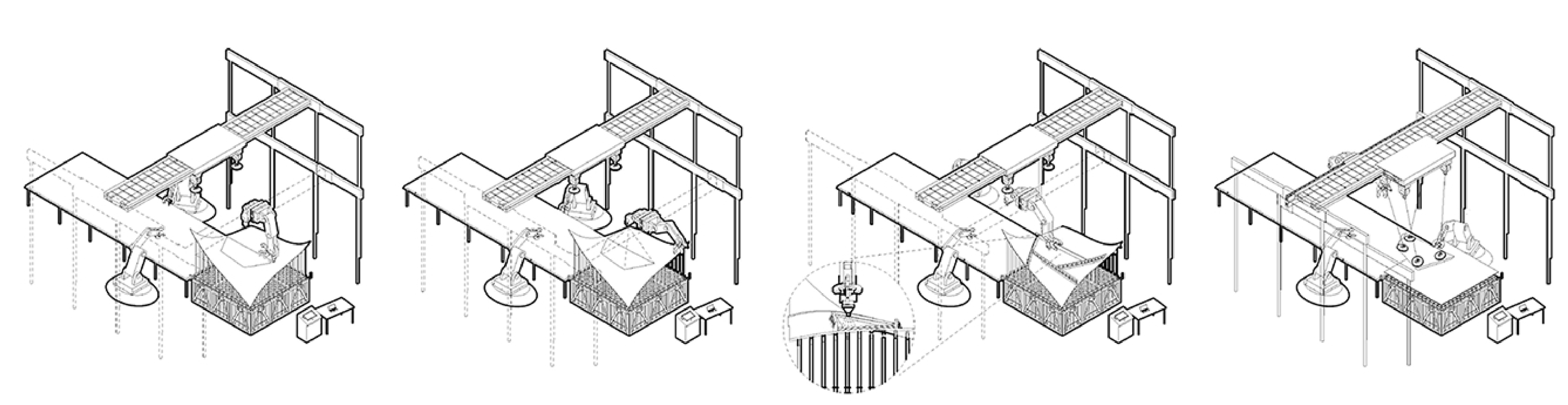

Figure 9. Emerging Manufacturing For Modular Rib Shell Modules: Robotic/CNC Pin Molding