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Article

Material-led design research through biomaterial transformation: Temporality, participation, and spatial production

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ABSTRACT

This article investigates how biomaterials can act as active drivers in material-led design research through time-dependent transformation. While biomaterials are often framed as sustainable alternatives, their role in generating spatial and experiential conditions remains underexplored. Addressing this gap, the study develops a practice-based research approach examining food-waste-derived biomaterials as surface-forming agents. The research is structured around Sta!ned, a participatory installation operating as a design research medium. Biomaterials are produced and applied through pouring protocols, while environmental conditions and participant interaction, observed qualitatively, act as sources of variation in material behavior. Longitudinal observation and structured analysis enable the systematic examination of transformation processes. Findings show that surface formation emerges through accumulation, diffusion, and decay, producing temporally evolving spatial conditions rather than fixed outcomes. The study proposes a transferable methodological framework integrating material agency, temporality, and participation, positioning material transformation as a generative component of design knowledge.

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INTRODUCTION

In material ecology, computational material culture, and material-driven design, architectural systems are defined as a set of configurations in which material performance, environment, and space interact as a set of interdependent variables, and architectural form is only partially determinable via the mediation of material systems and atmospheric forces (Menges, 2012; Oxman, 2016). In this regard, bio-based materials go beyond replacing traditional materials and incorporate temporality, heterogeneity, and transformation as inherent architectural features that require new modes of representation and performance (Thomsen & Tamke, 2022). Simultaneous advancements in architectural theory continue to redefine living and bio-based systems from design materials to co-design participants in architectural design and production. New paradigms of ecology highlight spatial creation as a result of the interplay between biological behavior, interior space, and design intention, diverting attention from form-making in architecture and focusing on spatial formation as a process of architecture (Chayaamor-Heil et al., 2024).

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Under this paradigm, experimental installations are made to function as architectural research tools capable of analyzing the interaction between materials and the environment at the interior scale. The experimental installations are made to function not as representational objects but as space apparatuses through which the behavior of materials may be analyzed at the interior scale. Research on responsive environments illustrates that the presence of the body may function as a controlled input capable of modulating architectural systems through participation that is structured and constrained (Achten, 2019; Costa Maia & Meyboom, 2015). Accordingly, in this research, participation is understood as an operative condition of the system rather than a symbolic act.

Critical discourse on bio-design further supports this approach by cautioning against reducing living systems to representational materials and encouraging their use within architecture based on performative and operational abilities, such as surface creation and organizational behavior (Collet, 2017). According to this perspective, installation practices are situated within architecture as a form of knowledge creation within architecture studies rather than being a form of artistic representation (Rendell, 2006). At the same time, biomaterials also take on a significant position in architectural research for their ability to act as adaptive systems that are responsive to their environment. The study of engineered living materials and biological composites illustrates that these materials maintain their functional integrity while also displaying adaptive, time-dependent behavior, causing biomaterials to be viewed not simply as reactive architectural options but dynamic architectural systems in their own right (Geng et al., 2024; Quijano et al., 2025). The study of bio-based building materials, such as engineered mycelium systems, illustrates the ability of biological growth to achieve material properties relevant to architectural surface creation and performance (Jones et al., 2020).

Despite advances, existing research largely focuses on material engineering or design concepts, revealing a gap in protocol-based architectural analysis that systematically integrates biomaterial properties into interior surface formation. While responsive architecture addresses interaction and environmental feedback, few studies establish structured procedures for biomaterial formulation, exposure, observation, and structured participation. Moreover, temporality—manifested through drying, cracking, diffusion, sedimentation, and growth—remains underdeveloped as an architectural variable despite its recognized significance (Thrift, 2008). Through biomaterial formulation, exposure, temporal recording, and protocol-guided participation, "Sta!ned" provides a transferable architectural research process for analyzing temporal surface formation on the interior scale. The practice of installation is here considered not only a type of exhibition design but also a spatial research tool that generates knowledge within a particular disciplinary field. This stance corresponds with practice-led interior research that conceives of installation-based thinking as a knowledge-generating tool, where interior space itself is understood not as a representation but rather a site of knowledge (Roes & Snowdon, 2018).

This study addresses the following research questions:

1. How can the properties and behaviors of biomaterials under interior atmospheric conditions be operationalized as active surface-forming agents rather than treated as representational or decorative layers in interior environments?
2. To what extent can practice-based architectural installation generate transferable knowledge on time-dependent surface production, interior atmospheric interaction, and material–environment relationships at the interior scale?

In response, the project Sta!ned is presented as a practice-based architectural research installation investigating surface formation generated through biomaterial behavior in interior environments. Biomaterials are applied through repeated, gravity-driven pouring actions, while participation follows a pouring protocol and is treated as an observed, but not quantitatively tracked, source of variability in flow paths, deposition height, and drying. Through this configuration, bodily presence and human participation become part of the system rather than external to it (Beesley, 2010).

METHOD

Research data were collected through a longitudinal observation protocol documenting drying rate, crack formation, flow behavior, layer overlap, detachment, chromatic change, olfactory response, and microbial indicators. Photographic and time-lapse recordings were captured immediately after deposition, and at 24-hour and 7-day intervals, with all data time-stamped for chronological analysis of surface evolution. Conducted at the interior scale, the study enables direct interaction between material behavior and atmospheric conditions such as humidity, airflow, and bodily proximity. While the single-site setup limits climatic generalization, the protocol is replicable and adaptable across interior contexts. The research positions the investigator as an embedded practitioner, integrating spatial, material, and environmental variables within a practice-based design research framework.

Research Design

The study adopts a practice-based architectural research methodology integrating material experimentation, spatial configuration, and environmental conditions. The installation is framed not as an artwork but as a research

device for examining biomaterial-driven surface and environmental formation at the interior scale. Conducted over six months, the research follows iterative cycles of material development and controlled activation within a single-case embedded design. Within this framework, the interior site functions as an environmental field, biomaterial formulations as experimental variables, surface evolution over time as the primary unit of analysis, and human presence as an observed source of variability in material behavior that was not quantitatively tracked. However, there was no controlled laboratory comparison setup because the aim was to test the materials under real atmospheric conditions rather than stabilized conditions. This reflects the architectural research viewpoint on space that considers space as a product of the intersection of material, environmental, and social factors rather than a self-contained form system (Till, 2009).

Biomaterial Formulation Protocol

Biomaterials were produced from food-waste-derived pigments, a cellulose-based binder, and plant plasticizers, with all mixtures standardized by weight-to-volume ratios (g/mL) to ensure traceability. Mixing, heating, and pause durations were controlled, following bioplastic and bio-fabrication prototyping principles that balance replicability and variation (Dunne, 2018). Each formulation was prepared in triplicate and evaluated for viscosity, flow behavior, adhesion to textile substrates, opacity, chromatic stability, and sensitivity to humidity and temperature. All tests were systematically documented through photographic and written records for comparative analysis. Moving beyond the classification of biomaterials as sustainable substitutes, the study adopts a material-agency perspective, positioning material behavior as constitutive of architectural knowledge and practice. Drawing on socio-material approaches, architectural outcomes are understood as emerging from intertwined social and material relations (Salama & Patil, 2025), where phenomena such as flow, adhesion, cracking, pigment migration, stratification, and early biodegradation operate as active agents in interior surface formation.

Spatial Application Protocol

Biomaterials were applied exclusively through gravity-driven pouring onto vertically suspended textile surfaces integrated into the installation. Application parameters were standardized as follows:

- pouring height: approximately 120–150 cm,
- pour volume: approximately 20–25 mL per action,
- resulting layer thickness: approximately 1–3 mm, depending on viscosity.

No corrective manipulation—such as brushing, smoothing, or mechanical spreading was permitted. Each deposition was applied directly onto previous layers without surface cleaning, enabling cumulative stratification, interlayer interaction, and emergent temporal behavior. This protocol ensured that surface formation resulted from material agency and environmental conditions, rather than external formal control, allowing spatial effects to emerge through process rather than representation.

Interior Environmental Conditions

All experiments were conducted under ambient interior conditions representative of a public indoor environment:

- temperature: 18–24 °C,
- relative humidity: 60–75%,
- indoor light exposure: approximately 9–11 hours per day,
- ventilation: passive airflow supported by an HVAC-equipped interior space.

Environmental variability was treated as an operative architectural parameter rather than a disturbance to be minimized. Rather, it is sought to explore how interior atmospheric conditions affect the development of materials and surfaces. In this research on interior atmospheres, these are not understood to provide the stable setting in which other phenomena unfold but are understood to be active environments that co-create surfaces in relation to moisture, air currents, light, and physical proximity. At the same time, research on cross-modal congruence (for instance, smell-color-language congruence) confirms that atmospheric experience is the result of organized relationships between sensory modalities and design parameters rather than by-products of these parameters (Tonin & Ferrara, 2025). Accordingly, the stratified biomaterial surfaces developed here operate as atmospheric registers: they capture and externalize time-dependent material–environment interactions, enabling interior atmospheres to be approached as measurable and designable conditions rather than purely experiential descriptors (Tonin & Ferrara, 2025; Treacy, 2025).

Analytical Framework

Analysis combined deductive structural coding and inductive thematic interpretation to translate observable material behavior into architectural outcomes. A structured coding matrix categorized behaviors including adhesion, crack development, detachment, stratification density, temporal instability, chromatic change, and olfactory/biological indicators, enabling comparative analysis across formulations and substrates. Inductive analysis proceeded through open coding (identifying recurring transformations), axial coding (establishing relationships between material behavior, substrate response, and environmental conditions), and selective coding. Material agency is used here in an operational sense, to refer to observable behaviors such as flow,

adhesion, cracking, and stratification under interior atmospheric conditions; the four categories organize these behaviors. In the axial step, the coded behaviors were grouped by the relationship they describe: between poured material and gravity (how far a deposit travels before it sets), material and substrate (whether it remains attached), material and time (how long it remains stable before cracking or biological activity), and successive deposits (whether earlier layers remain visible). Selective coding consolidated these groupings into Flow and Retention, Adhesion and Separation, Temporal Durability, and Layered Surface Formation, respectively, each tied to recorded indicators: lateral spread and drying time; adhesion and detachment; crack onset, first mold growth, and temporal stability; and layer overlap and previous-layer visibility (Table 1; Supplementary Table S2). These categories inform the interpretation of how biomaterial behavior generates evolving spatial conditions. Architectural outcomes were evaluated as spatial effects emerging from the interaction of controlled pouring, material response, environmental modulation, and cumulative temporal change, demonstrating that practice-based processes can operate as knowledge-producing systems rather than representational installations.

Participant Interaction Protocol

The installation was situated in a public interior space and enabled non-intrusive participation guided by a pouring protocol. Interaction occurred through:

- spatial proximity,
- bodily movement around suspended surfaces,
- localized atmospheric disturbance.

Comparable interior-scale constructs have been documented as 'interior skins' that register bodily presence and spatial interaction through controlled responsiveness (Wu,

Table 1. Biomaterial Recipes, Production Methods, and Qualitative Behavioral Evaluation

No	Material	Image	Results & Observations	Material Behavior Category	Epistemic Effect on the Surface	Layer Overlap Intensity	Lateral Spread Width
1	Turmeric		Gel-like, matte, slippery, layered surface	Flow retention + layered stratification	Slow temporal accumulation	High	Medium–High
2	Beetroot		Matte, grainy, detaches easily	Weak adhesion + surface separation	Fragmented traces	Low	Low–Medium
3	Purple Cabbage (Peel)		Thick, rigid, difficult to pour	Material resistance + rigidity	Restricted temporal agency	Very Low	Very Low
4	Purple Cabbage (Juice)		Soft, pourable, chromatic diffusion	High fluidity + pigment migration	Visible temporal color displacement	Medium	High
5	Coffee Grounds I		Dark, matte, strong pigmentation	Pigment dominance + surface saturation	Dense epistemic deposition	High	Low
6	Coffee Grounds II		Water-dependent firmness	Moisture-modulated agency	Variable temporal inscription	Medium–High	Medium
7	Coffee Grounds III		Thin, fragile surface	Structural fragility	Transient epistemic traces	Low	Medium
8	Banana Purée & Peel		Soft, light color	Diluted material agency	Low epistemic density	Low–Medium	High
9	Banana Peel Powder		Grainy, detaches easily	Granular fragmentation	Dispersed micro traces	Very Low	Medium–High
10	Spinach		Dark green, stains, fades	Chromatic migration + oxidative decay	Temporally legible color erosion	Medium	High

2018). In this study, participants poured within a restricted spatial setting and according to the application protocol described above. Because individual pours nevertheless differed, participation is treated as an observed source of variability in deposit thickness, flow path, and drying, not as a controlled variable. Participation was not quantitatively tracked; its effects were evaluated qualitatively by comparing the time-stamped photographic records of the surfaces, and no causal relationship between participant movement and specific surface changes is claimed. This reading resonates with participatory scholarship in architecture, which emphasizes what participation produces within experimental practices (e.g., new relations, new artifacts, new spatial arrangements) instead of treating participation as a representational add-on (Royer, 2022), and with longitudinal accounts in which participation is evaluated through experience and its impact on social interaction and spatial use (Loiseau et al., 2022). Accordingly, the pouring gestures are treated as a repeatable participatory protocol whose effects on the surface are reported descriptively (Bennett, 2025; Loiseau et al., 2022; Robson, 2023; Royer, 2022).

RESULTS

This section reports the empirical results of Sta!ned as a practice-based architectural research project investigating the formation of surfaces through biomaterials in a public indoor environment. These results have been obtained through cycles of biomaterial preparation, pouring, observation, and participation. These observations have been recorded in photographs, time-lapse recordings, as well as comparisons of surface characteristics.

Biomaterial Research, Experimental Tests, and Formulation Development

The screening phase evaluated the suitability of pigments and residues obtained from food waste for gravity-based applications in interior settings. This was based on the following criteria for which the materials would be disqualified: (i) the production of pungent smells and instability for interior applications, (ii) inability to pour the material uniformly in a standard manner, and (iii) the rate of color degradation leading to reduced legibility of the surface. The residues evaluated in the screening phase included those obtained from tomatoes, spinach, citrus fruits, beetroot, purple cabbage, coffee ground residues, tea leaf residues, plum residues, cumin seed residues, banana peel residues, and eggshell residues (Figure 1). Based on the results of the screening phase, the next phase evaluated the following ten biomaterial compositions for various applications in four principal color ranges and varied physical properties: turmeric, beetroot, purple cabbage (peel and juice), coffee ground residues (I-III), banana purée, banana peel powder, and spinach.

Figure 1. Biomaterial Research Process and Experimental Samples.

Table 1 identifies four recurring biomaterial behavior patterns based on layer overlap and lateral spread: (1) flow retention with stratification, (2) weak adhesion with surface separation, (3) high fluidity with pigment migration, and (4) pigment-dominant yet structurally variable compositions. The four analytical categories cut across these formulation-level patterns, as set out below. These results demonstrate that biomaterials actively generate differentiated surface conditions through their flow, adhesion, and temporal transformation, rather than functioning as passive finishes. Biomaterials have existed at the nexus of material culture studies and the production of knowledge in architecture and biotechnology (De Mol & Vandamme, 2024). All selected formulations were biodegradable, coming from renewable or recovered sources. The criteria included characteristics relevant to architectural surface layer formation, such as viscosity suitable for controlled pouring, binding ability to textile support, possibility of layer stratification, color stability, and migration, or changes over time under indoor humidity flow and air currents (Figure 2).

Within contemporary architectural research, biomaterials have moved beyond their initial framing as sustainable alternatives toward being understood as operative architectural systems whose material behavior actively contributes to spatial production. Bio-digital architectural studies have articulated how living and bio-based materials can act as generative agents, embedding metabolic processes, growth, and decay directly into architectural logic rather than treating biological activity as an external constraint (Pasquero & Poletto, 2020; Valenti & Pasquero, 2021). Parallel experimental research on bacterial cellulose and biologically active composites has demonstrated how such materials can be deployed as performative surface and skin systems, where flexibility, environmental responsiveness, and temporal transformation constitute design-relevant parameters (Massoud et al., 2024; Turhan-Haskara et al., 2024). Within the built environment discourse, engineered living materials further establish a methodological bridge between biological activity and architectural performance, positioning biomaterials as a legitimate subject of architectural research rather than material novelty (Proksch, 2024). At the interior scale, studies on mycelium-based composites and digitally fabricated bio-based components show how biomaterials

Figure 2. Experimental Material Responses, Biomaterial Samples and Formulations Mock-up.

can be systematically integrated into architectural assemblies through controlled fabrication protocols and spatial testing (Özkan & Güzelci, 2025). Taken together, these contributions consolidate biomaterials as architectural agents mediating form, surface behavior, and environmental interaction, providing the conceptual and methodological foundation upon which the present study builds.

In all the formulations, the successive layering was cumulative in its contribution to the deposition, but the degree of layering, adhesion, and diffusion differed among the formulations. This was helpful in making comparisons of the readings of surface formation (Table 1). The compositional ratios are shown in detail in Supplementary Table S1, whereas the comparative physical, temporal, and epistemic properties are shown in Supplementary Table S2.

Read against the four analytical categories (Table 1; Supplementary Table S2): in Flow and Retention, purple cabbage juice, banana purée and peel, and spinach spread widely, whereas Coffee Grounds I and purple cabbage peel stayed close to the point of deposition; in Adhesion and Separation, the same three formulations adhered strongly, while beetroot and banana peel powder detached easily after drying; in Temporal Durability, only purple cabbage juice and Coffee Grounds I were rated high in stability; and in Layered Surface Formation, earlier layers remained most visible under turmeric and Coffee Grounds I and least under purple cabbage peel and banana peel powder.

Throughout the observation period, all formulations showed time-dependent variation that was readable on the textile substrate. The most frequent patterns of transformation were:

- Drying and setting properties: Drying rate differences appeared as early setting (fast-setting) and delayed flow and diffusion (slow-setting).
- Cracking patterns were varied, ranging from fine, diffused micro-cracking to larger, discontinuous fracture patterns, depending on viscosity, pigment content, and binder ratio.
- Surface Detachment: The detachment process mostly occurred where the formulation had lower adhesive strength, which resulted in patchy deposits.
- Chromatic variation: there was chromatic variation in several formulations, in the form of pigment migration, fading, or oxidative tone changes.
- Biodegradation markers: odor formation and the growth of microorganisms were monitored in test formulations.

These results were recorded by means of timed photographic shots and time-lapse photography done at immediate, 24-hour, and 7-day intervals in order to facilitate comparisons regarding transformation sequences. Before their usage during the installation phase, the samples were kept for observation for three weeks, during which the outcomes of stability, such as the change in viscosity, color, smell, and growth of molds, could be marked, as follows:

- Class I: low fluidity, high density, slow drying rate, lower pigment retention.
- Class II: Has high fluidity, low density, and translucency characteristic of thin fabrics.
- Class III: Viscosity and flexibility are well balanced; chromatic saturation and operational stability are increased.

As a result, that Class III findings were most consistent with controlled pouring and layering under interior conditions. These observations played a role in the last modification to formulations prior to application.

Textile Material Research

This section explains how different types of fabric affect dripping, flow, and fixation of biomaterials in order to control visualizations of depth, stratification, and temporal unfolding in the installation setting.

Five fabrics of three major types, namely tulle, chiffon, and canvas, were chosen for their differences in permeability and flow properties (Figure 3). Thus, tulle facilitated fast dripping and heavy fixation, chiffon allowed for light-

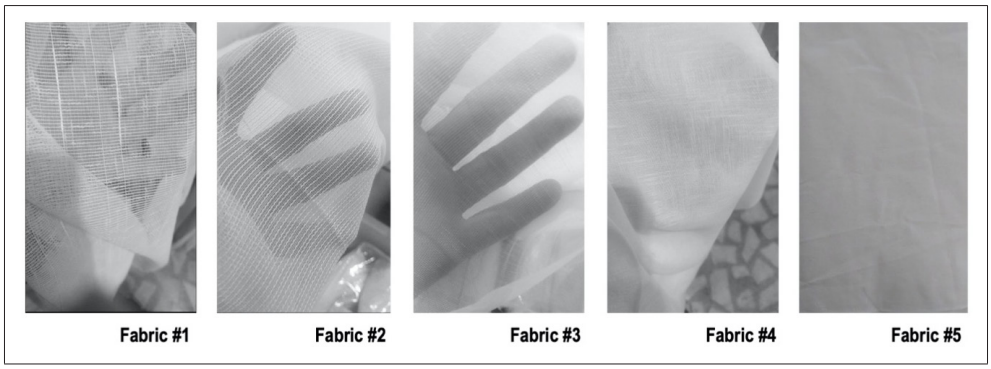

Figure 3. Fabric Tests and Material–Textile Interaction.

er and continuous flow, and canvas served as a support for the eventual fixation of pigments, enabling transient processes to be translated into permanence. Under all experimental scenarios, marked differences in biomaterial flow were found, depending upon viscosity, setting in a dynamic relation between biomaterial properties and textile properties. Biomaterial properties were found to display life-like qualities, in terms of odor, mold, viscosity, and pigments, reinforcing that production as a continuous investigational process represents a series of processes rather than a recipe. Across the five fabrics, different regimes of dripping were identified, from flow traces and rhythmic dripping to sedimentation, pigment deposition, and permanent fixation. The analysis of the relationship between textile permeability and biomaterials behavior shows that textile surface porosity plays a direct role in staining, layer formation, and material sedimentation. Compact textile surfaces enhance fixation and accumulation, whereas relatively permeable textile surfaces facilitate diffusion and the dispersal of pigments. Such negotiations in materials, as a result of absorption, resistance, and flow, form a textile register where the "palimpsestical" order of the work appears.

Project Implementation Process

The project, whose visual identity is shown in Figure 4, unfolded as a non-linear research process in which material experimentation, spatial configuration, and participant interaction occurred simultaneously. Rather than following a sequential workflow, spatial definition emerged through iterative testing of viscosity, color diffusion, and drying behavior. The Sta!ned installation employs a modular, vertical, and lightweight structure that enables stratification, where overlapping, semi-transparent layers regulate diffusion and accumulation.

Figure 4. Visual Identity of the Project.

The sacks above serve as the release points for dripping, and variations in textile properties manage exposure, absorption, and pigment retention at different spatial planes (Figures 5 and 6).

Structural Assembly Process

The structure was built as a digitally coordinated modular system of five dismantlable wooden units (M1-M5) (Figures 6-8). Metal grids in the upper levels and semi-permeable platforms regulated the vertical flow of biomaterial between layers (Figure 9), while the textile components defined different permeability thresholds. The reversible construction allowed the structure to be dismantled and reassembled across successive exhibitions.

The structural assembly was conceived not as a neutral exhibition support but as part of the research method. Pouring height, vertical sequencing, permeability gradients, and deposition areas were fixed by the structure, which provided a stable spatial setting within which material and environmental processes could be observed systematically.

Pigment layers accumulated through successive applications, each activating prior deposits. Weekly dripping sessions

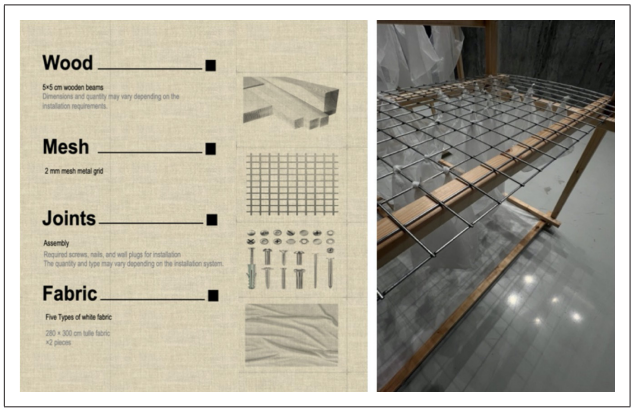

Figure 5. Prototype Development and Early Material Applications.

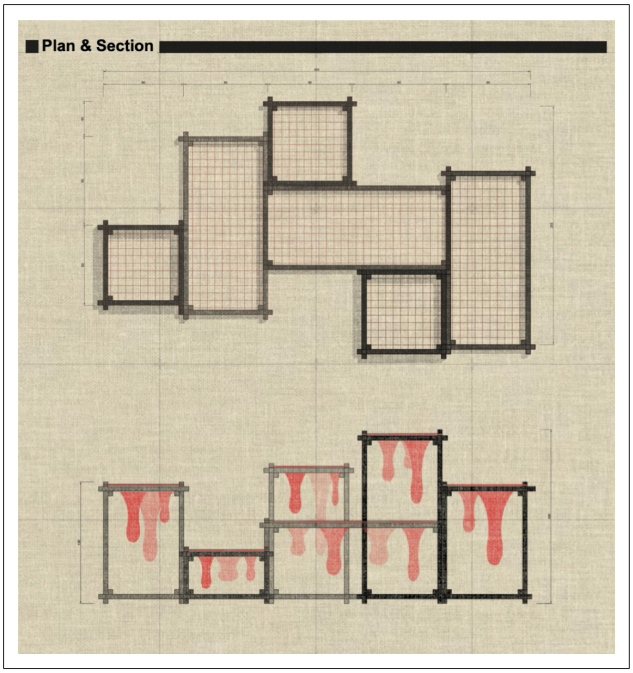

Figure 6. Spatial Arrangement and Layered Structure Formation.

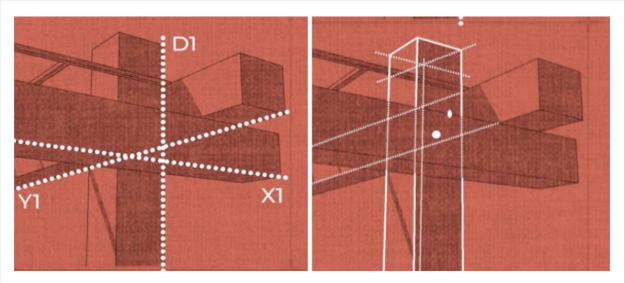

Figure 7. Structural Assembly Process: Modular Wooden Framework.

introduced participation and further variability, while drying, cracking, and coloration produced a palimpsest shaped by material behavior, time, and environment. Over three months, the system remained in continuous transformation, forming a temporally adaptive interface defined by deposition, erosion, and change. A time-based release system using biomaterial cartridges generated variations in viscosity, flow, and color, directly affecting surface formation. Participation was thus registered materially in the evolving surface.

Figures 10 and 11 present the final structure during the exhibition, with material deposited at multiple levels and flowing toward the canvas surfaces.

These results address RQ2 by demonstrating that spatial configuration itself can be operationalized as a methodological variable, stabilizing experimental conditions while allowing material behavior to remain dynamic and comparable across time.

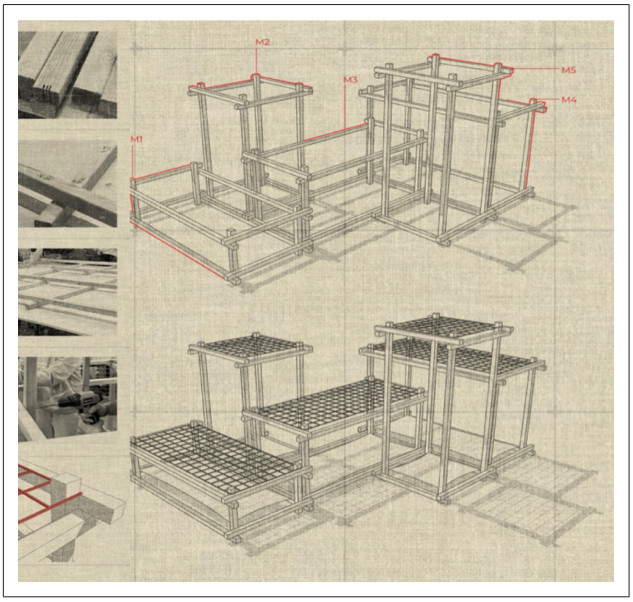

Figure 8. Installation Process: Material Application onto Textile Layers.

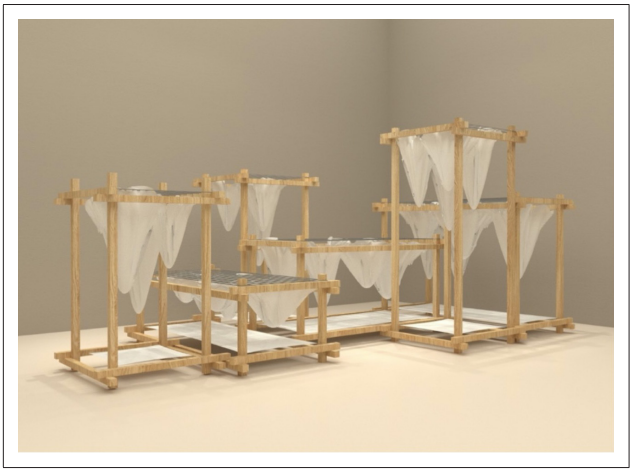

Figure 9. Render Image - Grid System and Textile Suspension.

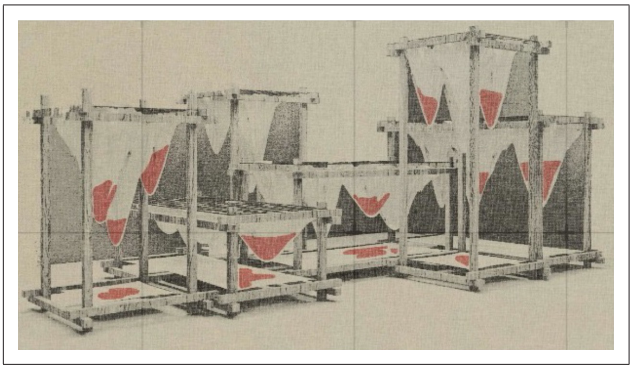

Figure 10. Surfaces Demonstrating Layer Formation.

Figure 11. Assembly and Exhibition: Day One of Dripping Cycles and Layer Accumulation.

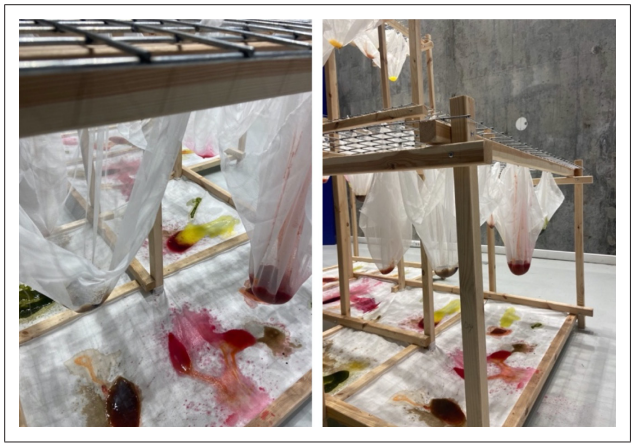

Figure 12. Collective Layer Formation.

Figure 13. Participant Interaction.

Participatory Process During Exhibition of the Spatial Installation

The participatory drip actions are documented in Figures 12 and 13, which show visitors' pours being added to the cumulative stratification. Each pour produced its own local flow pattern and deposit, which was then incorporated into the stratified surface. Participation is hence recorded not as a symbolic trace but as material deposited under gravity and ambient conditions.

With each iteration of observation and operation, the system demonstrated recursive transformation, where each new deposit interacted in some way with the pre-existing layers, whether it be by blending, occluding, cracking, and/or detaching. The surface developed here is a temporally layered material archive, recording traces of interaction rather than individual marks. It is through such a process that the installation receives the ability to become an interior-scale architecture, where collective activity is continually worked back into the material processes, and the formation of the surface becomes understood as an effect of procedural development and situated activity. Figure 13 shows participants dripping material onto the surfaces. Individual pouring actions differed, and the resulting deposits varied in flow, layer thickness, and drying; these differences contributed to stratification rather than producing symbolic traces. The installation constitutes an interior-scale environment in which spatial conditions are continuously produced through the interaction of material properties and human presence, with layered surfaces acting as records of these processes. Participation was not quantitatively measured: its effects were assessed only qualitatively, through photographic comparison of deposition, flow, and drying, and they cannot be separated from those of formulation, substrate, and environmental conditions. Participation is therefore reported as an observed source of variability rather than as a controlled variable, which is a limitation of the study.

DISCUSSION

The results of Sta!ned show that installations realized using biomaterials can become architectural research devices, within which the process of material transformation becomes a dynamic factor for space generation, rather than a secondary or representative result.

The internal environment factors, which include humidity, temperature, air current, and light, have a direct effect on

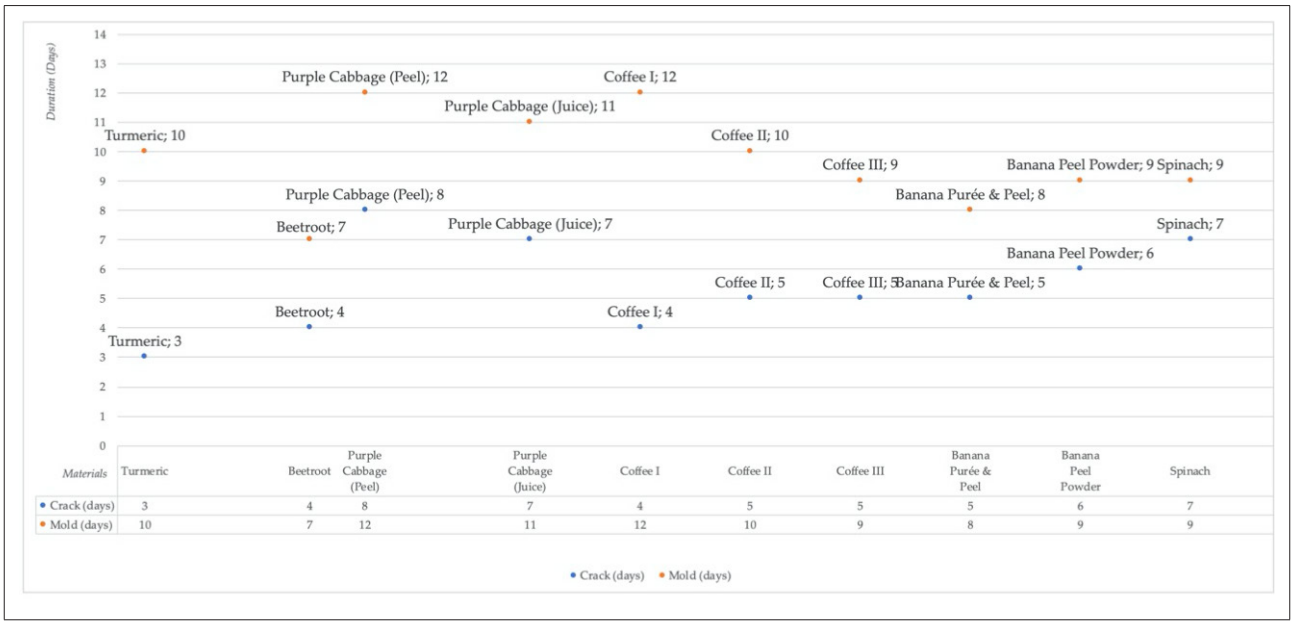

Figure 14. Temporal distribution of crack formation and first visible mold growth across ten biomaterials.

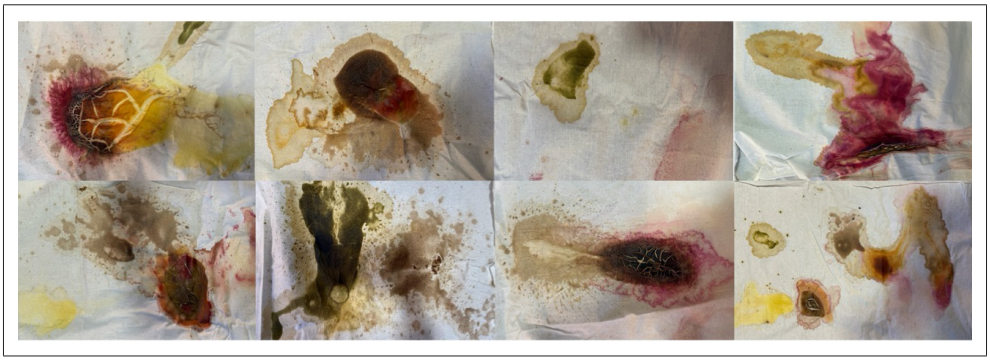

Figure 15. Surface Samples Showing Layer Formation and Material Transformation.

drying rate, pigment migration, formation of cracks, and sedimentation processes. Instead, the role of these environmental factors as external modifiers that act on the preformed object shifts to becoming an internal factor within the spatial system, thus placing the site in the role of a participant as an environment factor.

Moreover, in this model, time is conceptualized not as something that is externally applied from without upon space, but as a functional space dimension that continuously regulates surface behavior and spatial effects. The value of this study lies not within a singular installation, as it offers a repeatable and protocol-driven architectural research system that formalizes material formation, exposure, protocol-guided participation, and documentation as a systemizable whole. Accordingly, this study is pertinent within a methodological architectural research paradigm, wherein systematic procedures, such as simulation-informed evaluative procedures, are employed as a means of producing commensurable evidence and informing architectural practices (Balafoutis, 2025). In the present research, repeatability is secured through (i) explicit formulation ratios and deposition rules, (ii) controlled environmental observation intervals, (iii) standardized photographic documentation enabling temporal comparison, and (iv) a bounded participatory input, where pouring gestures follow a common protocol. While the proposed protocol does not seek to generalize biomaterial behavior across all interior contexts, it establishes a comparative architectural framework through which material-driven surface formation can be systematically observed, documented, and evaluated under varying interior atmospheric conditions. From such a point of view, sustainability is conceptualized as a design logic immanent in material cycles of use and re-entry, rather than in ethical assertions and symbolic statements external to design itself (McDonough & Braungart, 2002). This kind of design logic is in line with process-based philosophies of spatial production that emphasize material change and practices rather than representational outcomes (Thrift, 2008). The interior

space, therefore, can be understood not merely in terms of geometry and enclosure but in terms related to atmospheres arising out of material properties and bodily perceptions—stopping short of architectural theories which define atmosphere as medium rather than effect (Böhme, 2017).

Throughout the three-month period of observation, the deposition processes caused the formation of stratified surfaces, which were simultaneously sites of accumulation, erosion, and reactivation. The occurrence of cracking, which made known the layers of the stratified surface before the deposition, represents the non-linear logic of the formation of the surface itself, which did not follow the logic of progress but rather the logics of accumulation and cracking. In various studies using engineered living materials and biomaterial composites, the ability of biologically active systems to maintain integrity amidst environmental changes, which attest to the notion of biomaterial systems having performative potential rather than being passive material substrates, has been observed and described (Geng et al., 2024; Quijano et al., 2025).

Three mechanisms link these material processes to spatial production. First, sedimentation and retention: on canvas, pigment settled and fixed, so that successive pours thickened the surface, whereas on tulle and chiffon the material passed through or diffused and the layer remained thin. Because the textiles hung as overlapping, semi-transparent layers, these differences changed how much of the layers behind remained visible, and therefore the perceived depth of the installation. Second, cracking and detachment exposed earlier deposits, so that the surface showed several stages of its formation at once. Third, biodegradation—odor, chromatic change, and visible mold growth (Figure 14)—altered the olfactory and visual character of the interior beyond the plane of the surface. In each case a material process changed a spatial property (visual depth, legibility of layers, atmosphere) without any change in the geometry of the structure. These links rest on photographic documentation and direct observation; they were not measured instrumentally.

Surface and 'skin' systems have been theorized as performative interfaces that mediate environmental and experiential conditions, rather than as static finishes—an approach that frames interior surface behavior as an operative design parameter (Addington & Schodek, 2005; Wigginton & Harris, 2002; Wu, 2018). Reading interior surface formation through a performative lens positions material behavior and environmental mediation as design drivers rather than representational effects (Kolarevic & Malkawi, 2005).

Positioned within established accounts of practice-led inquiry, the Sta!ned installation is advanced here as a mode of architectural research in which making and observing are treated as primary knowledge-producing operations rather than as representational outputs (Frayling, 1993). By structuring the work as a protocol-led, single-case, longitudinal investigation—where the "case" is the interior-scale surface system and its time-variant behavior—the study aligns with architectural research method frameworks that legitimize systematic observation, documentation, and comparative interpretation as valid architectural evidence (Groat & Wang, 2013). Read through performance-oriented architectural discourse, the findings further support the claim that spatial outcomes can be understood as emergent effects of coupled material–environment processes, where performance is generated through interaction and temporal transformation rather than fixed form (Hensel, 2010).

Figure 14 plots two events for each of the ten formulations on a common time axis, counted in days from pouring (day 0): the first visible crack and the first visible mold growth, under ambient interior conditions (18–24°C; 60–75% relative humidity). Each formulation first dried (average drying time 10–36 hours) and then cracked, between day 3 (turmeric) and day 8 (purple cabbage peel). Visible mold followed between day 7 (beetroot) and day 12 (purple cabbage peel and Coffee Grounds I). The interval between cracking and mold ranged from two days for spinach (days 7 and 9) to seven days for turmeric (days 3 and 10) and eight days for Coffee Grounds I (days 4 and 12); for the remaining formulations it was three to five days. The sequence of drying, cracking, and biological activity was therefore common to all formulations, while its pace was formulation-specific; the interval marks the threshold at which physical transformation passes into biochemical change. Staining, cracking, and degradation thus operate as readable indicators of material response, allowing time to be encoded within the surface as an observable and comparable condition rather than as a symbolic construct.

The use of biomaterials from food waste situates the formation of surfaces into the larger metabolic processes of consumption, transformation, and decay. Far from being a symbol of sustainability, this installation actualizes it through material processes that are visibly reactive to environmental and human inputs. The engagement of the public through pouring introduces a further, observed source of variation in deposition thickness, flow pathways, and rates of drying. Because this variation was not quantitatively tracked, human presence is considered here a contributing condition of the system rather than a controlled parameter.

Figure 15 presents representative surface samples resulting from prolonged deposition and transformation cycles. Variations in viscosity, evaporation rate, substrate permeability, and environmental exposure produced differentiated patterns of diffusion, discoloration, fiber penetration, and crystallization. These outcomes confirm that layered surface formation emerges from the interaction of material properties, atmospheric conditions, and repeated application, generating quantifiable patterns of temporal stratification. Such patterns enable comparative evaluation across

formulations and substrates, reinforcing the role of biomaterials as analytical tools for studying time-based surface processes in interior architectural contexts.

However, this research deviates from experiments conducted in material science as it neither isolates variables within a controlled lab setting nor aims to normalize variables such as expression or symbolism, as is the case with art installations. The novelty of this research is based on creating a research environment within architecture that utilizes formulation, atmospheric exposure, and configuration as interconnected variables, together with protocol-guided participation. In this case, architectural knowledge is derived from making as well as observation at the interior level, which allows for the translation of time-related material properties into transferable insights at the interior level. As these effects are registered by bodily experience—the proximity, movement, and atmospheric change—the installation comes to be conceived as an interior architectural condition rather than a visual object per se (Pallasmaa, 2009). Architecturally speaking, the fragility and temporal flux of biomaterials pose a problem to the assumptions about the production and display of space in general. Instability, degradation, and transformation are no longer problems to be solved but conditions to be accommodated in architectural terms. Thus, the installation becomes a temporal architectural environment in which the surfaces are always receptive to change rather than being fixed in completion. In this way, stratification becomes an effect of the interaction between material agency, environment, and human action, which provides a model for architectural research in which process, temporality, and materiality take center stage.

CONCLUSION

This research establishes the potential of biomaterials to act as active architectural material systems capable of directly engaging with the production of space through time-variant processes of transformation, rather than merely acting as sustainable materials or representational surfaces. Through a systematic observation of the phenomena of flow, drying, cracking, pigment diffusion, sedimentation, degradation, and microbiology in interior climatic conditions, the project establishes these phenomena to be operative in a way that the resultant surface properties are measurable and comparable. In other words, time is introduced in material systems as an internal architectural variable to facilitate the creation of stratified surfaces with inherent spatial properties.

Methodologically, the work establishes a formal procedure for practice-led architectural research that combines the formulation of biomaterials, exposure to the environment, observation over time, and protocol-guided participation. The demountable and modular structure allows for the repetition of experiments under fluctuating interior conditions, and the photographic documentation allows for the observation of the material transformation. Accordingly, the proposed procedure can be applied to other architectural experiments that include material reactivity, environmental response, and timescale as relevant parameters at the interior scale.

Aside from the specificity of the case study, the results indicate an architectural model in which spatial outcomes emerge through the interaction of three interrelated factors:

Biomaterials Performance × *Temporal Process* × *Participatory Spatial Input*

With material agency understood in this operational sense, spatial memory is described not as a fixed entity, but as the material condition produced by the interaction between biological matter and activity, and the geological forces of the natural environment and constructed architecture. The stratified surfaces achieved in the installation can thereby be seen as material registers, signifying the process of accumulation, erosion, and activation, as an architectural reading of stratification.

Participation in the system is organized through a pouring protocol rather than as expressive or symbolic involvement. Pouring gestures were observed to vary the paths and drying of the deposits, but this effect was not quantitatively tracked: the study does not establish a causal relationship between participant movement and surface change, and this is acknowledged as a limitation. Human involvement is thus part of the logic of formation in the system, and measuring its contribution remains a task for future work.

The contributions of this research can be outlined as follows:

(1) Conceptual Contribution

- Repositions biomaterial transformation as an operative architectural parameter, rather than a secondary or representational surface condition, in the production of interior architectural space.
- Frames stratification as an empirically identifiable, time-dependent architectural condition, shaped by environmental and operational factors rather than symbolic intent.

(2) Methodological Contribution

- Establishes a replicable, practice-based architectural research protocol that integrates biomaterial formulation, longitudinal observation, environmental exposure, and protocol-guided participation.
- Proposes an analytical framework that systematically relates material-level behavior to temporal surface formation at the interior architectural scale.

(3) Practical Contribution

- Demonstrates the architectural viability of food-waste-derived biomaterials for responsive interior surface systems.

- Provides transferable insights into material durability, substrate interaction, and assembly logics relevant to temporally adaptive architectural systems.
- Offers actionable perspectives for architects and designers seeking to integrate process-oriented and environmentally responsive biomaterials into interior architectural practice.

Taken collectively, the results of this research indicate that the installations utilizing biomaterials, viewed through the lens of an architectural framework, represent an environment where the process of space formation occurs through the interaction of behavior, environment, and the intervention of human factors. This work, therefore, offers an important contribution to the literature in the realm of architecture.

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REFERENCES

Achten, H. (2019). Interaction narratives for responsive architecture. *Buildings, 9*(3), Article 66. https://doi.org/10.3390/buildings9030066

Addington, D. M., & Schodek, D. (2005). *Smart materials and technologies: For the architecture and design professions*. Routledge.

Balafoutis, T. (2025). Architectural lighting simulations as a method to evaluate emotions on cultural heritage building facades. *Architecture, 5*(1), Article 3. https://doi.org/10.3390/architecture5010003

Beesley, P. (2010). *Hylozoic ground: Liminal responsive architecture*. Riverside Architectural Press.

Bennett, J. (2025). Relational resilience and reparative design: Participatory practices and the politics of space in post-apartheid Johannesburg. *Architecture, 5*(4), Article 111. https://doi.org/10.3390/architecture5040111

Böhme, G. (2017). *Atmospheric architectures: The aesthetics of felt spaces*. Bloomsbury Academic.

Chayaamor-Heil, N., Houette, T., Demirci, Ö., & Badarnah, L. (2024). The potential of co-designing with living organisms: Towards a new ecological paradigm in architecture. *Sustainability, 16*(2), Article 673. https://doi.org/10.3390/su16020673

Collet, C. (2017, December 18). *Co-designing with natural living systems* [Conference presentation]. Geographies of Fashion and Style, University of Bristol, Bristol, United Kingdom. https://ualresearchonline.arts.ac.uk/id/eprint/12304/

Costa Maia, S., & Meyboom, A. (2015). Interrogating interactive and responsive architecture: The quest of a technological solution looking for an architectural problem. In G. Celani, D. M. Sperling, & J. M. S. Franco (Eds.), *Computer-aided architectural design futures: The next city – New technologies and the future of the built environment* (pp. 93–112). Springer. https://doi.org/10.1007/978-3-662-47386-3_6

De Mol, M. L., & Vandamme, E. J. (2024). Arts, cultural heritage, sciences, and micro-/bio-/technology: Impact of biomaterials and biocolorants from antiquity till today! *Journal of Industrial Microbiology and Biotechnology, 51*, Article kuae049. https://doi.org/10.1093/jimb/kuae049

Dunne, M. (2018). *Bioplastic cook book*. Fab Textiles, Institute for Advanced Architecture of Catalonia. https://issuu.com/nat_arc/docs/bioplastic_cook_book_3

Frayling, C. (1993). Research in art and design. *Royal College of Art Research Papers, 1*(1), 1–5. https://research.rca.ac.uk/en/publications/research-in-art-and-design-royal-college-of-art-research-papers-v/

Geng, Y., Jia, Z., & Li, L. (2024). Structural engineered living materials. *Nano Research, 17*(2), 715–733. https://doi.org/10.1007/s12274-023-6313-7

Groat, L. N., & Wang, D. (2013). *Architectural research methods* (2nd ed.). Wiley.

Hensel, M. U. (2010). Performance-oriented architecture: Towards a biological paradigm for architectural design and the built environment. *FORMakademisk, 3*(1), 36–56. https://doi.org/10.7577/formakademisk.138

Jones, M., Mautner, A., Luenco, S., Bismarck, A., & John, S. (2020). Engineered mycelium composite construction materials from fungal biorefineries: A critical

review. *Materials & Design, 187*, Article 108397. https://doi.org/10.1016/j.matdes.2019.108397

Kolarevic, B., & Malkawi, A. (Eds.). (2005). *Performative architecture: Beyond instrumentality*. Routledge.

Loiseau, B., Safin, S., & Tufano, A. (2022). Promoting social interaction through participatory architecture: Experimentation, experience, evaluation in a social housing complex (Grand'Goule, Poitiers, 1974–2021). *Architecture, 2*(2), 383–405. https://doi.org/10.3390/architecture2020021

Massoud, P., AbouSeada, N., Saada, A. M., & Zolfakkar, M. (2024). Creating sustainable and flexible architectural skin with microbial cellulose-based material: Synthesis and mechanical characterization. *Journal of Umm Al-Qura University for Engineering and Architecture, 15*(4), 455–466. https://doi.org/10.1007/s43995-024-00068-y

McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things*. North Point Press.

Menges, A. (2012). Material resourcefulness: Activating material information in computational design. *Architectural Design, 82*(2), 34–43. https://doi.org/10.1002/ad.1377

Oxman, N. (2016). Age of entanglement. *Journal of Design and Science*. https://doi.org/10.21428/7e0583ad

Özkan, M., & Güzelci, O. Z. (2025). Mycelium-based composites for interior architecture: Digital fabrication of acoustic ceiling components. *Biomimetics, 10*(11), Article 729. https://doi.org/10.3390/biomimetics10110729

Pallasmaa, J. (2009). *The thinking hand: Existential and embodied wisdom in architecture*. Wiley.

Pasquero, C., & Poletto, M. (2020). Bio-digital aesthetics as value system of post-Anthropocene architecture. *International Journal of Architectural Computing, 18*(2), 120–140. https://doi.org/10.1177/1478077120922941

Proksch, G. (2024). Engineered living materials (ELMs) for the built environment. In *112th ACSA annual meeting proceedings: Disruptors on the edge* (pp. 35–44). ACSA Press. https://doi.org/10.35483/ACSA.AM.112.4

Quijano, L., Fischer, D., Ferrero-Regis, T., & Navone, L. (2025). Exploring bacterial cellulose as an engineered living and programmable biomaterial across disciplines through qualitative thematic analysis. *Scientific Reports, 15*, Article 17980. https://doi.org/10.1038/s41598-025-01931-1

Rendell, J. (2006). *Art and architecture: A place between*. I.B. Tauris.

Robson, E. (2023). Assessing the social values of built heritage: Participatory methods as ways of knowing. *Architecture, 3*(3), 428–445. https://doi.org/10.3390/architecture3030023

Roes, R., & Snowdon, P. (2018). Conversations between interiors. *Journal of Interior Design, 43*(1), 65–77. https://doi.org/10.1111/joid.12113

Royer, M. (2022). What participation creates in experimental design practices: The case of a mobile third place built in a retirement home. *Architecture, 2*(1), 53–66. https://doi.org/10.3390/architecture2010004

Salama, A. M., & Patil, M. P. (2025). The socius in architectural pedagogy: Transformative design studio teaching models. *Architecture, 5*(3), Article 61. https://doi.org/10.3390/architecture5030061

Thomsen, M. R., & Tamke, M. (2022). Towards a transformational eco-metabolistic bio-based design framework in architecture. *Bioinspiration & Biomimetics, 17*(4), Article 045005. https://doi.org/10.1088/1748-3190/ac62e2

Thrift, N. (2008). *Non-representational theory: Space, politics, affect*. Routledge.

Till, J. (2009). *Architecture depends*. MIT Press.

Tonin, P. E., & Ferrara, M. (2025). Olfactory attribution circle (OAC): Designing crossmodal congruence between scent, color, and language. *Architecture, 5*(4), Article 121. https://doi.org/10.3390/architecture5040121

Treacy, G. (2025). Harvesting atmospheres—Exploring atmospheric elements in spatial design. *Architecture, 5*(4), Article 126. https://doi.org/10.3390/architecture5040126

Turhan-Haskara, G. D., Neseliler, P., & Akgun, Y. (2024). Exploration of bacterial cellulose-based biofilms for compliant mechanisms in adaptive façade applications. In P. Block, G. Boller, C. DeWolf, J. Pauli, & W. Kaufmann (Eds.), Proceedings of the IASS 2024 Symposium: Redefining the art of structural design (pp. 1–10). International Association for Shell and Spatial Structures. https://app.iass2024.org/files/IASS_2024_Paper_186.pdf

Valenti, A., & Pasquero, C. (2021). The second life of micro-organisms: Bio-digital design for a new ecology of space and behaviour. *AGATHÓN | International Journal of Architecture, Art and Design, 9*, 42–53. https://doi.org/10.19229/2464-9309/942021

Wigginton, M., & Harris, J. (2002). *Intelligent skins*. Routledge.

Wu, J. (2018). Ruga Lumina: Folding interior skin with dynamic light. *Journal of Interior Design, 43*(2), 55–63. https://doi.org/10.1111/joid.12123

Supplementary Table S1. Detailed Biomaterial Recipes and Preparation Protocols

No	Material	Recipe Composition	Preparation Protocol	Drying / Setting Characteristics
1	Turmeric	70 ml water; 5 tsp corn starch; 2 tsp glycerin; 2 tsp gelatin; 20 g turmeric powder	Turmeric powder is mixed with water; starch, glycerin, and gelatin are added. The mixture is heated while stirred for 1 minute until homogeneous. Poured onto flat surface.	Dries to gel-like, matte, slippery layered surface
2	Beetroot	50 ml water; 5 tsp corn starch; 2 tsp glycerin; 2 tsp gelatin; 1 beetroot	Beetroot scraps washed, chopped, blended into purée. Other ingredients heated; purée added. Mixed for 1–2 minutes and poured onto surface.	Matte, grainy surface; easily separable after drying
3	Purple Cabbage (Peel Mix)	400 ml water; 30 g starch; 25 g glycerol; 60 ml vinegar; purple cabbage peels	All ingredients mixed; cabbage peels added and boiled for 1 minute.	Thick, rigid, low pourability due to low water content
4	Purple Cabbage (Juice Mix)	300 ml cabbage juice; 30 g starch; 25 g glycerol; 60 ml vinegar	Cabbage juice strained. All ingredients boiled for 10 minutes under continuous stirring.	Soft, pourable consistency; light magenta tone
5	Coffee Grounds I	100 ml water; 3 tbsp starch; 1 tsp glycerin; 1 tsp vinegar; 3 tbsp coffee grounds	Coffee grounds added to homogenized mixture. Heated for 10 minutes and dried.	Dark brown, matte, strong pigmentation
6	Coffee Grounds II	50 ml water; 3 tbsp starch; 1 tsp glycerin; 1 tsp vinegar; 1 tbsp coffee grounds	All ingredients homogenized and heated for 10 minutes.	Increased firmness with lower water content
7	Coffee Grounds III	100 ml water; 1 tbsp starch; 1 tsp glycerin; 1 tsp vinegar; 1 tbsp coffee grounds	Ingredients mixed and heated for 10 minutes, then dried on flat textile surface.	Thin, fragile texture; reduced structural cohesion
8	Banana Purée & Peel	100 ml water; 1 tbsp starch; 1 tsp glycerin; 1 tsp vinegar; 3 tbsp banana peel purée	Banana and peel blended into purée, mixed with other ingredients, heated for 10 minutes.	Soft consistency, light coloration
9	Banana Peel (Powder)	70 ml water; 5 tsp starch; 2 tsp glycerin; 2 tsp gelatin; 20 g banana peel powder	Banana peels dried and ground to powder; all ingredients heated and mixed for 1 minute.	Matte, grainy texture; dark yellow tone
10	Spinach	70 ml water; 5 tsp starch; 2 tsp glycerin; 2 tsp gelatin; 20–25 g spinach leaves	Spinach blended into purée; mixed with base ingredients and heated for 1–2 minutes.	Dark green wet tone; lightens as it dries

These biomaterial formulations were developed through iterative experimentation to achieve varying viscosity, chromatic intensity, and temporal transformation behaviors under changing environmental conditions.

Supplementary Table S2. Comparative behavioral characteristics of biomaterial formulations under interior atmospheric conditions

Material	Surface Adhesion Level	Avg. Drying Time	Crack Onset	First Visible Mold Growth	Smell	Temporal Stability	Previous Layer Visibility	Key Epistemic Effect	Material Behavior Category
Criteria	**(Low / Medium / High)**	**(hours)**	**(Day)**	**(Day)**	**(None/ Natural/ Moderate/ High)**	**(Low / Medium / High)**	**(Low / Medium / High)**		
Turmeric	Medium–High	12h	3	10	Natural	Medium	High	Gel-like, matte, slippery, layered surface	Flow retention + layered stratification
Beetroot	Low–Medium	24h	4	7	Moderate	Low	Low	Matte, grainy, detaches easily	Weak adhesion + surface separation
Purple Cabbage (Peel)	Very Low	36h	8	12	High	Low	Very Low	Thick, rigid, difficult to pour	Material resistance + rigidity
Purple Cabbage (Juice)	High	24h	7	11	Moderate	High	Medium	Soft, pourable, chromatic diffusion	High fluidity + pigment migration
Coffee Grounds I	Low	12h	4	12	Natural (low)	High	High	Dark, matte, strong pigmentation	Pigment dominance + surface saturation
Coffee Grounds II	Medium	10h	5	10	Natural	Medium	Medium–High	Water-dependent firmness	Moisture-modulated agency
Coffee Grounds III	Medium	10h	5	9	Natural	Low	Low	Thin, fragile surface	Structural fragility
Banana Purée & Peel	High	16h	5	8	Natural	Low	Low–Medium	Soft, light color	Diluted material agency
Banana Peel Powder	Medium–High	16h	6	9	Natural	Low	Very Low	Grainy, detaches easily	Granular fragmentation
Spinach	High	18h	7	9	Moderate	Medium	Medium	Dark green, stains, fades	Chromatic migration + oxidative decay

Comparative physical, temporal, and epistemic characteristics of ten biomaterials under uniform interior ambient conditions. The table summarizes surface adhesion, average drying time, crack onset, first visible mold growth, olfactory response, temporal stability, previous layer visibility, and associated epistemic effects for each biomaterial. All samples were exposed to uniform interior ambient conditions corresponding to Istanbul spring climate (18–24 °C, 60–75% relative humidity), and all interventions were performed exclusively through pouring.