HTGAA 2026 Individual Final Project Documentation

Pulse Space: Biological Memory Interfaces for Interior Architecture

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1 Section 1: Abstract

Pulse Space investigates how interior surfaces might move beyond instant responsiveness toward long-term biological memory formation. Contemporary smart interiors often use sensors, lighting automation, HVAC control, and computational feedback systems to react quickly to occupancy or environmental conditions. Although these systems can improve comfort, they rarely leave a persistent material trace of human presence or accumulated environmental activity. Pulse Space addresses this gap by proposing a speculative bio-integrated interior system in which physiological or environmental data are translated into gradual biological color transformation within sealed material interfaces. The broad objective is to develop a proof-of-concept living tile that demonstrates visible chromoprotein-based color change under controlled activation, while also framing a future architectural system made from modular bio-responsive panels. The central hypothesis is that inducible chromoprotein expression in a contained non-pathogenic bacterial chassis can serve as a slow material transformation mechanism, producing visible pigment accumulation over time rather than instantaneous digital feedback. The specific aims are to design and validate an inducible AmilCP chromoprotein expression workflow at the micro scale, extend the prototype toward modular microfluidic wall panels at the meso scale, and speculate on future interiors that operate as biological memory systems at the macro scale. Methods include DNA construct design, bacterial chassis selection, inducible gene-expression planning, microfluidic containment design, temporal image documentation, and colorimetric analysis of pigment development.

2 Section 2: Project Aims

Aim 1 — Experimental Aim: Living Tile Prototype

The first aim of my final project is to design and validate a contained living tile prototype capable of producing visible chromoprotein-based color transformation by utilizing DNA construct design, an IPTG-responsive AmilCP expression strategy, non-pathogenic *E. coli* K-12 chassis planning, bacterial culturing protocols, and sealed microfluidic containment strategies. This aim is achievable within the HTGAA framework because it focuses on one core mechanism: controlled visible biological color expression rather than a full architectural installation. Relevant methods include

plasmid design in Benchling, promoter and coding-sequence organization, transformation planning, IPTG induction, temporal photographic documentation, and image-based color analysis. If ordering is possible, the construct could be synthesized through Twist Biosciences or assembled through standard cloning methods using an appropriate educational laboratory strain.

Aim 2 — Development Aim: Modular Biological Wall System

The second aim is to extend the validated living tile into a modular panel system in which multiple sealed biological chambers are connected through a microfluidic distribution layer. This development stage would test scalability, localized activation, panel-to-panel variation, maintenance cycles, nutrient delivery, pigment stability, and replaceable containment modules. A successful Aim 2 would transform the single proof-of-concept tile into a realistic spatial component that could be studied as an interior surface rather than only as a laboratory sample.

Aim 3 — Visionary Aim: Biological Memory in Interior Architecture

The third aim is to propose a long-term architectural paradigm in which interior surfaces function as slow biological memory interfaces. If fully realized, Pulse Space could challenge the dominant model of responsive environments as systems that only sense and react instantly. Instead, it could enable interiors that gradually record collective environmental and physiological patterns through controlled material transformation, opening new research directions for synthetic biology, biodesign, atmosphere studies, and interior architecture.

3 Section 3: Background

3.1 Background and Literature Context

Responsive architecture and smart environments have become important areas of research in human-building interaction. Many current systems rely on sensors, control algorithms, and immediate actuation to adjust lighting, thermal conditions, ventilation, or acoustic parameters. This work has advanced comfort and efficiency, but it also tends to privilege real-time response over long-term material change. As a result, many interiors remain materially passive even when they are computationally responsive.

Synthetic biology and engineered living materials offer a different temporal model. Tang et al. describe how synthetic biology can be used as a materials-design platform, allowing biological systems to produce, organize, or modify material properties over time.[1] Rodrigo-Navarro et al. similarly define engineered living biomaterials as systems that integrate living cells with material matrices in order to produce functions such as sensing, self-repair, production, or environmental response.[2] These studies are relevant because Pulse Space treats biological systems not as decorative motifs, but as active temporal material agents.

[1] Tzu-Chieh Tang et al., "Materials Design by Synthetic Biology," *Nature Reviews Materials* 6 (2021): 332–350, https://www.nature.com/articles/s41578-020-00265-w.

[2] Aleixandre Rodrigo-Navarro et al., "Engineered Living Biomaterials," *Nature Reviews Materials* 6 (2021): 1175–1190, https://www.nature.com/articles/s41578-021-00350-8.

A second relevant body of research concerns microbial pigments and visible chromoproteins. Chromoproteins such as AmilCP can generate visible color in bacterial systems without requiring fluorescence imaging, making them useful for direct visual outputs in synthetic biology workflows.[3] Research on microbial pigment production also shows that biological color can be tuned, produced, and evaluated as a material output.[4] Pulse Space applies this biological capability to an interior design question: whether color-producing living systems can become slow spatial memory interfaces.

3.2 Novelty and Innovation

Pulse Space is novel because it shifts the role of biological color from laboratory readout or industrial pigment production toward spatial memory in interior architecture. Instead of using synthetic biology primarily for sensing, the project uses biological expression as a material transformation mechanism. The project also challenges the assumption that responsive environments must operate through speed, optimization, and real-time feedback. By emphasizing slow pigment accumulation, microfluidic containment, and architectural atmosphere, Pulse Space expands synthetic biology into a speculative design framework for long-duration spatial experience.

3.3 Significance and Potential Impact

The project matters because contemporary interiors increasingly rely on invisible computational systems while their material surfaces remain largely static. This creates a gap between responsive technology and embodied spatial experience: the building may react, but the surface rarely remembers. Pulse Space addresses this gap by proposing a system in which environmental or physiological patterns become materially legible over time. The work could benefit society by encouraging more reflective and less extractive models of smart environments, especially in spaces such as healthcare waiting rooms, recovery settings, educational interiors, or contemplative environments. Scientifically, the project links synthetic biology, microfluidics, and image-based material analysis with spatial design. Technically, it provides a small-scale framework for testing living material interfaces under contained conditions. At the field level, the project suggests that future responsive interiors might be evaluated not only by speed and efficiency, but also by their ability to support memory, reflection, and gradual environmental transformation.

3.4 Ethical Implications

Pulse Space raises ethical questions related to biosafety, physiological data, interpretation, consent, and responsibility. The project uses non-pathogenic biological systems only as contained research organisms, but any living material system introduced into design must be evaluated through the

[3] Josefine Liljeruhm et al., "Engineering a Palette of Eukaryotic Chromoproteins for Bacterial Synthetic Biology," *Journal of Biological Engineering* 12 (2018), https://jbioleng.biomedcentral.com/articles/10.1186/s13036-018-0100-0.

[4] Harshita Singh et al., "Research Progress, Challenges, and Perspectives in Microbial Pigment Production for Industrial Applications – A Review," *Dyes and Pigments* 210 (2023): 110989, https://www.sciencedirect.com/science/article/pii/S0143720822009111.

principle of non-maleficence: it should not expose users, researchers, or the environment to avoidable harm. The use of physiological signals also requires caution. Pulse Space is not a medical diagnostic device, an emotional surveillance system, or a tool for accurately detecting mental states. Physiological data should therefore be treated as abstract environmental input, not as evidence of a person's emotional condition. Justice and responsibility are also relevant because bio-responsive environments could affect users differently depending on access, vulnerability, health status, or cultural interpretation of living systems.

To conduct the project ethically, the biological layer should remain sealed within microfluidic or material containment, with no direct contact between users and engineered organisms. Data collection should be minimized, anonymized, and translated into aggregate non-diagnostic signals whenever possible. The system should include clear language explaining that any visual transformation represents environmental trends, not clinical evaluation. Potential unintended consequences include over-interpretation of color states, anxiety caused by responsive surfaces, maintenance failure, contamination, or normalization of biometric monitoring in interiors. The project may also be wrong in assuming that users will perceive biological memory as meaningful or beneficial; user studies would be needed to evaluate this. Alternatives include cell-free expression systems, freeze-dried biological systems, non-living bio-reactive materials, or fully synthetic pigment-generating substrates.

4 Section 4: Experimental Design, Techniques, Tools, and Technology

4.1 Detailed Experimental Plan and Timeline

1. **Day 1: Define the design objective.** The experimental objective is to validate visible AmilCP chromoprotein expression as the biological color-output mechanism for a contained living tile.

2. **Day 1: Select biological chassis.** A non-pathogenic educational *E. coli* K-12 derivative, such as DH5α or another BSL-1 compatible strain, is selected for safety and accessibility.

3. **Day 1–2: Choose genetic parts.** The planned construct includes an IPTG-responsive promoter, ribosome-binding site, AmilCP coding sequence, terminator, antibiotic selection marker, and compatible plasmid backbone.

4. **Day 2: Design DNA construct.** The construct is organized digitally in Benchling, checked for orientation, part compatibility, restriction sites, coding-sequence integrity, and documentation quality.

5. **Day 2–3: Review construct order strategy.** If synthesis is available, the construct can be prepared as a Twist order; otherwise, it can be planned for Gibson assembly or restriction-enzyme cloning from available parts.

6. **Day 3: Prepare transformation workflow.** Chemically competent *E. coli* cells are prepared or obtained, and transformation conditions are selected according to the host strain and plasmid backbone.

7. **Day 3–4: Transform cells.** The inducible AmilCP plasmid is introduced into the selected bacterial chassis using standard heat-shock or comparable educational transformation methods.

8. **Day 4: Plate transformed cells.** Transformed cells are plated on selective media and incubated under documented conditions.

9. **Day 5: Screen colonies.** Colonies are checked for growth and, if available, confirmed by colony PCR, sequencing, or plasmid verification.

10. **Day 5–6: Start liquid culture.** Verified colonies are grown in selective liquid media to produce enough culture for induction testing.

11. **Day 6: Induce chromoprotein expression.** IPTG is added to the induced condition while an uninduced control is maintained under identical conditions.

12. **Day 6–9: Document temporal color formation.** Cultures are photographed at 0, 12, 24, 48, and 72 hours using fixed lighting, distance, exposure, and background conditions.

13. **Day 7–9: Test sealed chamber visibility.** Induced culture or pigment-producing material is placed in a sealed transparent microfluidic chamber or chamber mock-up to evaluate whether color remains visible through the material interface.

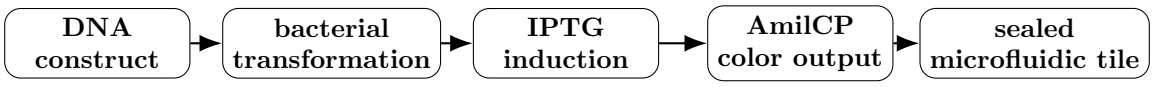
14. **Day 9–10: Analyze images.** Images are analyzed by extracting RGB, HSV, or CIELAB values from a consistent region of interest and calculating color distance from baseline.

15. **Day 10: Compare expected and observed outcomes.** Induced and uninduced conditions are compared for onset time, color intensity, spatial distribution, and stability.

16. **Day 10–11: Evaluate containment.** The chamber is inspected for leakage, visibility, maintenance feasibility, and suitability for later modular wall-panel development.

17. **Day 11–12: Document final results.** Experimental outcomes, limitations, and next-step design decisions are summarized for integration into the final project documentation.

4.2 Experimental Workflow Figure



validation focuses on visible, gradual, contained biological color transformation

4.3 Relevant HTGAA Techniques

Technique area	Relevant checked techniques for Pulse Space
Core laboratory practice	Pipetting; Lab Safety; Bioethical Considerations
DNA design and analysis	DNA Construct Design; Databases; Designing a Twist Order; Registry of Standard Biological Parts
Cloning and verification	Plasmid Preparation; Quality Control / Analysis; DNA Sequencing or colony verification if available
Bioproduction	Chassis Selection; Bacterial Culturing; Bacterial Processing; Bioproduction
Models and notebooks	Benchling; simple image-analysis notebooks for color quantification
Automation and future work	Creating code for laboratory automation; possible Opentrons workflow for liquid handling
Cell-free alternatives	Cell-Free Reactions and Freeze-Dried Cell-Free Systems as future alternatives if live-cell containment becomes impractical

4.4 Expanded Technique Descriptions

DNA construct design. DNA construct design is central to the project because the living tile depends on a controlled genetic system that can produce visible pigment. The construct would include an IPTG-responsive promoter, an AmilCP coding sequence, and a compatible bacterial plasmid backbone. Benchling would be used to document the construct, check sequence orientation, annotate parts, and prepare the design for synthesis or cloning. This technique directly tests whether the project's biological color-output mechanism can be specified as a buildable synthetic biology design.

Bacterial culturing and inducible expression. Bacterial culturing is necessary to maintain transformed *E. coli* cells under controlled laboratory conditions. After transformation, cultures would be grown under selective conditions and induced with IPTG to activate AmilCP expression. The expected result is visible blue-purple pigmentation that increases over time in the induced condition relative to the uninduced control. This technique connects the DNA design to the project's spatial aim by producing a material color change that can be observed, photographed, and eventually embedded within a sealed chamber.

4.5 Associated HTGAA Industry Council Companies

Relevant companies include Addgene for plasmid resources, Twist Biosciences for DNA synthesis, New England Biolabs for cloning enzymes and molecular biology reagents, Thermo Fisher Scientific for laboratory supplies and analytical tools, Opentrons for possible liquid-handling automation, Ginkgo Bioworks for autonomous-lab inspiration, Asimov for design and simulation tools, and Millipore Sigma for media, IPTG, and general laboratory reagents.

5 Section 5: Results & Quantitative Expectations

5.1 Aspect Chosen for Validation

The validation focuses on one aspect of the final project aims: whether an inducible AmilCP chromoprotein expression system can plausibly produce visible biological color transformation over time in a contained material workflow. This validation does not claim to prove the full architectural system. Instead, it tests the core mechanism that supports the larger proposal: controlled biological color accumulation as a slow material output.

Because final architectural integration is beyond the scope of this stage, the validation combines DNA construct design with an expected time-course analysis for visible pigment development. The data may be collected experimentally if lab access and materials are available, or generated as simulated time-course data to evaluate the expected analysis workflow.

5.2 Validation Protocol

1. Select AmilCP as the visible chromoprotein because it can produce blue-purple color under ambient light.
2. Design an IPTG-inducible expression cassette containing promoter, ribosome-binding site, AmilCP coding sequence, terminator, selection marker, and plasmid backbone.
3. Annotate and review the construct in Benchling, checking reading frame, part order, and cloning or synthesis feasibility.
4. Select a non-pathogenic *E. coli* K-12 derivative such as DH5α as the chassis.
5. Transform the construct into competent cells or document the full transformation plan if the experiment is not physically executed.
6. Grow transformed cells under selective conditions and maintain an uninduced control.
7. Add IPTG to the induced condition to activate chromoprotein expression.
8. Photograph samples at 0, 12, 24, 48, and 72 hours under fixed lighting and camera settings.
9. Place induced culture or a safe visual substitute into a sealed transparent chamber to test visibility through the proposed material interface.
10. Extract mean color values from a consistent image region and calculate color change relative to baseline.
11. Compare induced and control samples for visible onset time, pigment intensity, stability, and containment performance.

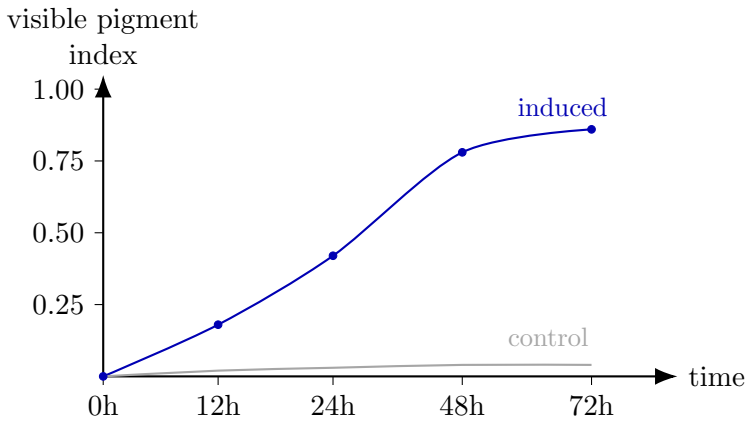
5.3 Synthetic Biology Techniques Used in Validation

The validation uses DNA construct design because the project requires a genetic expression system capable of producing a visible chromoprotein. It uses chassis selection because the biological system must be compatible with a non-pathogenic educational bacterial strain. It uses bacterial culturing and inducible gene expression because AmilCP production depends on viable transformed cells and controlled IPTG activation. It also uses quality-control and analysis techniques, including sequence annotation, photographic documentation, and colorimetric image analysis, to evaluate whether visible transformation occurs over time. Bioethical considerations and lab safety are included because the system involves engineered organisms and must remain contained.

5.4 Simulated Data and Analysis

The table below presents a simulated expected dataset for visible pigment development. The pigment index is an illustrative value from 0 to 1, where 0 represents no visible chromoprotein accumulation and 1 represents strong visible pigmentation. The values are not presented as completed experimental measurements; they define the expected analysis structure and the type of quantitative evidence that would be collected or compared during validation.

Time	**Induced pigment index**	**Control pigment index**	**Expected observation**
0 h	0.00	0.00	Baseline; no visible blue-purple pigmentation.
12 h	0.18	0.02	Faint local pigmentation may begin in induced sample.
24 h	0.42	0.03	Visible blue-purple expression becomes legible.
48 h	0.78	0.04	Stronger pigment accumulation and clearer spatial distribution.
72 h	0.86	0.04	Pigment approaches stabilization or saturation.



A simple quantitative metric for image analysis is color distance from the baseline image:

$$\Delta E_t = \sqrt{(L_t - L_0)^2 + (a_t - a_0)^2 + (b_t - b_0)^2}$$

where L, a, and b are CIELAB color coordinates measured from the same region of interest over time. A successful validation would show increasing color distance in the induced condition, minimal change in the control condition, visible pigment onset within the expected time window, and no visible leakage from the sealed chamber.

5.5 Expected Challenges and Alternative Strategies

Potential challenges include weak chromoprotein expression, delayed pigment maturation, inconsistent growth conditions, poor visibility through the chamber material, contamination, or leakage from the containment prototype. Expression timing may vary depending on temperature, oxygen availability, media composition, plasmid copy number, and induction conditions. If live-cell work proves too variable or difficult to maintain safely, the project could shift toward cell-free expression, freeze-dried systems, non-living bio-reactive pigments, or synthetic hydrogel-based color systems. If image analysis is inconsistent, the protocol should use a fixed light box, a color reference card, and standardized camera settings. If the biological system produces color too quickly for the conceptual goal of slow architectural memory, the design can treat the laboratory timescale as a compressed prototype of a longer architectural process.

6 Section 6: Additional Information

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