

## AeroTerra — A TPMS-Based Ceramic Module System for Urban Façade Farming

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Abstract:	<p>AeroTerra investigates the integration of vertical agriculture into architectural façades through 3D-printed ceramic modules structured by Triply Periodic Minimal Surface (TPMS) geometry. Situated in hot, arid urban contexts such as Abu Dhabi, the project addresses heat stress, water scarcity, and food production by reframing the building envelope as an active climatic and ecological interface. Computational modeling informs the additive fabrication of porous ceramic modules whose geometry regulates moisture retention, airflow, and plant anchorage. Micro-scale surface textures support capillary transport and root anchorage, while the material strategy draws on established work on moisture-cycling ceramics and passive evaporative effects. The modular system supports aeroponics cultivation and is adaptable across interior, façade, and retrofit conditions, proposing a soil-informed, material-driven framework for productive architecture in arid cities.</p>

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## AeroTerra — A TPMS-Based Ceramic Module System for Urban Façade Farming

### Abstract

AeroTerra investigates the integration of vertical agriculture into architectural façades through 3D-printed ceramic modules structured by Triply Periodic Minimal Surface (TPMS) geometry. Situated in hot, arid urban contexts such as Abu Dhabi, the project addresses heat stress, water scarcity, and food production by reframing the building envelope as an active climatic and ecological interface. Computational modeling informs the additive fabrication of porous ceramic modules whose geometry regulates moisture retention, airflow, and plant anchorage. Micro-scale surface textures support capillary transport and root anchorage, while the material strategy draws on established work on moisture-cycling ceramics and passive evaporative effects. The modular system supports aeroponics cultivation and is adaptable across interior, façade, and retrofit conditions, proposing a soil-informed, material-driven framework for productive architecture in arid cities.

**Keywords:** TPMS geometry, ceramic 3D printing, urban farming, adaptive façade, bioclimatic architecture

### Context

This study uses Abu Dhabi as a representative hot-arid coastal context to frame the constraints relevant to façade cultivation. In this setting, vertical agriculture is shaped by exposure conditions, irrigation feasibility, and long term serviceability as much as by horticultural ambition. The project therefore approaches façade farming as an envelope problem. It asks how a building surface can be configured to host plant growth while remaining legible as an architectural assembly with predictable maintenance and repair cycles.

The argument does not depend on site-specific monitoring or building-scale simulation claims.

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3 Abu Dhabi is introduced through widely used climate classifications and typical meteorological  
4 year (TMY) datasets, including standard climate classifications and typical meteorological  
5 datasets, to define boundary conditions and design criteria. This framing is used to situate the work  
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7 without shifting the paper into a site report. The focus remains on module-scale mechanisms and  
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9 on how those mechanisms can inform façade deployment in comparable hot-arid cities.  
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13 Façade exposure varies across a single building, and this variation has direct implications for  
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15 planting viability and substrate behavior. Orientation is therefore treated as a placement criterion  
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17 for organizing a modular system, not as a quantified performance result. The study distinguishes  
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19 between higher exposure zones and more sheltered zones and uses this distinction to guide module  
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21 differentiation. In higher exposure conditions, the design emphasis shifts toward moderating direct  
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23 radiation and limiting rapid moisture loss at the rooting interface. In more sheltered conditions, the  
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25 system can support denser planting and longer moisture residence. This logic is presented as a  
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27 design method for distributing a family of modules, without asserting numerical cooling or yield  
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29 outcomes for a particular building.  
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35 Water supply is addressed as an operational constraint rather than an assumed input. The project  
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37 is designed to be compatible with non-potable water sources that can plausibly exist in cooling  
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39 intensive buildings, including recovered HVAC condensate and treated greywater where  
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41 regulations and building services allow safe distribution. The paper does not claim access to these  
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43 streams at a specific site and does not estimate volumes. Their role is to clarify an infrastructural  
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45 pathway that makes façade cultivation more defensible in arid contexts, and to motivate a substrate  
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47 that can operate under intermittent supply, recirculation, and variable water quality. This approach  
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49 keeps the focus on how the module manages moisture regimes under constraint rather than on  
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51 resource accounting.  
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3 [Typological Setting for Prototype Evaluation]  
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5 A research-oriented deployment is framed through institutional campuses and cultural or research  
6 facilities. These settings often provide facilities management capacity, controlled access, and a  
7 programmatic rationale for demonstrative environmental infrastructure. The typology is  
8 introduced as a plausible context for prototype evaluation, where installation logistics and  
9 maintenance routines can be studied alongside environmental behavior. It is not presented as  
10 evidence of market readiness or as a claim that a specific facility has been secured for deployment.  
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12 Green façades and living walls have established a precedent for vegetated envelopes, yet many  
13 systems are developed primarily for visual coverage. Their assemblies often rely on polymer-based  
14 matrices and continuous irrigation, which can increase maintenance demand and shorten service  
15 life under harsh exterior exposure. A more structural limitation is that soil is typically treated as a  
16 separate imported layer, with the façade acting as support rather than substrate. When the goal  
17 shifts from greening to cultivation, this separation becomes consequential because consistent  
18 rooting, nutrient delivery, and harvest logistics require a stable growing medium and repeatable  
19 moisture management. AeroTerra positions itself as a move toward façade agriculture by treating  
20 substrate behavior as an architectural design variable.  
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40 [Porous Ceramics as Mineral Substrates]  
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42 Ceramic is treated as an exterior-grade porous medium capable of participating in moisture  
43 transport and microclimatic moderation while remaining compatible with architectural  
44 construction. Work on porous ceramic assemblies and moisture-cycling thermal devices supports  
45 the relevance of capillary wetting and hygrothermal buffering to passive environmental  
46 performance (Bae and Park 2019; Ichniowski 2025). Related thermal studies using TPMS as heat-  
47 transfer surfaces provide additional precedent for coupling geometry and environmental exchange  
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3 in controlled porous networks (Min et al. 2024). Cultivation-oriented precedents suggest that  
4 porous clay bodies can serve as plant-support substrates when wetting pathways and surface  
5 conditions support adhesion and oxygen exchange (Arja 2025; Luna 2014). AeroTerra extends  
6 these lines of work by treating porosity distribution and micro-surface texture as explicit design  
7 parameters that coordinate water residence with the rooting interface.  
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10 Additive manufacturing enables ceramic components whose internal channels, thickness variation,  
11 and surface morphology can be produced within continuous toolpaths. This fabrication condition  
12 is relevant to substrate design because continuity and graded microstructure influence both  
13 moisture transport and structural behavior at the scale of the building component. Architectural-  
14 scale clay printing provides precedent for performance-differentiated ceramic components and  
15 embedded environmental logic without mold tooling (Severi 2024).  
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18 [TPMS Geometry as a Controllable Porous Matrix]

19 Triply Periodic Minimal Surface geometries offer continuous curvature and parametric control  
20 over porosity and thickness, and they have been investigated as porous media and lightweight  
21 structural systems (Qin et al. 2017). For façade cultivation, TPMS enables a coupled design space  
22 in which airflow paths, moisture residence, and rooting interfaces can be tuned within a continuous  
23 matrix. Continuity also supports stable printing toolpaths and reduces stress concentrations  
24 associated with discretized lattice systems. AeroTerra uses TPMS as a controllable porous matrix  
25 that can be adjusted across a modular family to support different exposure conditions and planting  
26 modes.  
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29 The project frames the façade as a constructed ground condition. It proposes an envelope  
30 component that behaves as a mineral substrate by supporting root attachment, mediating air and  
31 moisture exchange, and contributing to local climatic moderation at the surface of the building.  
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3 Within the Soil discourse, the contribution is to treat substrate microstructure and material agency  
4 as architectural variables, and to situate these variables within the constraints of hot-arid urbanism  
5 without relying on unverifiable site-specific claims. The result is a context sensitive framework  
6 for productive envelopes that can be adapted to comparable Gulf cities through placement criteria,  
7 infrastructural compatibility, and performance tuned ceramic geometry.  
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## 14 **Methods**

### 15 [Research Objectives and Climatic Criteria]

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20 The research develops a façade cultivation module that can function as a building component rather  
21 than a standalone horticultural device. The technical objective is to define a ceramic substrate  
22 geometry that supports plant establishment on a vertical plane while remaining compatible with  
23 additive fabrication and architectural assembly. The work proceeds as a prototype-driven study. It  
24 treats Abu Dhabi as a representative hot-arid coastal context to define boundary conditions for  
25 design decisions, without claiming site monitoring or building-scale performance verification.  
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27 These boundary conditions inform two methodological commitments. First, module variants are  
28 designed to be placeable under different exposure regimes through geometric differentiation rather  
29 than through a single universal configuration. Second, irrigation is treated as a constrained  
30 operational input and is framed around compatibility with non-potable building-coupled sources  
31 such as recovered HVAC condensate and treated greywater when permitted. The emphasis is  
32 therefore placed on how the substrate manages moisture retention, drainage, aeration, and root  
33 anchorage under intermittent watering rather than on projecting annual yield.  
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### 50 [Computational Geometry and Parametric Control]

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53 AeroTerra is organized around a family of Triply Periodic Minimal Surface geometries that are  
54 parameterized to control surface thickness, pore connectivity, and local curvature (Figure 3). The  
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3 TPMS scaffold is used as a continuous porous matrix in which void size and surface density can  
4 be adjusted to accommodate different rooting behaviors and watering modes. Geometry generation  
5 and module tuning were carried out in Rhinoceros 3D and Grasshopper. The parametric model  
6 was structured to preserve topological continuity while allowing controlled variation across  
7 modules. Within this family, the Lidinoid variant was further refined through equation-level  
8 customization to tune local curvature and pore openness(Figure 4). This continuity supports  
9 fabrication feasibility in clay printing and reduces geometric discontinuities that can compromise  
10 structural performance or create undesirable water pooling.  
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22 The module system is conceived as an architectural assembly. Variants are not treated as aesthetic  
23 options but as exposure- and cultivation-informed configurations within a shared dimensional and  
24 connection logic. Exposure zoning informs the parametric differentiation of thickness and pore  
25 openness across module variants. Higher exposure conditions motivate configurations that reduce  
26 direct surface desiccation at the rooting interface and preserve moisture residence through adjusted  
27 pore openness and local surface density. More sheltered conditions allow configurations that  
28 prioritize planting capacity and sustained wetting. These criteria are implemented as a design  
29 method for distributing a module family across the façade, rather than as quantified environmental  
30 claims for a specific building.  
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43 Plant selection and module calibration were developed together, treating crop requirements as  
44 constraints on geometry. The study focuses on cultivation types compatible with façade servicing  
45 and shallow rooting, including microgreens and sprouting vegetables. Establishment strategies  
46 include hydroseeding or gel-assisted adhesion to support germination on vertical planes. Aromatic  
47 herbs were included as a second crop class because intermittent irrigation tolerance and crevice-  
48 based anchorage align with micro-topographic substrates. Planting is organized as a micro-ecology  
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3 within each module: exposure-tolerant species occupy more exposed zones, while moisture-stable  
4 species occupy recessed or shaded zones (Figure 5, Figure 6, Figure 7). Root morphology and  
5 cultivation method inform pore size distribution and surface density. Larger voids are reserved for  
6 root suspension and aeroponic zones, while denser regions provide contact area and moisture  
7 buffering. Material-level tuning draws from bioreceptive ceramic research indicating that organic  
8 additives can alter porosity and surface roughness after firing (Rotondi et al. 2024). Prototype trials  
9 introduced small fractions of plant-fiber additives to assess changes in water uptake and seed  
10 adhesion.  
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#### 22 [Ceramic Material System and Micro-Surface Engineering]

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25 Ceramic was selected for its compatibility with porous substrate behavior and exterior architectural  
26 use. The material strategy leverages the ability of porous clay to absorb and release water through  
27 capillarity, enabling localized moisture retention near the rooting interface. This behavior is treated  
28 as a mechanism for reducing irrigation frequency and stabilizing the near-surface water condition  
29 needed for germination and early root establishment. The study also considers the thermal behavior  
30 of ceramics in wet and dry states. Moisture stored in pores can support evaporative cooling at the  
31 surface, while the mineral mass provides thermal inertia that moderates short-term temperature  
32 swings. Related work on unglazed ceramic cooling assemblies and hybrid moisture-cycling  
33 ceramics provides precedent for treating ceramic bodies as passive climatic devices rather than  
34 inert cladding (Bae and Park 2019; Ichniowski 2025).  
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48 Micro-surface design is addressed as a functional layer rather than as texture for appearance.  
49 Surface roughening is used to increase contact area for seeds and to support early-stage adhesion  
50 in hydroseeding. Micro-relief also supports root anchorage against gravity and wind-induced  
51 vibration by providing crevice-scale purchase points (Vakant 2012). These surface conditions are  
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3 developed alongside TPMS porosity tuning so that water transport and biological attachment are  
4 coordinated within a single monolithic substrate.  
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#### 7 8 [Cultivation Interfaces and Irrigation Strategies] 9

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11 The cultivation interfaces explored in AeroTerra prioritize methods that can operate within the  
12 constraints of a façade assembly. Aeroponic cultivation is treated as a primary mode because it  
13 can decouple root hydration from bulk growing media while benefiting from a porous ceramic  
14 surface that buffers humidity and intercepts intermittent wetting. Hydroseeding is treated as a  
15 complementary technique for establishing shallow-root crops on vertical planes (Figure 9). In this  
16 mode, a nutrient gel or binding medium assists initial adhesion and supports germination before  
17 roots penetrate surface micro-topography. Microgreens are included not as a stylistic choice but  
18 because their growth cycle and root depth are compatible with façade maintenance and harvesting.  
19  
20 Irrigation is framed around operational compatibility rather than guaranteed supply. The system is  
21 designed to accept intermittent non-potable sources that may be available in cooling-intensive  
22 buildings, such as HVAC condensate and treated greywater where permitted. This framing  
23 motivates design decisions about drainage, salt accumulation risk, and cleaning access without  
24 requiring the paper to claim a specific water budget. Within the scope of the prototype study,  
25 irrigation strategies are evaluated through their effects on substrate wetting stability and plant  
26 establishment rather than through full lifecycle resource accounting.  
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#### 30 31 [Fabrication Workflow] 32

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34 Module variants were developed through a digital-to-physical workflow that links parametric  
35 TPMS generation to large-format clay extrusion (Figure 8). TPMS families were generated and  
36 tuned in Rhinoceros 3D and Grasshopper, where thickness, pore connectivity, and curvature were  
37 adjusted while preserving topological continuity across variants. Prior to fabrication, each module  
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3 was converted into a watertight, manifold mesh and checked for non-manifold edges, self-  
4 intersections, and minimum feature thickness to reduce printing instability and loss of dimensional  
5 fidelity. Where structural screening was required, preliminary evaluations were conducted in  
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8 Grasshopper using Millipede to verify that thickness differentiation remained compatible with  
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10 handling and assembly at the component scale. Fabrication followed a WASP large-format  
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12 ceramic printing workflow: print geometry was translated into continuous extrusion toolpaths  
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14 through the printer's slicing and control environment. Slicing constraints, including nozzle-scale  
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16 resolution and curvature-dependent path continuity, informed iterative refinement of geometry,  
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18 particularly in regions where thin sections tended to distort during deposition. Printed parts were  
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20 dried and fired following studio protocols for unglazed porous bodies. Post-firing surface condition  
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22 was documented because capillary wetting and early-stage plant adhesion depend on both designed  
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24 porosity and extrusion-induced micro-roughness.  
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## 30 31 **Results**

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34 [Façade deployment logic under hot-arid constraints]  
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37 AeroTerra is developed as a modular cultivation layer that can be mounted on, or integrated into,  
38 exterior envelope assemblies in hot-arid coastal cities, using Abu Dhabi as a representative  
39 boundary condition (Figure 10). The system is organized as a replaceable field of ceramic  
40 components with a shared dimensional and connection logic, enabling localized variation while  
41 maintaining serviceability at the façade scale (Figure 11). Among these candidate settings,  
42 restaurants offer high visibility and routine maintenance cycles, making them a practical pilot  
43 typology for public-facing cultivation infrastructure (Figure 12). Placement follows exposure  
44 zoning as a design criterion, where higher-radiation zones motivate geometries with greater surface  
45 density and moderated pore openness, and lower-exposure zones accommodate configurations that  
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3 prioritize planting capacity and longer moisture residence. This section reports the deployment  
4 logic as an organizational method for distributing module variants, not as a quantified prediction  
5 of thermal or yield performance.  
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10 [Mechanical test dataset and specimen series]

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13 A mechanical test series was conducted to evaluate the scaling behavior of a customized Lidinoid  
14 TPMS geometry derived from the AeroTerra module family. The tested geometry corresponds to  
15 the fourth module in a vertical row in the proposed façade assembly. Specimens were generated  
16 by varying shell thickness from 20% to 100% of the original definition in 10% increments while  
17 holding topology constant. Each thickness condition was produced and tested in triplicate using  
18 PLA and ABS prints as polymer analogs to isolate geometric effects and establish a baseline for  
19 future ceramic testing. The dataset includes tensile and compression tests; the results reported here  
20 focus on compression to reflect common façade loading conditions associated with local bearing,  
21 mounting interfaces, and out-of-plane pressure.  
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34 [Normalized scaling relations]

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37 Mechanical metrics were normalized using the base properties of solid PLA ( $E_s$  and  $\rho_s$ ) and  
38 plotted in log–log space against normalized density ( $\rho^*/\rho_s$ ) to align the analysis with established  
39 scaling descriptions for cellular solids and TPMS lattices (Qin et al. 2017). The normalized  
40 Young’s modulus ( $E^*/E_s$ ) follows a power-law trend with an exponent of approximately 1.62  
41 (Figure 14). The normalized tangent modulus, computed from the slope of the stress–strain  
42 response, yields an exponent of 1.10 (Figure 15). Normalized compressive strength, defined as  
43 peak load prior to buckling, yields an exponent of 1.67 (Figure 16). These fitted exponents place  
44 the customized Lidinoid series within the range reported for TPMS-derived porous media and  
45 provide a consistent basis for comparing future material translations, including greenware and  
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3 fired ceramics (Qin et al. 2017; Zheng et al. 2018). (Figure 17) reproduces the scaling-law  
4 compilation from Zheng et al. (2018), providing an external reference frame for interpreting the  
5 fitted exponents and situating the present dataset within published cellular-solid behavior.  
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10 [Peak strength anomalies and fabrication sensitivity]  
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13 When peak strength is plotted directly against density (Figure 18), several intermediate thickness  
14 conditions, including 30%, 70%, and 80%, exhibit non-monotonic behavior in which higher-  
15 density samples register lower peak strength. Test notes record localized tip damage, material  
16 labeling inconsistencies between PLA and ABS, and printing adhesion issues as plausible  
17 contributors to these deviations. The pattern indicates that intermediate thickness regimes can be  
18 sensitive to handling and deposition stability, and that peak strength measurements in this range  
19 are more exposed to fabrication artifacts than modulus-based measures.  
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23 Representative stress–strain curves show an elastic regime followed by progressive buckling and  
24 distributed deformation, particularly in the 100% thickness condition (Figure 19). The response  
25 is characterized by a smooth load increase prior to instability and a deformation pattern that  
26 distributes across the connected surface network. This observation documents a failure mode  
27 associated with the tested topology and print conditions and is reported as a mechanical behavior  
28 of the geometry–fabrication system rather than as a material claim about fired ceramics.  
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## 31 32 33 34 35 36 37 38 39 40 41 42 43 44 **Discussion**

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46 For Soil, the design contribution rests on treating substrate microstructure as an architectural  
47 variable that can be tuned with geometric control. The scaling relations reported in Section 3  
48 provide a quantitative linkage between relative density and stiffness/strength across the Lidinoid  
49 thickness series. In design terms, thickness and porosity can be treated as controllable parameters  
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3 within a shared topological family, allowing module variants to be distributed across façade  
4 exposure zones while remaining legible within a consistent mechanical envelope. This does not  
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6 replace façade engineering, but it establishes a transferable method: geometry can be  
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8 differentiated by placement criteria while retaining a density-normalized framework for  
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10 estimating relative structural behavior.  
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15 The density-versus-peak-strength anomalies in Section 3.4 shift part of the performance question  
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17 from topology alone to production stability. For a façade substrate, robustness depends on  
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19 whether thin features survive printing, drying, handling, and assembly without accumulating  
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21 defects that dominate peak failure metrics. The present dataset therefore supports a fabrication-  
22  
23 aware definition of “robust geometry,” where porosity targets are paired with minimum feature  
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25 thickness, mesh integrity checks, and print-path continuity constraints. For ceramic translation,  
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27 this framing is directly relevant because firing shrinkage, microcracking, and warpage introduce  
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29 additional pathways for defect amplification. The current results define a clear next step that  
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31 stays within the same analytical method: repeating the thickness series in ceramic and appending  
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33 the results to the density-normalized scaling framework.  
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39 AeroTerra frames façade cultivation as an envelope substrate problem that intersects moisture  
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41 management, air exchange, and maintenance access. The ceramic strategy draws on capillary  
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43 wetting and hygrothermal buffering as substrate mechanisms that can stabilize near-surface  
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45 moisture for germination and early-stage establishment (Bae and Park 2019; Ichniowski 2025).  
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47 TPMS geometry provides a continuous porous matrix in which pore connectivity, surface  
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49 density, and curvature can be tuned to coordinate airflow paths with moisture residence within a  
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51 monolithic body (Qin et al. 2017). In Abu Dhabi-scale constraints, the infrastructure question  
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53 remains decisive. The project therefore positions HVAC condensate and treated greywater as  
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3 plausible non-potable pathways for intermittent irrigation where building services and  
4 regulations permit distribution, without claiming site access or volumetric sufficiency. This  
5 coupling clarifies how the module is intended to operate within a building envelope system while  
6 keeping the argument focused on substrate behavior and serviceability.  
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12 [Toolchain as a reproducible design-to-fabrication method]

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15 The project is organized as a repeatable toolchain in which geometric parameters, mesh validity,  
16 and fabrication constraints are treated as a single design space. TPMS generation and module  
17 differentiation were executed in Rhino and Grasshopper through a parametric definition that  
18 preserves topology while allowing controlled variation in thickness and porosity. Mesh  
19 conditioning prior to slicing was treated as a precondition for extrusion reliability, since  
20 discontinuities and thin features directly propagate into deposition breaks, local over-extrusion,  
21 and dimensional drift. Toolpath generation in the WASP printing workflow was therefore used  
22 as an evaluative step: features that could not be deposited as continuous paths were revised in the  
23 parametric model rather than corrected downstream. This feedback loop supports the production  
24 of variant-rich module families without mold tooling while maintaining a consistent assembly  
25 logic at the façade scale (Severi 2024).  
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### 41 **Data Availability and Reproducibility**

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44 The study produces three datasets that support reproducibility across geometry, fabrication, and  
45 mechanical testing. The first dataset is a parametric geometry series documenting the customized  
46 Lidinoid definition and the thickness sweep from 20% to 100% in 10% increments, generated in  
47 Rhino and Grasshopper. The second dataset is a fabrication and specimen log containing  
48 specimen identifiers, material assignment (PLA/ABS), thickness condition, and recorded print or  
49 handling notes relevant to interpreting peak strength anomalies. The third dataset contains the  
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3 mechanical testing outputs and derived metrics, including density, normalized density, elastic  
4 modulus, tangent modulus, and compressive strength, together with the regression fits used to  
5 obtain scaling exponents. The datasets are structured so that fired-ceramic specimens can be  
6 appended under the same normalization framework in future work, enabling cross-material  
7 comparison without altering the analysis method.  
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## 15 **Conclusion**

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18 AeroTerra proposes a façade-based cultivation substrate that treats the building envelope as a  
19 constructed ground condition in hot-arid urban contexts. The project develops a coupled  
20 geometry–material approach in which TPMS provides a controllable porous matrix and porous  
21 ceramics provide capillary wetting and hygrothermal buffering that are relevant to vertical  
22 establishment. Within this framework, porosity, thickness, and micro-surface conditions become  
23 design variables that can be differentiated across a modular family and distributed by exposure  
24 zoning while retaining serviceability at the façade scale.  
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34 The mechanical test series on a customized Lidinoid geometry contributes a density-normalized  
35 dataset that links geometric differentiation to consistent scaling relations across thickness  
36 conditions. The results also identify sensitivity to fabrication artifacts in intermediate thickness  
37 regimes, motivating a robustness criterion that treats print integrity and defect pathways as part  
38 of substrate performance. The next phase of validation follows directly from this method:  
39 repeating the thickness series in ceramic and extending the same normalization and regression  
40 framework to quantify the effects of drying and firing on stiffness, strength, and deformation  
41 modes.  
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53 By situating substrate behavior, toolchain reproducibility, and infrastructural compatibility  
54 within an arid-city constraint frame, the project contributes to Soil by shifting façade agriculture  
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3 from decorative greening toward a material-driven substrate agenda. The work remains  
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5 prototype-based and does not claim site-specific resource sufficiency or building-scale  
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7 environmental outcomes. It establishes a transferable research pathway that connects parametric  
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9 TPMS design, architectural-scale ceramic printing, and performance evaluation for productive  
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13 envelope systems.  
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## 15 16 **References**

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Figure 1: Photograph of a 3D-printed TPMS module cultivating green onion.



Figure 2: Photograph of a 3D-printed TPMS module cultivating bok choy.

SECTION	STANDARD GEOMETRY	VARIATE POLE	VARIATE PERIOD	EQUATION
				<b>Schwarz P</b> $\cos(x) + \cos(z) + \cos(y)$
				<b>GYROID</b> $\cos(x) \sin(y) + \cos(y) \sin(z) + \cos(z) \sin(x)$
				<b>Neovius</b> $3 * (\cos(x) + \cos(y) + \cos(z)) + 4 * \cos(x) * \cos(y) * \cos(z)$
				<b>iWP</b> $(\sin(x) \cos(y) * \sin(z) + \sin(y) \cos(z) * \sin(x) + \sin(z) \cos(x) * \sin(y)) - (\cos(x) \cos(y) + \cos(y) \cos(z) + \cos(z) \cos(x)) / VC$
				<b>Split P Surface</b> $1.1 * (\sin(2 * x) \cos(y) \sin(z) + \sin(2 * y) \cos(z) \sin(x) + \sin(2 * z) \cos(x) \sin(y)) - 0.2 * (\cos(2 * x) \cos(2 * y) + \cos(2 * y) \cos(2 * z) + \cos(2 * z) \cos(2 * x)) - 0.4 * (\cos(2 * y) + \cos(2 * z) + \cos(2 * x))$

Figure 3. Typology design customization of TPMS geometries.

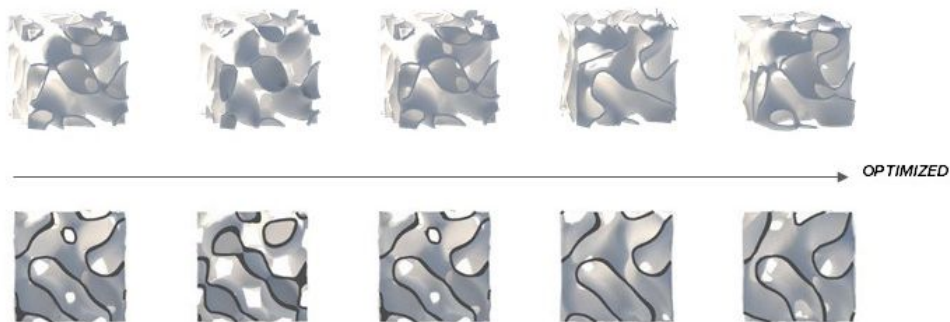


Figure 4. Optimized the Lidinoid geometry by customizing the equation.

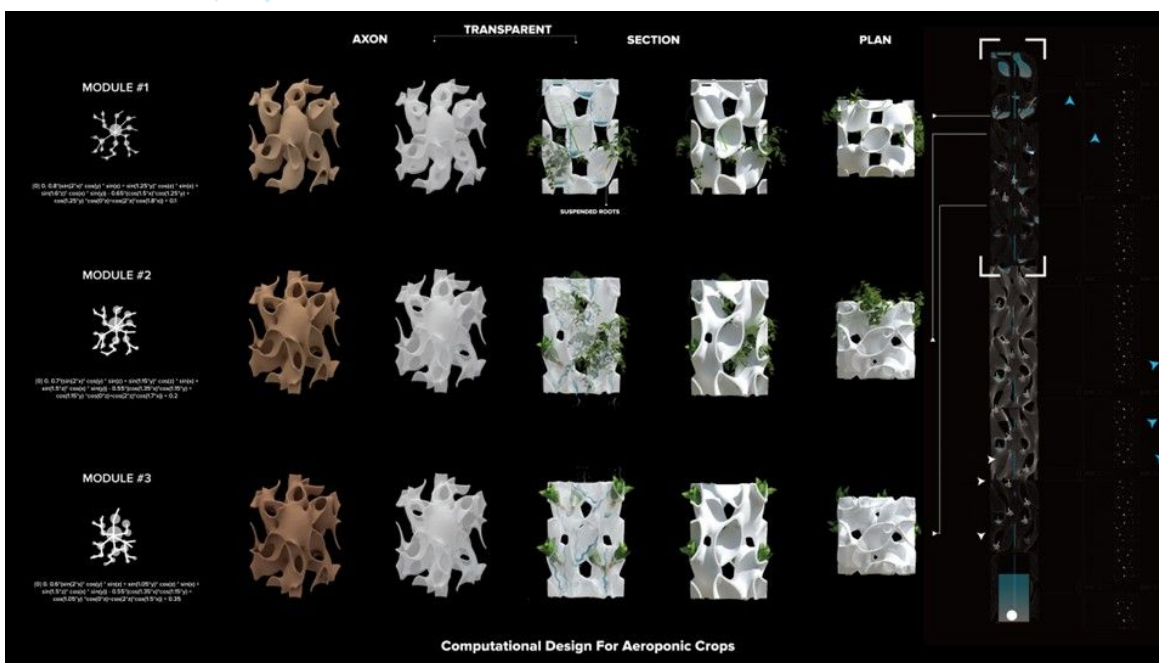
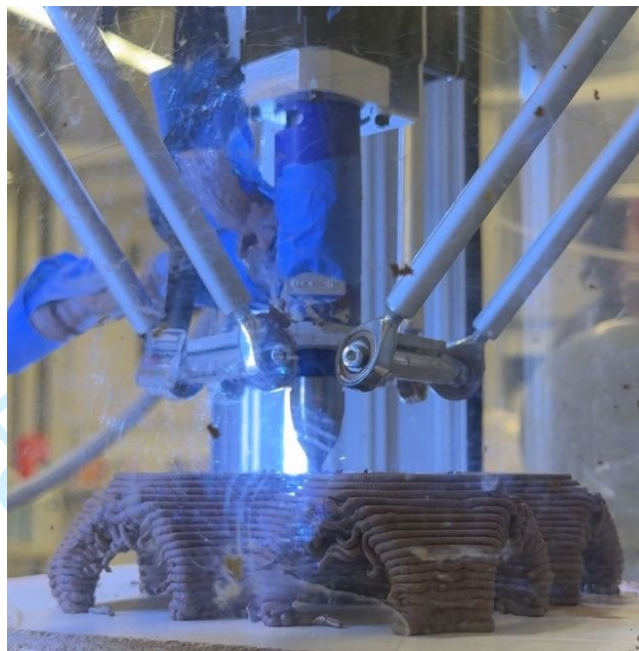


Figure 5. The top three modules, as one tier, grow bok choy with aeroponic mist, requiring deeper voids and high void connectivity to hold suspended roots.





*Figure 8. The process of 3D clay printing*



*Figure 9. A real-life photo demonstrating how nutrient mist irrigates the clay façade.*

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Figure 10. Structure of secondary façade applied to a retrofitted building (render)



Figure 11. AeroTerra is applied to outdoor retrofit façades, serving as a secondary skin for the building.



*Figure 12. In restaurants, they offer a visible, organic source of produce that builds trust and adds*

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Figure 13. Compression test – before and after loading.

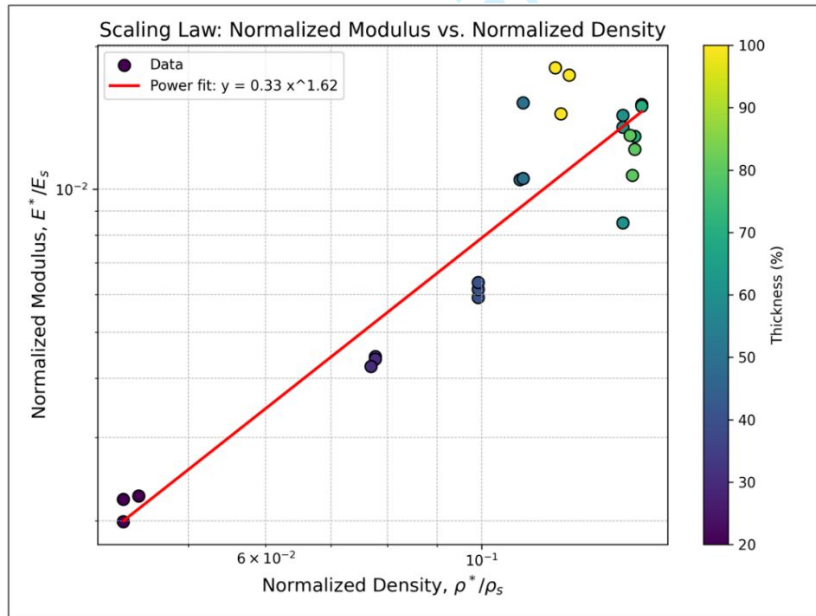


Figure 14: Scaling Law: Normalized Modulus vs. Normalized Density.

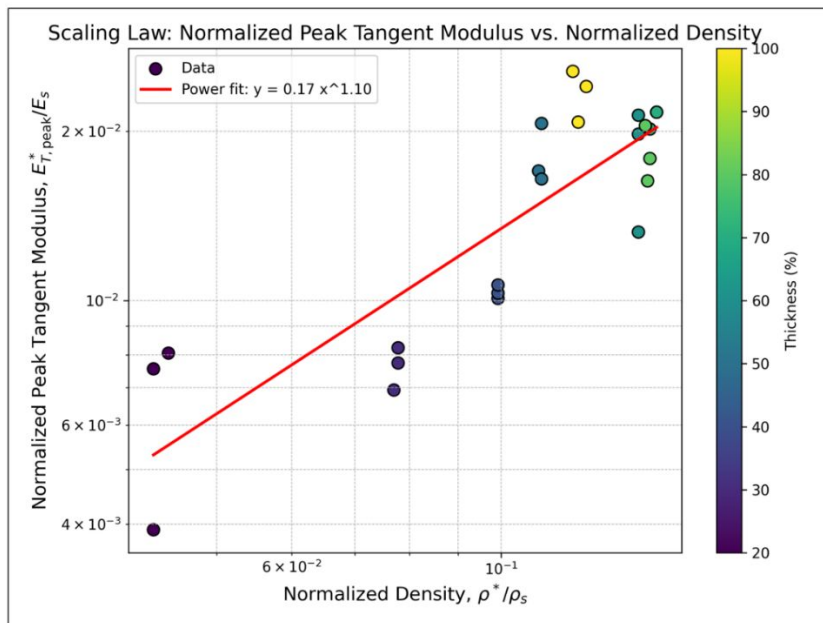


Figure 15: Normalized Peak Tangent Modulus.

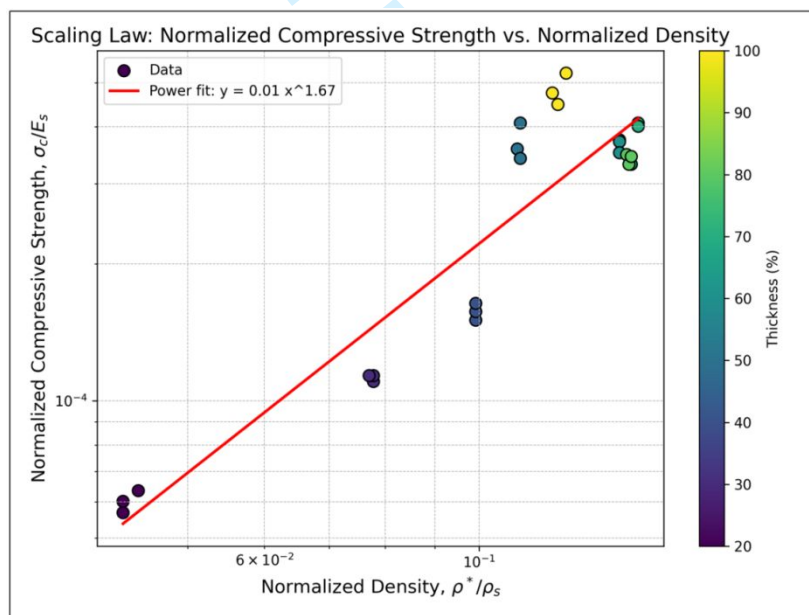


Figure 16: Normalized Compressive Strength vs. Normalized Density.

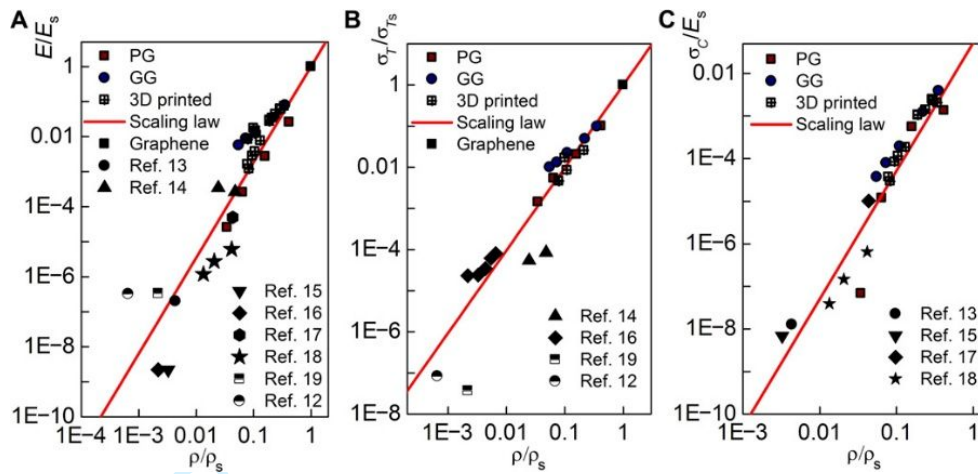


Figure 17: Reference scaling-law maps for normalized modulus and strength versus relative density across porous material families, including TPMS-based architectures (Adapted from Zheng et al. 2018).

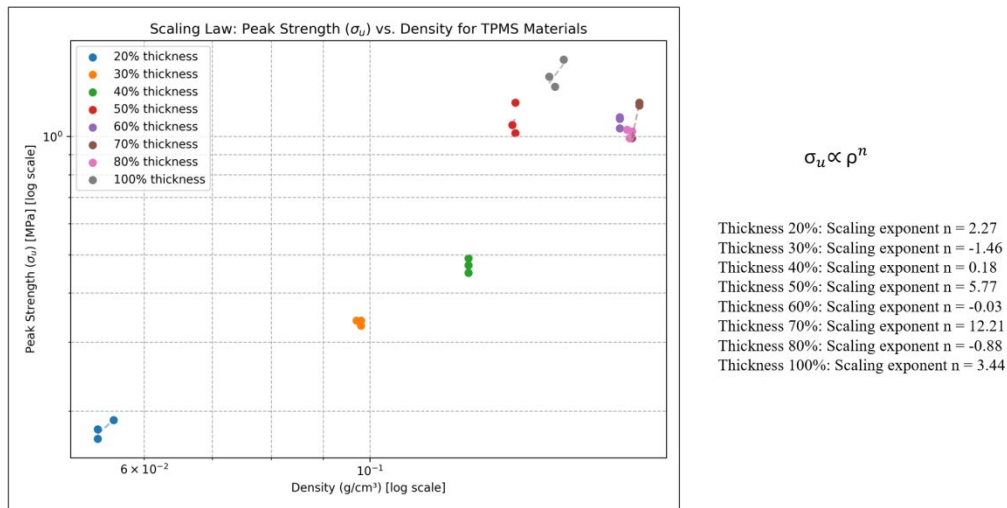
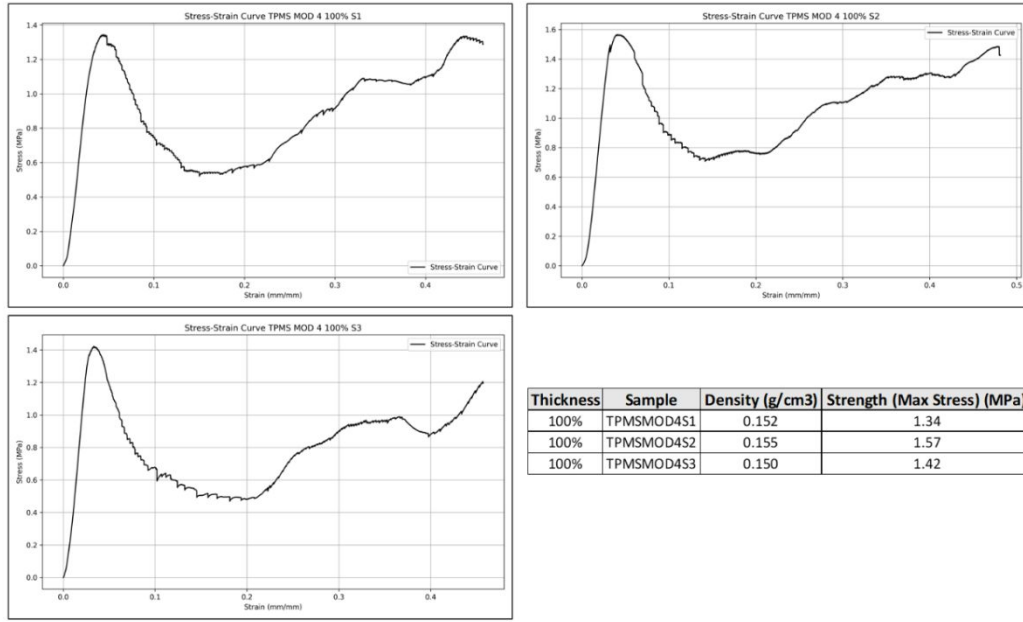


Figure 18: Scaling Law: Peak Strength vs Density for TPMS Materials



**TPMS: MOD 4 -100% S1, S2 & S3**

*Figure 19: Stress–Strain Curve For 100% thickness.*

Review Only