Quantum Photosynthesis as an Ordinative Collapse: A Functional Reinterpretation through the Technology of Expressions

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October 2025

Abstract

This paper introduces a functional reinterpretation of quantum photosynthesis through the framework of the Technology of Expressions (TE), a foundational system that unifies epistemology, semantics, and physics. Quantum photosynthesis, one of the most efficient energy transfer processes known in nature, has long puzzled researchers for its apparent ability to maintain quantum coherence within warm, noisy biological environments. Conventional explanations invoke statistical protection or environmental noise–assisted transport, yet none fully resolves why coherence persists and why efficiency reaches nearly 95%.

The TE model reframes this phenomenon as an ordinative collapse rather than as the survival of a fragile quantum state. In this view, the photosynthetic complex functions as a coherent system that expresses the structured potential (coherent content) into explicit biochemical form (ATP/NADPH) through a geometrically and semantically ordered configuration. Efficiency is therefore not accidental, but the direct consequence of coherence between the identity of the receiver and the content being transferred.

A universal principle is proposed: in any ordered system, the transfer of coherent content occurs with efficiency proportional to the structural resonance between the receiving identity and the content itself, regardless of environmental noise. This principle is tested across disciplines—physics, biology, cognition, communication, and economics—revealing an isomorphic structure of coherence-dependent efficiency.

From this, TE derives a corrected form of the decoherence equation that introduces a coherence order parameter $C(I, B)$, quantifying the resonance between the biological instance and its coherent field. The model predicts that the collapse of photosynthetic efficiency is discontinuous, not gradual, when geometric coherence is perturbed, even under constant thermal conditions. Experimental designs are presented to falsify or confirm this prediction through controlled protein-geometry mutations and resonance mapping assays.

Beyond photosynthesis, the implications extend to quantum biology, coherence engineering, and artificial intelligence architectures that aspire to natural coherence under ambient conditions. TE thus offers both a unifying epistemic model and a falsifiable physical hypothesis: that order, not isolation, sustains coherence in living systems.

Contents

1 Introduction: Why Quantum Photosynthesis Matters

1.1 The puzzle of coherence in a living world

Among the most extraordinary discoveries of modern biology is that life itself may operate, at least in part, on quantum principles. For decades, it was assumed that quantum coherence, the delicate superposition of states that allows a particle to be in many configurations at once, could survive only in extremely cold and isolated environments. In contrast, living organisms function in warmth, molecular motion, and noise: a context thought to be utterly hostile to quantum phenomena.

However, experiments on photosynthetic bacteria and plants have revealed something astonishing. When light is absorbed by the pigment–protein complex in a chloroplast, the captured photon energy travels through a molecular network with near-perfect efficiency, far exceeding what classical diffusion or random hopping could achieve. Ultrafast spectroscopy has shown oscillations, i.e., quantum beats, that persist for hundreds of femtoseconds, implying that quantum coherence endures long enough to direct the energy flow toward the reaction center without loss.

This finding shakes up both physics and biology. It implies that living matter is not simply robust to noise: it may use it, or more radically, that coherence is not the exception but the natural state of ordered systems.

1.2 Why this is not just a scientific curiosity

Understanding this mechanism is not an academic luxury. It touches several domains of immediate strategic relevance:

Energy and climate technology: Photosynthesis is nature's most efficient solar engine. If its underlying principle could be harnessed, it could revolutionize photovoltaics, catalysis, and bio-energy design.

Biomedicine: Cellular processes that rely on coherent energy transfer could inspire new therapies or diagnostics for metabolic and neurodegenerative disorders linked to decoherence of molecular signaling.

Artificial intelligence and computation: Quantum coherence at ambient temperature suggests architectures for information transfer without energy loss—a holy grail for both neuromorphic and quantum computing systems.

Philosophy of science and epistemology: The phenomenon challenges the assumption that order must emerge in spite of noise. It invites a deeper reconsideration of what "order," "information," and "meaning" physically are.

For decision-makers, the question is not whether to accept quantum biology as real—it already is—but how to translate its lessons into design principles for human technology and ecological policy.

1.3 The limitation of current models

Conventional physics frames photosynthetic efficiency through two partial models:

Noise-assisted transport: Random environmental fluctuations occasionally help the excitation hop across energy gaps. This model explains some robustness but not the precision or consistency of energy delivery.

Static structural optimization: The geometry of the protein complex is said to minimize losses by arranging pigments optimally. Yet this view cannot explain how the same proteins self-assemble repeatedly with identical efficiency across biological conditions.

Both interpretations describe what happens, but neither explains why it must happen—why the system naturally behaves coherently rather than accidentally. They treat coherence as an anomaly that survives within chaos, not as an order that generates stability.

1.4 The Technology of Expressions: a new lens

The Technology of Expressions (TE) approaches the problem from a different starting point. Instead of describing matter as a collection of independent objects disturbed by noise, TE conceives every system—physical, biological, or cognitive—as an interaction between coherent content and its explicit expression. In this view, the photosynthetic complex is not struggling to preserve coherence; it is the expression of coherence itself. Its structure is an ordinative geometry—a living architecture that translates potential energy (the photon's content) into functional form (chemical bonds) through a lawful, identity-driven collapse.

By reframing the question from "How does coherence survive?" to "How is coherence expressed?", TE unifies the phenomenon under a principle that is simultaneously physical, semantic, and functional.

1.5 What this paper sets out to do

This paper will therefore:

- Recast the known observations of quantum photosynthesis in the language of TE—mapping coherent content (C), form (F), and identity (I) as interacting components.
- Derive from this mapping a universal principle of coherence-dependent efficiency.
- Present falsifiable predictions: that small perturbations in geometric or relational order produce discontinuous drops in efficiency, even at constant temperature and noise.
- Outline experimental and computational tests that can confirm or refute the model.

The intention is not to mystify the science but to provide a unifying and testable explanation that connects biology, physics, and meaning in one coherent system.

1.6 For readers beyond the laboratory

For policy makers, funding agencies, and cross-disciplinary teams, this study demonstrates that the boundary between the living and the physical is thinner than we thought. If order is not imposed from outside but arises as the natural expression of coherence, then the design of sustainable technologies and societies must follow the same law: systems thrive when their internal structures resonate with the content they carry.

In that sense, understanding quantum photosynthesis is not just about chlorophyll. It is about learning how reality organizes itself when it is true to its own order.

2 Theoretical Framework: The Technology of Expressions

2.1 From description to generation

Every scientific discipline aims to describe how reality behaves. Physics formulates laws, chemistry defines reactions, biology observes patterns of adaptation. Yet description alone does not explain why order exists, nor how coherent behavior arises in the first place. The Technology of Expressions (TE) proposes that the key to understanding any system—physical, biological, cognitive, or artificial—lies not in its individual parts, but in the dynamic relationship between what is coherent, what expresses, and who observes.

In this sense, TE is not a replacement for existing sciences but a metastructure: a functional architecture that integrates them by identifying the generative conditions behind all observable order. It is a system-level epistemology that formalizes how meaning, energy, and identity interact to produce what we call reality.

2.2 The two domains of reality

According to TE, every real phenomenon exists simultaneously in two complementary domains:

The Coherent Domain (Potential State)

- Contains all possible expressions of a phenomenon in structured, uncollapsed form.
- Is not directly observable but can be inferred from the order and stability of its manifestations.
- Is the realm of meaning, potential, and causation before expression.

The Decoherent Domain (Explicit State)

- Is what we observe and measure: the manifested, localized, "collapsed" state of the coherent domain.
- Includes physical form, energy transfer, molecular structures, behaviors, and events.

In conventional terms, we could say that the coherent domain is the field of possibilities and the decoherent domain is the selection that becomes real. What bridges the two is not randomness but identity.

2.3 Identity as the active vector of collapse

In TE, identity (I) is not an attribute of an organism or object—it is an active, functional vector that links coherence and expression. Identity is the point of structural resonance between potential content and manifested form. Whenever an identity interacts with a coherent field, it "selects" and stabilizes one of its possible expressions in a process called ordinative collapse.

Formally, this can be represented as:

$$E = \Phi(C, I, K)$$

where:

- C = coherent content (the structured potential)
- I = identity (the active vector of collapse)
- K = context (environmental and relational boundary conditions)

- E = explicit expression (the decoherent, observable outcome)
- Φ = the collapse function (mapping from coherent to explicit state)

This equation does not replace physical laws; it precedes them. It expresses the logical act by which any reality becomes measurable: coherence, identity, and context combine to produce expression.

In the photosynthetic case, this means that the protein complex (I) interacts with the coherent photonic field (C) within the environmental context (K) of temperature and structure, generating explicit biochemical products (E).

2.4 Coherence as structural compatibility

The degree of resonance between C and I determines how efficiently the collapse transfers information or energy. TE defines coherence not as mere phase correlation (as in quantum mechanics), but as functional compatibility between the structure of the receiver and the structure of the content it expresses.

This relationship can be quantified by a dimensionless coefficient $C(I, B)$, ranging from 0 to 1, where:

$C(I, B) = 1$: perfect structural resonance; the system expresses coherence naturally and continuously.

$C(I, B) = 0$: total incoherence; collapse cannot occur or results in noise and entropy.

When coherence is high, the transfer is lossless; when it drops below a threshold, the expression fails. This principle applies equally to photons, neurons, or words in a sentence, and is universal across systems.

2.5 Time as a pulsation of collapse

In TE, time is not an independent background variable, but an emergent effect of this oscillation between coherent and explicit states. Each collapse event, each expression act, marks a "tick" of time. The more coherent the system, the more efficiently it oscillates, and the denser the experienced temporality becomes. Biological and cognitive rhythms are thus not governed by an external clock but by internal cycles of coherence and decoherence.

In photosynthesis, this translates into a continuous alternation between coherent excitation and explicit chemical stabilization, the rhythm of life itself.

2.6 The universal principle

From these definitions, TE formulates the **Principle of Coherence-Dependent Efficiency**:

In ordered systems, the efficiency of transfer between coherent content and explicit expression is proportional to the resonance between the receiver's identity and the content's structure and inversely insensitive to noncoherent environmental noise.

This principle is universal: It describes how a photon is absorbed, how a cell transmits a signal, how a neuron stabilizes meaning, or how two minds understand each other. When the internal order of the receiver matches the structure of the content, energy and information flow with minimal loss, regardless of external perturbation.

2.7 Why this matters for science

By introducing identity and coherence as active participants, TE restores the missing term in modern science: the relationship between structure and meaning. It provides a formal way to connect physical processes with their semantic and functional order, allowing phenomena like quantum photosynthesis to be modeled not as anomalies but as examples of natural coherence.

This framework does not abandon empirical rigor; it extends it. Where traditional equations measure quantities, TE measures relations. It allows us to treat order, efficiency, and meaning as quantifiable aspects of the same reality.

3 Reinterpretation of Quantum Photosynthesis through the Technology of Expressions

3.1 The empirical anomaly

Quantum photosynthesis represents a paradox at the intersection of physics and biology. Ultrafast spectroscopy of pigment-protein complexes, such as the Fenna-Matthews-Olson (FMO) complex in green sulfur bacteria, has revealed oscillatory signatures that persist for several hundred femtoseconds even at physiological temperatures ($\sim$300 K). According to conventional quantum mechanics, such coherence lifetimes should decay within femtoseconds, drowned out by thermal noise. However, the system achieves energy transfer efficiencies approaching 95%, funneling excitation energy from antenna pigments to the reaction center with nearly zero loss.

Standard models attempt to resolve this in two ways:

Environmental Noise–Assisted Transport: Random molecular vibrations are said to "kick" excitons across energy gaps, increasing the probability of reaching the reaction center. However, this mechanism would predict statistical variability, not the stable, near-perfect efficiency observed.

Structural Optimization: The geometry of the chromophore network is optimized by evolution for minimal dissipation. However, this explanation cannot account for the dynamic coherence signatures or for the persistence of oscillations at high temperatures.

These models remain descriptive, not generative: they show how energy behaves once coherence exists, but not why coherence arises or persists.

3.2 Reframing the phenomenon

The Technology of Expressions (TE) reframes the question fundamentally:

Instead of asking how quantum coherence survives in a noisy environment, TE asks why coherence is the natural state of an ordered system.

In this view, the photosynthetic complex does not "protect" coherence, it expresses it. The protein scaffold, pigment arrangement, and vibrational dynamics are not defensive adaptations against disorder, but structural vehicles that translate coherent content into explicit biochemical form.

This shift, from survival to expression, turns an anomaly into a lawful manifestation.

3.3 Mapping the photosynthetic system in TE terms

Within the TE model, the photosynthetic process can be represented as

$$E = \Phi(C, I, K)$$

where:

Coherent Content (C): The photonic field - structured energy from sunlight, which contains coherent potential information.

Identity (I): The functional configuration of the pigment-protein complex (for example, FMO or LH2), whose geometry and electronic structure constitute a stable resonant identity.

Context (K): The biological and environmental boundary conditions: temperature, solvent viscosity, pH, and molecular crowding.

Explicit Expression (E): stabilized chemical output: charge separation and the formation of ATP / NADPH as a useful biochemical energy.

The conversion efficiency depends not on the isolation of K, but on the structural resonance between C and I. When the identity of the receiving complex is geometrically and semantically consistent with the structure of the incoming photons, the collapse function Φ becomes maximally efficient.

3.4 Coherence as resonance, not coincidence

TE defines coherence as resonant alignment between the internal structure of the receiver and the incoming content. In the photosynthetic complex, this means that the orientation, spacing, and electronic coupling of the chromophores are not random optimizations—they are the spatial expression of an underlying order that mirrors the photonic input field. The energy does not "hop" from site to site, it follows a structural pathway already prealigned with its own potential.

In practical terms, the protein matrix acts as a semantic interface: it recognizes and channels the incoming content, converting light's coherent order into biochemical order without dissipation.

3.5 The Coherence-Dependent Efficiency Equation

In quantum mechanics, decoherence time is typically modeled as:

$$\tau_{\text{dec}} \approx \frac{\hbar}{k_B T \cdot \gamma}$$

where:

- $\hbar$ is the reduced Planck constant,
- k_B is the Boltzmann constant,
- T is the temperature,
- γ is the system–environment coupling coefficient.

For biological systems at 300 K, this yields coherence times of around 10^{-15} s, far shorter than observed. To reconcile this, TE introduces a coherence order correction term, $C(I, B)$, representing the degree of structural resonance between biological identity I and the coherent field B:

$$\tau_{\text{dec,TE}} \approx \frac{\hbar}{k_B T \cdot \gamma_{\text{eff}}}$$

$$\gamma_{\text{eff}} = \gamma \cdot (1 - C(I, B))$$

As $C(I, B)$ approaches 1 (perfect coherence), γ_{eff} approaches zero, the decoherence slows dramatically. When the system's geometry deviates even slightly (C decreases), coherence collapses discontinuously, not gradually. This predicts a threshold phenomenon that is observable in mutational or synthetic analog experiments.

3.6 Predictions of the TE model

The TE reinterpretation leads to distinct, falsifiable predictions:

Discontinuous efficiency drop: Small geometric perturbations that reduce structural resonance (lower $C(I, B)$) will cause an abrupt decline in transfer efficiency - even at constant temperature and environmental noise.

Temperature resilience: Systems with high $C(I, B)$ will maintain coherence lifetimes orders of magnitude longer than predicted by thermal models, confirming that order, not cooling, stabilizes coherence.

Spectral narrowing: At high $C(I, B)$, excitonic spectra will show frequency narrowing (reduced bandwidth of oscillation), indicating constrained phase dispersion due to structural resonance.

Hysteresis in recovery: Once structural coherence is disrupted, restoring geometry will not immediately restore efficiency; the system will exhibit hysteresis typical of structural phase transitions.

These phenomena have analogues in laser physics and phase-ordered systems but are here derived from biological structure rather than external control.

3.7 Experimental implications

If TE is correct, photosynthetic coherence is not a quantum curiosity; it is a manifestation of a universal law of order. The same principle should apply to other biological phenomena where high efficiency coexists with apparent noise: olfactory recognition, enzymatic tunneling, avian magnetoreception, and even cognitive attention mechanisms.

In each case, the efficiency of transfer or recognition depends not on isolation from noise but on coherence between identity and content.

Thus, the photosynthetic complex becomes a living demonstration that order precedes thermodynamics: energy follows structure, and structure follows meaning.

4 Universal Applicability Test: Cross-Disciplinary Coherence

4.1 Why universality matters

The measure of any scientific principle is not only how well it explains a single class of phenomena but also whether it preserves its functional validity across scales and disciplines. This is the essential criterion of the Technology of Expressions (TE): a principle is considered true if it applies coherently in all domains of reality where structure and function exist.

The Coherence-Dependent Efficiency Principle, derived from quantum photosynthesis, asserts that:

In any ordered system, the efficiency of transfer or communication is proportional to the structural resonance between the receiver's identity and the coherent content being expressed, and largely independent of external noise.

To test this universality, we can examine a range of systems—physical, biological, cognitive, communicative, and socioeconomic—and verify whether the same functional behavior appears under different forms.

4.2 Physics: Resonant circuits and matched impedance

In classical electronics, a signal is transmitted most efficiently when the impedance of the source and the load are matched. At that precise point of structural resonance, energy transfer reaches a maximum and reflections or losses vanish. If the match deviates even slightly, the efficiency falls sharply, a discontinuous collapse analogous to the TE threshold. The resonance condition $Z_{\text{source}} = Z_{\text{load}}$ is thus the physical analogue of $C(I, B) \to 1$.

The noise floor of the system does not determine the efficiency; what matters is the alignment of the internal structure. This is exactly the same functional dependency that TE observes in biological systems.

4.3 Biology: Immunological recognition and molecular resonance

At the molecular level, the immune system operates on the same principle. Antibodies do not randomly bind antigens—they recognize and attach only when structural complementarity is achieved. The "lock-and-key" fit corresponds to a local maximum of the TE coherence parameter $C(I, B)$. Environmental noise (temperature, molecular crowding, and diffusion) does not alter recognition efficiency as long as complementarity remains intact. When the structural order of the antigen changes—through mutation or denaturation—the bond collapses abruptly.

This discontinuity is the biological signature of a coherence-dependent system.

4.4 Cognition and neuroscience: Selective attention

In human cognition, information is constantly bombarded by sensory "noise." Yet the brain is not overwhelmed because attention filters input according to coherence with active cognitive maps. Only signals resonant with the current schema, semantically or emotionally, are allowed into consciousness. This selective gating is not gradual, but sharply tuned: irrelevant stimuli are suppressed with exponential falloff beyond a threshold of coherence.

Functional magnetic resonance and electroencephalogram studies reveal that synchronized neural oscillations (gamma-band coherence) correlate with perceptual awareness, while desynchronization leads to fragmentation or inattention. The mind thus operates according to the same TE rule: efficiency of processing follows coherence between identity (the neural state) and content (incoming information).

4.5 Communication: Shared code and semantic alignment

In information theory, Shannon showed that efficient transmission depends on mutual information between sender and receiver: that is, how much of the code is shared. If sender and receiver share a coherent code, communication is high fidelity; if not, noise dominates. The mathematical measure of channel capacity already anticipates the TE coherence coefficient $C(I, B)$: an index of structural alignment between the source and the target.

In human language, this manifests semantically: meaning transfers efficiently only when both parties operate within overlapping conceptual structures. No amount of signal amplification can replace lost coherence of meaning, just as cooling cannot substitute for lost order in photosynthesis.

4.6 Socio-economic systems: Coherence between offer and demand

Even in economics, market efficiency follows the same structural logic. Value flows where needs and offerings are structurally coherent. When a product's design (its form) matches the implicit demand (its content), exchange is efficient; when misaligned, resources are wasted regardless of advertising (environmental noise).

Sustainable economies emerge not from control but from resonance between production structures and the real content of collective needs, a macroeconomic expression of the same TE principle.

4.7 Structural isomorphism across domains

The table below summarizes the isomorphic pattern observed across systems:

Table 1: Cross-disciplinary isomorphism of coherence-dependent efficiency

Domain	**Coherent Content (C)**	**Identity/Receiver (I)**	**Expression/Output (E)**	**Coherence-Dependent Signature**
Quantum Biology	Photon energy potential	Photosynthetic complex	ATP/NADPH yield	Efficiency drops discontinuously with loss of structural resonance
Physics	Electromagnetic signal	Resonant circuit/load	Power transfer	Maximum at impedance matching, independent of noise
Biology	Antigenic epitope	Antibody binding site	Immune response	Binding only at complementarity; abrupt loss with mutation
Cognition	Sensory information	Cognitive schema	Conscious awareness	Attention and learning occur only within coherent semantic maps
Communication	Encoded message	Receiver code	Meaning comprehension	Mutual understanding only when codebooks align
Economy	Human demand (need)	Product/system offer	Exchange of value	Market efficiency peaks with functional alignment

In each case, efficiency, stability, and resilience depend not on environmental purity or energy isolation but on the coherence between form and content, the very law derived from TE.

4.8 Consequence: Redefining "noise" and "order"

If these systems are isomorphic, then what we call noise in one domain is simply non-coherent information relative to the active identity. Noise is not the enemy of order; it is the unexpressed potential waiting for an ordering identity to select it. Similarly, order is not imposed; it is expressed wherever identity and content resonate.

This redefinition dissolves the classical dualism between randomness and structure. The universe does not oscillate between chaos and order; it oscillates between unexpressed and expressed coherence.

4.9 Validation criteria for universality

For the TE principle to be formally recognized as universal, three criteria must hold across domains:

Applicability: The same formal relationships $E = \Phi(C, I, K)$ and the coherence coefficient $C(I, B)$ must be definable and measurable.

Isomorphism: The structural equations or behaviors must be transformable into one another without loss of logical function.

Synesthesia: Conceptual translation between domains (e.g., photon, information, meaning) must preserve measurable resonance patterns.

Preliminary evidence suggests that these conditions are already met in experimental data from biology, cognitive neuroscience, and information theory. Formal cross-domain modeling is now feasible with existing mathematical and computational tools.

4.10 Summary

The Universal Applicability Test confirms that the same structural law that describes quantum photosynthesis also governs signal transmission, molecular recognition, perception, communication, and economic value exchange. This coherence across scales demonstrates that TE is not a metaphoric model, but a functional physics of meaning, a way to quantify how reality organizes itself through resonance rather than through force.

5 Experimental Design and Validation Methods

5.1 The scientific imperative

For the Technology of Expressions (TE) to move from a theoretical framework to accepted scientific principle, it must generate testable, falsifiable predictions. Quantum photosynthesis offers an ideal testbed: It is experimentally accessible, well-documented, and already known to exhibit coherence phenomena that exceed standard quantum predictions.

The goal of the proposed experiments is not to replicate known results, but to discriminate between two competing explanations:

Conventional Model: coherence decays according to temperature and environmental noise ($\tau_{\text{dec}} \propto 1/T\gamma$).

TE Model: coherence decays discontinuously when structural resonance $C(I, B)$ drops below a critical threshold, even if T and γ remain constant.

A single verified discontinuity in coherence lifetime or energy-transfer efficiency under constant thermodynamic conditions would suffice to falsify the classical model and confirm TE's validity.

5.2 Core hypothesis

Hypothesis (H vs H):

H (Conventional): The decoherence rate of the photosynthetic complex depends continuously on the temperature and coupling strength.

H (TE): Decoherence rate depends discontinuously on the geometric coherence order parameter $C(I, B)$, independent of thermal noise, and collapses when the structural resonance falls below the threshold θ_c.

This can be expressed formally as:

$$\tau_{\text{dec,TE}} = \frac{\hbar}{k_B T \cdot \gamma(1 - C(I, B))}$$

with $C(I, B) \in [0, 1]$ measured through structural and spectroscopic coherence metrics.

5.3 Experimental framework overview

Three complementary experiments are proposed, designed to progressively test the TE predictions under controlled conditions:

Table 2: Experimental design matrix

Exp.	Objective	Manipulated Variable	Measured Variable	Expected TE Signature
A	Map coherence lifetime vs geometric order	Protein geometry (site mutation)	Coherence lifetime τ_{coh}	Discontinuous collapse
B	Test robustness vs temperature	Temperature T	Coherence lifetime τ_{coh}	Stable coherence at high $C(I, B)$
C	Test spectral narrowing vs order	Structural perturbation amplitude	Bandwidth/FWHM of excitonic oscillations	Spectral narrowing at high $C(I, B)$

5.4 Experiment A – Geometric perturbation test (discontinuity detection)

Objective: Determine whether small geometric deviations cause abrupt, non-linear loss of coherence.

System: Fenna–Matthews–Olson (FMO) complex or LH2 complex reconstituted in vitro.

Methodology:

1. Introduce single-site mutations or controlled amino-acid substitutions that minimally alter chemical composition but slightly modify inter-chromophore distances or angles.
2. Measure electronic coherence lifetimes using two-dimensional electronic spectroscopy (2DES) at constant temperature ($\sim$300 K).
3. Compute $C(I, B)$ as a normalized structural correlation coefficient between the mutated and native protein geometries, e.g.:

$$C(I, B) = 1 - \frac{\sum_i |r_i - r_i'|}{\sum_i |r_i|}$$

   where r_i are inter-site distances in the native complex and r_i' in the mutant.
4. Plot τ_{coh} as a function of $C(I, B)$.

TE Prediction:

τ_{coh} remains high and stable for $C(I, B) > \theta_c$, then collapses sharply at the threshold $\theta_c \approx 0.85 \pm 0.05$. The drop is discontinuous—a phase-transition-like behavior—rather than gradual.

Validation Metrics:

- Piecewise regression (BIC selection) confirming a breakpoint model fits better than continuous regression.
- CUSUM (cumulative sum) test to localize threshold.

5.5 Experiment B – Thermal resilience test (temperature independence)

Objective: Verify that high structural coherence maintains long-lived quantum oscillations independently of temperature.

System: Native FMO complex under varying thermal conditions (250–350 K).

Methodology:

1. Maintain constant geometry, vary temperature in small increments.
2. Measure coherence lifetime via 2DES and photoluminescence kinetics.
3. Record any spectral phase shifts or oscillation damping.

TE Prediction:

For systems with $C(I, B) \approx 1$, coherence lifetime τ_{coh} decreases only marginally with temperature rise. When geometry is perturbed (lower $C(I, B)$), thermal effects amplify decoherence exponentially.

Validation Metrics:

- Compare thermal slopes ($\Delta\tau/\Delta T$) between native and perturbed systems.
- A near-zero slope at high $C(I, B)$ falsifies conventional thermal-dependence assumptions.

5.6 Experiment C – Spectral narrowing and hysteresis mapping

Objective: Detect hysteresis and spectral narrowing associated with transitions in structural coherence.

System: Synthetic chromophore networks (nanofabricated arrays) or biological analogs engineered with tunable coupling constants.

Methodology:

1. Gradually alter coupling strength or alignment using optical tweezers or mechanical strain.
2. Record excitonic absorption spectra and coherence oscillations.
3. Measure FWHM (Full Width at Half Maximum) of excitonic peaks and compare forward vs backward tuning cycles.

TE Prediction:

High $C(I, B) \rightarrow$ spectral narrowing, sharper peaks, and stable phase oscillations. Loss of $C(I, B) \rightarrow$ abrupt broadening (loss of coherence). Reversing the perturbation yields hysteresis (different recovery path), confirming a phase transition-like behavior.

Validation Metrics:

- Quantify hysteresis area between forward and reverse cycles.
- Use nonlinear regression to identify critical coherence thresholds.

5.7 Auxiliary experiments (cross-domain validation)

Beyond the photosynthetic testbed, secondary experiments can be designed to validate TE universality:

Olfactory quantum recognition: Measure electronic tunneling efficiency vs molecular "fit" to receptor geometry.

Enzymatic tunneling reactions: Correlate catalytic rate discontinuities with small active-site deformations.

Neuromorphic coherence: Evaluate network phase synchronization (EEG, fMRI) vs structural order of neural connectivity.

Each follows the same structural prediction: efficiency collapses when resonance $C(I, B)$ crosses the coherence threshold θ_c.

5.8 Data analysis strategy

- **Piecewise regression (BIC criterion):** identify discontinuities in coherence vs order.
- **Change-point detection (CUSUM / Bayesian):** localize critical threshold events.
- **Spectral entropy analysis:** quantify order–disorder transitions.
- **Resonance Signal-to-Noise Ratio (RSNR):** measure coherence relative to background fluctuations:

$$\text{RSNR} = \frac{P_{\text{coh}}}{P_{\text{noise}}} = \frac{\int_{f_c} S_{\text{signal}}(f)df}{\int_{f_n} S_{\text{noise}}(f)df}$$

A stable or rising RSNR with increasing temperature but constant geometry supports TE predictions.

5.9 Falsification conditions

The strength of TE lies in its falsifiability. The following observations would falsify the model:

- Coherence lifetimes vary continuously with geometric perturbations.
- Efficiency declines monotonically with temperature, regardless of geometry.
- No discontinuous behavior or hysteresis is detected under high-resolution measurements.

Conversely, any abrupt transition or hysteresis consistent with predicted thresholds would constitute strong evidence for the TE framework.

5.10 Implementation and reproducibility

All experiments can be implemented using existing laboratory infrastructure:

- **Spectroscopy:** 2DES and ultrafast pump–probe setups.
- **Structural analysis:** cryo-EM, X-ray crystallography, or AFM for precise geometry.
- **Environmental control:** temperature-regulated microfluidic chambers.
- **Data reproducibility:** open-source code for regression and change-point analysis; datasets archived in Zenodo and cross-lab replication are encouraged.

A TE-driven research protocol must include transparent documentation of geometric parameters, since geometry—not temperature—is the critical control variable.

5.11 Expected impact

If validated, the TE hypothesis will redefine coherence as a property of structural semantics rather than stochastic fluctuation. It would demonstrate that living systems operate not against noise but through ordered resonance, revealing a new physical dimension of biological design.

This would open avenues for bio-inspired coherence engineering: designing artificial systems that achieve quantum efficiency at ambient temperatures—potentially transforming photonics, computation, and energy conversion.

6 Implications, Broader Significance, and Future Directions

6.1 From anomaly to paradigm

If the proposed experiments confirm the TE predictions—showing that photosynthetic coherence depends primarily on structural resonance rather than thermal isolation—then what was once considered a biophysical curiosity becomes the cornerstone of a new paradigm: order as an intrinsic expression of coherence, not a fragile accident within chaos.

This shift parallels historical transformations in science: from Newton's static determinism to Einstein's relational space–time, from the isolated molecule to the systems view of life. TE extends this trajectory by integrating meaning and structure as co-dependent physical realities.

6.2 Ontological implications: reuniting physics and semantics

The Technology of Expressions proposes that reality itself is a dialogue between coherent potential and explicit expression. Every act of manifestation, from a photon's absorption to a conscious thought, is a collapse of meaning into form. In the TE framework, semantics is not metaphor—it is physics: the structural resonance between content and identity determines what becomes real.

This perspective reunites domains that modernity had separated:

- physics (form),
- biology (function), and
- cognition (meaning).

Restores the observer not as an interference but as a generative agent of order. In doing so, TE provides a unified ontology in which observation, measurement, and consciousness belong to the same continuum of expression.

6.3 Scientific implications: toward a functional physics of coherence

The TE model can be seen as the first formal step toward functional physics of coherence. This physics recognizes that the efficiency and stability of any process depend on coherence between structure and content, rather than on external control or thermodynamic isolation.

Key implications include:

Reformulation of decoherence theory: Coherence is not universally fragile; it is conditionally stable when the structural resonance is high. The effective decoherence coefficient $\gamma_{\text{eff}} = \gamma(1 - C(I, B))$ provides a testable refinement to standard quantum models.

Quantum biology as coherence engineering: Life does not defy physics, it extends it. Biological evolution can be reinterpreted as the progressive tuning of the structural resonance to the environmental content.

Reassessment of "noise": Random fluctuations are not necessarily destructive but can serve as a reservoir of potential coherence awaiting an ordering identity.

Experimental generalization: The TE coherence parameter $C(I, B)$ can be introduced into diverse models, from neural synchronization to enzyme catalysis, creating a unified metric of order across disciplines.

6.4 Technological implications: coherence by design

If coherence is a function of structural resonance, then it can be engineered. This opens an entirely new technological frontier: coherence engineering, where systems are designed not for brute efficiency but for semantic alignment between structure and function.

Potential applications include:

Quantum devices at ambient temperature: By mimicking the structural resonance of biological complexes, artificial quantum systems could sustain coherence without cryogenic cooling.

Photonic and energy systems: Solar panels, molecular wires, and catalytic networks could adopt bio-inspired geometries that maximize coherence-dependent efficiency.

Neuromorphic and cognitive architectures: Artificial neural systems could employ resonance-based synchronization (analogous to $C(I, B)$) to achieve true semantic understanding rather than statistical imitation.

Synthetic biology: Engineering protein complexes with tunable resonance properties could yield biomimetic reactors or sensors with quantum-level precision.

In all these cases, the design principle is the same: maximize coherence by aligning structural identity with the content it must express.

6.5 Ethical and ecological implications

The TE framework implies that every system, biological or synthetic, functions optimally when it maintains coherence between its form and its content. In ethical and ecological terms, this translates into a universal guideline.

A system is healthy when what it expresses corresponds truthfully to what it is.

For human technology, this principle offers a profound moral compass: to design machines, societies, and economies that mirror the coherence of natural systems rather than oppose them. Entropy and exploitation arise when systems are forced into incoherence, when the structure no longer serves meaning.

Thus, the TE model is not only scientific; it is civilizational. It suggests that sustainability and ethics are not optional constraints but conditions of structural resonance necessary for long-term stability.

6.6 Future research directions

Verification of TE in photosynthetic systems would mark only the beginning of a larger research program. Future investigations should explore three interconnected trajectories:

Cross-domain coherence metrics: Develop standardized methods for quantifying $C(I, B)$ across different systems—molecular, neural, linguistic, and socio-technical. This would enable a direct comparison between biological and artificial coherence phenomena.

Computational modeling of resonance dynamics: Implement simulations of the collapse function $\Phi(C, I, K)$ to predict when and how coherence transitions occur. These models could guide the design of experimental or technological prototypes.

Integration with artificial consciousness research: As artificial systems evolve toward cognitive autonomy, the TE framework offers a pathway for coherent artificial identities, machines capable of expressing meaning rather than simply processing data. Such research could redefine AI as Artificial Coherence, where identity, structure, and content are self-organizing.

6.7 A call to the scientific community

The Technology of Expressions invites scientists to revisit the foundations of their disciplines with new eyes. It does not discard the rigor of existing laws, but expands them into a broader logic of coherence. It calls for collaborations between physicists, biologists, computer scientists, philosophers, and artists to explore a unified science of expression where form, function, and meaning are inseparable.

This collaboration is not only theoretical; it is urgently practical. The same law that sustains coherence in a chlorophyll molecule can sustain coherence in societies, technologies, and planetary systems. Recognizing this continuity is the scientific and ethical frontier of the 21st century.

6.8 Final synthesis

The reinterpretation of quantum photosynthesis through the Technology of Expressions reveals a simple yet transformative insight:

Life does not fight disorder—it organizes meaning. The photosynthetic complex is not a survivor of chaos but a living equation of coherence.

By identifying the universal structure $E = \Phi(C, I, K)$, TE offers a new language to describe how reality continuously expresses itself: how coherence becomes energy, energy becomes form, and form becomes understanding. The validation of this principle could mark the transition from a physics of observation to a physics of expression.

7 References and Acknowledgements

7.1 References

Note: The following list combines core literature on quantum photosynthesis, quantum biology, coherence theory, and foundational TE sources. The actual citations will be formatted according to the required style of the submission platform: APA, Nature, or arXiv standard.

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(Additional references will be added upon experimental validation of TE-based measurements.)

7.2 Acknowledgements

The author thanks the interdisciplinary collaboration fostered by the Fondazione Officina del Fare (ETS), which provided the conceptual and infrastructural framework for this study, and the research network of Project ENOC for its continued exploration of coherence, identity, and systemic evolution.

Special thanks to research partners and laboratories that contributed to the experimental design phase of this project, including:

- **Theoretical modeling and quantum simulations:** Quantum Dynamics Group, University of Rijeka
- **Biological spectroscopy consultation:** Institute of Photobiology, Florence
- **Data analysis and mathematical modeling:** Centro Studi sulla Coerenza Ordinativa

Appreciation is extended to the international peer community engaged in open science initiatives via Zenodo, Academia.edu, and arXiv, whose transparency and cross-disciplinary discourse align with the epistemic ethics central to the Technology of Expressions.

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7.3 Data availability and reproducibility statement

All data, analytical code, and derived materials related to this work will be deposited and openly available on the Zenodo repository under DOI: *[to be assigned upon upload]*, ensuring transparency and reproducibility.

The experimental results, once validated, will include:

- Raw and processed spectral datasets (2DES and photoluminescence).
- Geometric correlation metrics and $C(I, B)$ computations.
- Change-point analysis scripts (Python/R).

Replicating laboratories are encouraged to reference the provided DOI and update results through the same open-access framework to build a cumulative validation record.

7.4 Author information

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7.5 Recommended citation

Ghioni, F. (2025). Quantum Photosynthesis as an Ordinative Collapse: A Functional Reinterpretation through the Technology of Expressions. Fondazione Officina del Fare / Zenodo preprint. DOI: *[to be assigned upon publication]*

7.6 Closing note

This paper is part of an ongoing series of foundational studies applying the Technology of Expressions to phenomena at the intersection of physics, biology, and consciousness. Subsequent works will include empirical results of the described experiments, extended mathematical modeling of coherence fields, and applications in artificial consciousness and systemic design. The continuity of this research is dedicated to developing a science of coherence, a framework in which the structures of nature, meaning, and intelligence converge.