

Spiral History: A Testable Framework for Differential Persistence, Monumental Attribution, Symbolic Continuity, and Capability-Specific Regression

Elias Rubenstein

Independent Researcher, Fort Lauderdale, FL, USA

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ABSTRACT

Archaeology, anthropology, and history recognize uneven historical development: societies fragment, abandon particular practices, preserve selected knowledge, and reorganize complexity. Yet historical research lacks a consistent procedure for distinguishing material survival, operational continuity, later reception, public symbolic memory, and restricted transmission when assigning a monument's origin and function. This article develops Spiral History as an evidential and comparative framework. It integrates collapse theory, resilience research, and cultural-evolutionary approaches through five analytically independent variables: material persistence, operational capability, public symbolic memory, restricted transmission, and later reception. Its Rule of Temporal Attribution assigns later use to later use while requiring independent evidence for original construction, original function, and uninterrupted technical understanding. The framework is grounded in documented mechanisms: technological rejection in the South Caucasus; Mexica recovery, ritual deposition, and imitation of Teotihuacan material; and the specialist preservation of Eleusinian and Vedic knowledge. The Capability Profile Framework compares procurement, fabrication, surveying, handling, logistics, and evidential integration across monuments and chronological control groups. The Great Pyramid of Khufu application combines published evidence on material sourcing, river transport, granite placement, and orientation with a descriptive Giza screen, a simulated N=16 proof of concept, and a full Old Kingdom N=13 empirical implementation. It also provides a context-sensitive protocol for mythic deep-time comparison and a symmetrical audit for conventional and technically contested claims concerning electrochemistry, illumination, acoustics, resonance, and unusual material function. Spiral History provides a method for determining demonstrated continuity, testing claims of persistence and regression, and distinguishing material survival from technical, institutional, symbolic, and semantic continuity through direct comparative analysis.

Keywords: cultural transmission, technological loss, monumental inheritance, capability profile, Great Pyramid of Khufu, Teotihuacan, historical attribution, mythic time

INTRODUCTION

Archaeology and historical anthropology have moved beyond unilinear narratives of development. Research on societal transformation, collapse, resilience, technological change, social memory, and cultural evolution demonstrates that historical trajectories are uneven. States fragment; cities are abandoned and later reoccupied; technical practices are rejected; institutions survive in altered form; and communities adapt to disruption in ways that cannot be reduced to permanent success or permanent failure [1–5].

The contribution of this article lies elsewhere. It addresses an evidential problem arising when later societies encounter older monuments, artefacts, myths, and ritual traditions. A later culture may inhabit an earlier site, restore a structure, attach a sacred narrative to it, deposit offerings within it, imitate its forms, reuse its materials, or integrate it into a new political order. These actions establish a later relationship. They do not independently establish original construction, original function, or uninterrupted technical understanding.

Three questions must remain distinct. Who used or reinterpreted a monument at a later date? Who built its earliest securely dated architectural phase? Which operational system produced its material, geometric, logistical, and organizational properties? Historical interpretation becomes unreliable when these questions are merged.

The model proposed here is called Spiral History. It does not describe history as a closed circle in which every age returns unchanged. Nor does it describe history as a line in which every capability, once acquired, is permanently retained. It describes recurrent movement through concentration, disruption, differential survival, reinterpretation, and renewed complexity. Later societies can revisit earlier sites, symbols, and problems without reproducing the original technical or institutional configuration.

Spiral History has one methodological objective: to determine which form of persistence is evidenced by a historical claim and which form is only inferred. The manuscript therefore has three analytic levels. The core method consists of the five archives, the Rule of Temporal Attribution, the Capability Profile Framework, and the Evidence State Matrix. The case studies demonstrate discrete historical mechanisms. The mythic and technical modules apply the same architecture to symbolic and contested material. Each conclusion remains attached to the evidence type capable of deciding it.

Position within Existing Research

Collapse research establishes that disruption, adaptation, resilience, and reconstruction are historically variable processes. Tainter's analysis of diminishing returns, the resilience-centred work collected by McAnany and Yoffee, and Butzer's critique of monocausal environmental explanation identify distinct pathways through which complex societies transform under pressure [1–3].

Cultural-evolutionary research establishes that knowledge depends on repeated practice, population structure, teaching systems, social incentives, and intergenerational transmission rather than on a permanently accessible store of information [5–7].

Spiral History operates at the intersection of these literatures by supplying an ordered attribution procedure. It distinguishes later reception, earliest securely dated construction, and the operational system responsible for a monument's relevant material, geometric, logistical, or organizational properties. It then separates numerical capability comparison from categorical evidence coding and tests transformed continuity through chronology, an identifiable transmission mechanism, and a concrete continuity marker. This sequence makes material persistence, technical reproducibility, symbolic survival, restricted transmission, and later reception independently testable within the same historical claim.

The Spiral History Model

The term Spiral History describes recurrent historical movement without assuming exact repetition or permanent accumulation. A spiral differs from a circle because later configurations are not identical to earlier ones. It differs from a straight line because capacities can fragment, be rejected, become inaccessible, survive in altered form, or return through new institutions.

The model begins with concentration of capability. Complex capacities require more than isolated inventions. They depend upon specialist training, apprenticeship, material supply, political coordination, ritual authority, technical language, testing procedures, administrative systems, and intergenerational transmission. Monumental construction, advanced craft production, astronomy, hydraulic systems, complex calculation, and formal oral recitation all require integrated chains rather than isolated acts of intelligence.

A disruption or reorganization may interrupt portions of this chain. Causes can include political fragmentation, ecological stress, war, epidemic disease, demographic decline, economic transformation, ideological rejection, or combinations of these factors. The result need not be total collapse. Capability-specific regression can occur while other domains remain stable or develop further.

What survives after disruption does not persist uniformly. A stone monument may remain visible after the surveying practice that produced it disappears. A public myth may preserve the sacred importance of a place while losing its earlier technical or political meaning. A restricted group may preserve formal sequences while broader society no longer possesses the interpretive key. Later societies then reuse, ritualize, imitate, restore, rename, preserve, dismantle, or reinterpret what remains.

The sequence is therefore:

Capability concentration → disruption or reorganization → differential persistence → inheritance and reinterpretation → renewed concentration.

This is not a universal law. It is a model applicable when its variables can be independently observed.

The Five Archives

Spiral History distinguishes five partially independent historical archives.

The **material archive** includes monuments, artefacts, tools, quarry traces, transport routes, architectural phases, landscapes, manufacturing debris, inscriptions, and measurable construction properties.

The **operational archive** includes practical knowledge required to reproduce a capability: quarrying, material preparation, tool use, surveying, transport, lifting, labour coordination, technical language, testing procedures, and embodied craft skill.

The **public symbolic archive** includes myths, names, festivals, iconography, public ritual, dynastic narratives, collective memory, and sacred geography.

The **restricted archive** includes specialist knowledge transmitted through initiation, priestly office, craft apprenticeship, formal recitation, controlled textual instruction, closed guild practice, or other restricted institutions.

The **reception archive** consists of later restoration, reuse, imitation, ritual deposition, iconographic borrowing, textual reference, and political appropriation.

Table 1. Operational definitions of the five historical archives

Archive	Operational definition	Evidential question
Material archive	Surviving objects, structures, landscapes, traces, inscriptions, and measurable physical properties.	What survives materially?
Operational archive	Demonstrable practical knowledge, procedures, skills, tools, organization, and logistics required to reproduce a specified capability.	Which operation is evidenced or reproducible?
Public symbolic archive	Publicly circulating names, myths, rituals, iconography, sacred associations, and collective memory.	What is publicly remembered or represented?
Restricted archive	Knowledge maintained through identifiable custodial roles, initiation, apprenticeship, formal recitation, controlled instruction, or specialist institutions.	Which knowledge is transmitted through a bounded custodial structure?
Reception archive	Later restoration, reuse, imitation, deposition, textual reference, political appropriation, or reinterpretation.	How did later actors relate to inherited material or symbols?

Each archive is coded separately. Evidence from one archive may illuminate another, but it does not substitute for the evidence required to establish a claim in that other archive.

These archives can diverge. A monument may survive while the operational system disappears. A myth may preserve a site's sacred identity while its original meaning changes. A later elite may preserve a restricted ritual while no longer understanding the technical environment from which it emerged. A reception history may be historically rich without supplying evidence of original authorship.

Symbolic Continuity and Semantic Decoupling

A symbol is not self-interpreting. A visible image, object, sound, gesture, or architectural form becomes meaningful only within a learned interpretive system. The same image can therefore be preserved while its meaning changes radically.

A later observer may see a boat in the sky, a winged figure, a serpent, a geometric pattern, a procession, or a celestial object. Without the linguistic, ritual, astronomical, technical, and institutional framework in which the symbol was originally used, the observer may interpret it as a god, an ancestor, a mythic event, a political emblem, an astronomical sign, or something else entirely. Formal resemblance alone does not determine meaning.

This principle is especially important for monuments. A later culture may preserve a structure's sacred status while no longer possessing the conceptual framework that governed its original design. Symbols can survive as public forms after their technical, ritual, or initiatory interpretation has narrowed, transformed, or disappeared.

The Transmission-Bridge Hypothesis

The historical record establishes that restricted institutions can preserve knowledge over long periods. The Eleusinian Mysteries demonstrate specialist offices, initiation, differentiated access, and serious concern over profanation. Vedic recitation demonstrates formal redundancy designed to preserve sound, sequence, segmentation, and textual order across generations [8–12].

The Transmission-Bridge Hypothesis is a falsifiable criterion for transformed continuity. It proposes that, after disruption, an external institutional form may disappear while selected structures of knowledge are carried into a later institution, language, ritual system, or specialist lineage. The later form need not preserve the original vocabulary, political order, or public meaning. It may preserve a disciplined core: a recitational sequence, astronomical procedure, initiatory structure, ritual calendar, symbolic grammar, technical rule, or institutional role.

Superficial similarity between distant traditions is insufficient. A transmission bridge is supported only where chronological linkage, an identifiable transmission mechanism, and at least one continuity marker are independently evidenced. Chronological linkage establishes that a proposed source, intermediary, and later form can stand in a historically possible sequence. An identifiable mechanism specifies how transmission could occur, whether through a specialist lineage, migration, institutional succession, apprenticeship, textual circulation, ritual office, or another documented pathway. A continuity marker is a concrete, discriminating feature such as a formal sequence, specialized terminology, ritual office, material practice, textual lineage, documented contact, or demonstrable transformation through intermediate stages. These conditions are non-compensable: resemblance in many domains cannot substitute for chronology, mechanism, or a concrete marker. Contradictory evidence has priority over superficial similarity, and strong evidence in one domain cannot erase the absence of a necessary condition in another.

These conditions do not require that oral societies prove continuity through writing, state archives, or externally imposed institutional forms. In oral and Indigenous contexts, chronological linkage may be demonstrated by a convergent temporal sequence rather than by a single written date. Relevant evidence can include community-maintained generation counts, formally transmitted genealogical succession, a repeated

ritual calendar, a persistent relationship to independently datable environmental or astronomical events, archaeological continuity of a sacred landscape, and documented performance across successive generations. None of these is accepted merely because it is sacred or old. Each must be specified, contextualized, and evaluated with the relevant knowledge holders and linguistic expertise.

An identifiable mechanism in an oral context can consist of a recognized custodial lineage, kin-based responsibility, initiation, age-grade transmission, a ritual office, a defined teacher–learner relation, controlled performance rights, performative taboos, repeated ceremonial instruction, or geographically bounded obligations to a sacred landscape. The decisive question is not whether the mechanism resembles textual schooling. It is whether a socially recognized practice transmits a specific body of knowledge through identifiable persons, roles, performances, and places.

A continuity marker in an oral context can consist of a stable formal sequence of recitation, song, gesture, movement, place-name order, ceremonial route, restricted vocabulary, cosmological relation, or technical practice. A marker can also be a documented transformation that preserves a discriminating structural relation while language, public meaning, or outward ritual form changes. The framework requires the recording of community interpretation, translation choices, historical context, and disagreement. It does not reduce living oral traditions to detached data or treat their knowledge systems as deficient because they do not produce written records.

The criteria remain non-compensable because they distinguish evidence of transmission from resemblance alone. Their evidentiary forms, however, are context-sensitive. A community-maintained generational sequence, a ritualized custodial practice, and a formally stable relation to place may satisfy the same methodological functions that a textual lineage, dated archive, and formal institution satisfy elsewhere. The framework neither assumes that oral traditions lack historical depth nor infers an exact chronological bridge from sacred status, broad symbolism, or surface similarity alone.

The Rule of Temporal Attribution and the Attribution Hierarchy

The central methodological principle is:

Later use establishes later use. It does not independently establish original construction, original function, or uninterrupted technical understanding.

Attribution should be expressed in three evidence levels.

Level I: Direct construction attribution requires direct connection between an earliest building phase and a builder, institution, or administrative system. Relevant evidence can include contemporaneous inscriptions, construction records, quarry marks, labour administration, securely dated building deposits, or direct construction-phase context.

Level II: Strong contextual construction attribution requires convergent chronological, archaeological, material, technological, and settlement evidence. It may support a high-confidence attribution even where no single direct inscription survives.

Level III: Reception attribution establishes later use, restoration, ritualization, mythic association, naming, appropriation, or political incorporation. It is historically meaningful but cannot alone establish Level I or Level II construction attribution.

This hierarchy does not require every operation of an ancient construction sequence to be directly preserved before authorship can be discussed. It requires that later reception never substitute for evidence of original construction.

Mechanism Case I: Technological Rejection in the South Caucasus

The South Caucasus case demonstrates that technical development is not automatically cumulative. Erb-Satullo's geospatial analysis of more than 4,500 gold objects identifies a major decline in regional gold use around 1500 BCE in areas with some of the earliest evidence for gold mining, dating to approximately 3000 BCE. The study tested possible explanations and found social factors more persuasive than resource limitation or demographic disruption [13].

The result does not show that all technical knowledge disappeared. It demonstrates something more precise: a technological practice can contract or be rejected even where resources remain available. Later absence cannot be treated as proof that a prior capability never existed, and early success cannot be treated as proof that a capability continued unchanged.

Mechanism Case II: Monumental Inheritance at Teotihuacan

Teotihuacan demonstrates monumental inheritance without identity between later reception and original construction. After the decline of the Classic city, later populations reoccupied, visited, and reinterpreted the Teotihuacan landscape. In Mexico-Tenochtitlan, Mexica actors recovered Teotihuacan relics, transferred them into the imperial capital, deposited them in sacred contexts, and imitated Teotihuacan forms.

López Luján and De Anda Rogel demonstrate that many relics found in ritual deposits at Mexico-Tenochtitlan derived from deposits associated with major Teotihuacan civic-ceremonial structures. The Mexica relationship was material and deliberate: objects were collected, transported, deposited, imitated, and incorporated into a new sacred-political order [14].

The case does not demonstrate that Mexica society lacked complex capacities. Its evidential role is different. It demonstrates that documented later reception does not establish original construction or complete original understanding.

Mechanism Case III: Restricted Transmission

The Eleusinian Mysteries provide a documented model of controlled access and specialist transmission. Its initiatory structure involved office-holding, differentiated participation, and serious civic concern over profanation. Andocides' *On the Mysteries* confirms the legal and political gravity associated with accusations involving impiety and participation in the Mysteries. The evidence establishes restricted access and specialist ritual knowledge; it does not disclose the full inner content of the rites [8–10].

Vedic recitation demonstrates a distinct mechanism: formal redundancy in oral transmission. The recitational forms of *saṃhitā-pāṭha*, *pada-pāṭha*, *krama-pāṭha*, *jaṭā-pāṭha*, and *ghana-pāṭha* preserve sequence, segmentation, sound, and repetition through multiple ordered pathways. This is not generic memorization. It is an oral error-correction architecture in which deviation becomes more detectable because the same material is encoded and performed in different forms [11, 12, 15].

These cases establish that long-duration, highly structured, and selectively accessible transmission is historically possible.

The Capability Profile Framework

The Capability Profile Framework replaces vague statements such as “advanced civilization” with measurable comparison. It does not assign a culture a universal rank. It compares a specific technical or architectural capability with relevant chronological and regional control groups.

For a monument (M), the framework records six dimensions: procurement; fabrication; surveying and geometry; handling and placement; logistics and throughput; and integrated evidential coverage.

Procurement records source location, material type, mass, transport path, elevation change, and route constraints. Fabrication records shaping, cutting, drilling, surface finish, joint geometry, tool marks, material hardness, tolerances, and production waste. Surveying and geometry record orientation, level, plan regularity, angular deviation, alignment, proportional layout, and error accumulation. Handling and placement record individual block mass, maximum mass, lift height, placement position, lifting geometry, staging area, and evidence for temporary support systems. Logistics and throughput record total material volume, plausible construction window, transport frequency, labour organization, work season, route capacity, provisioning, and achievable daily placement rates. Integrated evidential coverage records the extent to which the full construction chain is supported by direct evidence, strong inference, limited inference, or remains unresolved.

Each dimension has its own comparison logic. Orientation is compared with orientation. Quarry-to-site distance is compared with quarry-to-site distance. Maximum handled mass is compared with maximum handled mass. No global civilizational score is created. Orientation precision is a surveying variable within a multidimensional capability profile. It cannot by itself establish general technological sophistication, construction authorship, quarrying capacity, transport capacity, lifting capacity, or the continuity of an institutional tradition. Each of those propositions requires its own variable and evidence state.

For a numerical variable (x_i), the comparison with a defined reference group is:

$$A_i = (x_i, M - \tilde{x}_i, R) / \sqrt{(u^2_{i, M} + u^2_{i, R} + s^2_{i, R})}$$

where x_i, M is the measured value for the monument, $\tilde{x}_i, R$ is the reference-group median, u represents measurement uncertainty, and $s_{i, R}$ represents reference-group dispersion. Where a lower value represents greater precision, such as angular deviation, the sign is reversed before calculation. Reference distributions, uncertainty propagation, and confidence intervals must be reported for every comparison.

A reference group must be large enough, internally documented, and sufficiently independent to estimate a distribution rather than merely express the difference between two observations.

The metric uses the reference-group median because it identifies the central observed value without allowing a single extreme observation to determine the comparison. The dispersion term records heterogeneity within the reference group, while the uncertainty terms preserve the contribution of measurement error and finite-sample instability. The point estimate and the resampling interval answer different questions: the point estimate locates the target within the specified reference structure, whereas the interval records the range generated by resampling and uncertainty propagation. Every expanded empirical application that is used to support a historical inference about capability change must also report parallel results using justified robust alternatives, including median absolute deviation and interquartile-range scaling where the structure and size of the corpus permit them. A numerical value may not be presented as a standardized comparative result when measurement uncertainty is set to zero as a substitute for unavailable survey information or when the reference set is too small to support a defensible estimate of dispersion.

Evidence State Matrix and Mixed Method Comparison

Numerical comparison is one analytic layer of the Capability Profile Framework, not its entire evaluative mechanism. Procurement routes, temporary support systems, tool traces, construction phases, and the integration of a construction sequence often contain categorical or qualitative evidence that cannot be converted into a defensible common number without concealing the distinction between direct documentation, inference, absence of documentation, and contradiction. The framework therefore uses a fixed Evidence State Matrix alongside A_i . The matrix makes non-numerical findings systematically comparable while preserving the evidential character of each finding.

For every construction phase and operational module, the same four questions are coded: whether the provenance and archaeological context are secure; whether the temporal allocation is secure; whether the finding directly supports the proposed mechanism; and whether an independent source, method, or dataset

confirms it. The resulting state is recorded as direct documentation, convergent inference, compatible but unverified, no documented support, taphonomically non-diagnostic, or contradicted. Direct documentation requires a securely provenanced and temporally assigned record that directly bears on the claimed operation. Convergent inference requires independent lines of evidence that jointly support the operation without directly recording it. Compatible but unverified identifies a finding that permits an explanation but does not establish it. No documented support records the absence of evidence for the claimed operation in the available record. Taphonomically non-diagnostic records a case in which a documented taphonomic model shows that expected traces would probably not survive or would not be recoverable under the relevant conditions. Contradicted records evidence that conflicts with the proposed operation or its necessary conditions.

Taphonomically non-diagnostic is not a positive evidentiary state. It cannot establish a mechanism, fill a gap in an operational chain, or be aggregated with positive evidence. It means only that the absence of a predicted trace is not capable, in that defined context, of counting against the mechanism. The status may be assigned only where the proposed mechanism specifies its expected traces, the physical and depositional history of the site is assessed, the expected preservation of those traces is modelled, and the reason for non-survival is documented.

The matrix is implemented through a published codebook that defines the unit of analysis, the source requirements, and the decision rule for every state. For prospective applications, the codebook is fixed before coding begins. Each coded cell retains its source citation, quotation or observation, chronological assignment, taphonomic assessment where applicable, and explanation of the coding decision. Reproducibility is operationalized through documentary traceability: every categorical assignment identifies the applicable decision rule, the supporting source and precise locator, the alternative state considered where classification is contested, and the reason for its exclusion. The complete coding sheet and source record for an application permit each classification to be inspected, challenged, and independently recoded from the same published criteria. This procedure follows established principles of transparent content analysis while adapting them to archaeological and technical evidence [16]. It permits route constraints, support systems, tool marks, construction phases, and taphonomic loss to be compared across sites without pretending that they are commensurable measurements.

The quantitative metric and the Evidence State Matrix are read together, not added into a global civilizational score. A_i states the position of a numerical property relative to a defined reference distribution. The matrix states what kind of evidence supports each module of the operational chain. A strong numerical contrast cannot convert an unsupported lifting mechanism into direct documentation, and a well-documented transport route cannot by itself account for a separate placement operation. Contradicted evidence remains visible and cannot be averaged away by supporting evidence elsewhere in the profile. Taphonomic non-diagnostic status also remains visible and cannot be converted into confirmation.

If an earlier monument in a defined region has a measurably more demanding capability profile than later local structures, and if later builders are not positively documented to reproduce the relevant profile, capability-specific discontinuity becomes a serious explanatory possibility. This does not prove unknown builders. It prevents continuity from being assumed without evidence.

Data-Grounded Pilot: The Great Pyramid of Khufu

The Great Pyramid of Khufu is an appropriate pilot because it contains unusually rich evidence, exceptional measurable properties, and unresolved questions about the complete construction sequence. The pilot tests whether a construction attribution is supported evenly across the operational chain.

The material record distinguishes several procurement streams. Much core limestone was quarried locally at Giza. Fine casing limestone came from Tura. The Diary of Merer provides direct documentary evidence for the shipment of Tura limestone toward the Giza construction zone during Khufu's reign. Granite used in the chamber system originated at Aswan, hundreds of kilometres upstream [17].

The Merer documentation supports the movement of Tura limestone by boat. Independent palaeoenvironmental research demonstrates that Nile waterscapes facilitated access to the Giza plateau during the pyramid-building period [18]. This establishes a substantial part of the transport chain. It does not itself establish final overland movement, staging arrangements, or lifting procedures for every material type.

The King's Chamber system contains Aswan granite blocks of approximately sixty tonnes. Their presence and placement create a measurable high-demand handling problem: source location, river transport, transition from water to plateau, staging, lifting geometry, final elevation, and installation sequence must be assessed as distinct operations [19]. A solution to long-distance transport does not automatically establish vertical lifting; a solution to lifting does not automatically establish final placement in sequence.

Nell and Ruggles conducted a Total Station survey of the Giza pyramids and associated structures using multiple points along preserved architectural segments rather than relying solely on extrapolated corners. Their survey showed only a slight difference, approximately 0.5 arc minutes, between the north-south axes of Khufu and Khafre and confirmed the unusually close cardinal orientation of the principal Giza pyramids. For the four sides of Khufu, the reported deviations are $-3.6'$, $-3.4'$, $-0.5'$, and $-3.7'$, producing a mean absolute deviation from cardinality of approximately 2.8 arc minutes. Khafre's corresponding values, $-3.8'$, $-4.0'$, $-5.8'$, and $-4.2'$, produce approximately 4.5 arc minutes. Menkaure's mean absolute deviation is approximately 22 arc minutes. The three principal pyramids therefore do not form a uniform orientation-precision series: Khufu and Khafre form a closely aligned high-precision cluster, while Menkaure is materially less close to cardinality on this variable [20].

Direct Pilot Application of the Orientation Metric

The orientation data permit a limited but genuine application of the numerical component of the framework. For the immediate descriptive Giza comparison, the reference group is defined before calculation as the two later principal Fourth-Dynasty pyramids at the same site, Khafre and Menkaure. The orientation variable is coded so that greater precision has the higher value: $x_{\text{orientation}} = -\text{mean absolute angular deviation from cardinality}$. Khufu therefore has $x_{\text{orientation}} = -2.8'$; the two descriptive Giza reference values are $-4.5'$ and $-22.0'$. Their arithmetic median is $-13.25'$, and their sample dispersion is $12.37'$.

$$A^{(0)}_{\text{orientation}} = [-2.8 - (-13.25)] / \sqrt{(0^2 + 0^2 + 12.37^2)} = 0.84$$

The superscript (0) identifies a descriptive calculation in which the uncertainty terms are held at zero because the compact published summary used for this calculation does not provide a harmonized monument-level uncertainty term for all three summary values. It does not imply that survey uncertainty is zero.

This calculation remains useful as a transparent demonstration of the formula's input structure, direction of scoring, and arithmetic workflow. It is not, however, a statistically valid standardized pilot result. The reference group has $N=2$. Its median is only the midpoint of two values, and its dispersion is wholly determined by their separation. It does not estimate the variability of a later Old Kingdom reference population.

Menkaure may not be classified as a formal statistical outlier within a two-case reference group. It is nevertheless a high-leverage divergent case: its value necessarily determines both the reference midpoint and the calculated spacing. The mechanical value $A_{\text{orientation}}(0)=0.84$ therefore describes only the numerical relation among Khufu, Khafre, and Menkaure under a deliberately restricted and uncertainty-free calculation. It may not be used as evidence of a regional chronological law, as a robust effect estimate, or as validation of the full uncertainty-aware metric.

The metric's operational proof of concept now has two deliberately distinct parts. Appendix C is a fully specified synthetic verification of arithmetic, error propagation, resampling intervals, and leave-one-out sensitivity analysis. Appendix D is an empirical computational demonstration using published Total Station orientation measurements from the Khufu complex [20]. Neither exercise is presented as a completed

regional test of chronological capability change: the latter requires a preregistered Old Kingdom monument population with genuinely independent architectural cases.

Khufu lies on the more precise side of this narrowly defined immediate Giza comparison. That descriptive observation is retained. Appendix D shows that the uncertainty-aware metric can also be executed on a real, auditable set of seventeen separately identified architectural units rather than only on synthetic values. Its result is a computational proof of concept, not a historical causal conclusion, because the units derive from one complex and do not constitute an independent regional Old Kingdom control population.

Appendix E provides the first fully published implementation of the orientation metric on a defined Old Kingdom corpus. It separates computational implementation validation from a claim of regional causal change. For an expanded corpus used to support a historical inference, the dataset must record chronological range, monument class, preservation state, survey instrument, number of observed sides or courses, extraction rule, and stated measurement uncertainty. The primary analysis must use only observations meeting published inclusion criteria. Secondary sensitivity analyses must then test the effect of lower-resolution measurements, partially preserved sides, alternative uncertainty models, alternative justified dispersion estimators, and changed reference-group definitions. Independent validation of a historical inference requires a separately assembled corpus, preregistered eligibility criteria, and replication by researchers who did not construct the original dataset.

The pilot therefore produces a structured evidence map rather than a narrative substitute for analysis. Khufu's procurement profile is coded as direct documentation for several major material streams. Its water-transport profile receives direct documentation from the Merer record and convergent inference from the palaeoenvironmental evidence for Nile access. Its high-mass placement profile is materially evident but remains compatible but unverified at the level of integrated lifting, staging, and final placement. Its surveying profile is numerically measurable, directly comparable, and accompanied by an explicit requirement for a statistically defensible reference dataset and uncertainty model. The same matrix can record route constraints, temporary support systems, tool traces, construction phases, and taphonomic loss without collapsing them into a single score.

The appropriate conclusion is neither "construction solved" nor "construction impossible." The result distinguishes documented capability, convergent inference, compatible but unverified operations, taphonomically non-diagnostic gaps, and unresolved integration. It also distinguishes an arithmetical demonstration of a formula from a validated statistical application of that formula. The next empirical phase is a complete comparative dataset including later Egyptian pyramid and temple complexes, with the same variables measured under stated inclusion criteria, published uncertainty terms, and sensitivity analysis.

High Culture Is Multidimensional

The presence of digital technology does not provide a universal measure of civilizational height. Computers, satellites, artificial intelligence, and industrial production indicate extraordinary modern capabilities. They do not demonstrate superiority in every historical domain.

A society may excel in digital computation while lacking the capacity to reproduce a long-duration oral transmission system, build a monument designed to endure millennia with locally available materials, preserve specialist craft knowledge outside industrial supply chains, organize high-precision labour without electronic infrastructure, or maintain symbolic and ritual continuity through long historical ruptures.

The reverse is equally true. An ancient society's exceptional achievement in stonework, astronomy, maritime navigation, acoustics, oral preservation, or calendar calculation does not imply possession of every modern technology.

Cosmological and Inner Knowledge Systems

Capability profiles extend beyond material production. They include codified systems for modelling

cosmological order and for training perception, memory, attention, and self-regulation when these are preserved in institutions, texts, calendars, built environments, or repeatable disciplines. Spiral History tests whether their formal structure, transmission pathway, and practical framework remained continuous, were transformed, or were lost independently of material technology [21, 22].

Extension Module I: Mythic Deep Time and the Global Corpus

Mythological traditions preserve accounts of prior worlds, ages, floods, destructions, survivors, renewals, dynastic resets, and extensive time structures. These records deserve historical attention without being reduced either to literal chronicle or arbitrary fiction.

The comparative project must be global, but it cannot be extractive. It must include Mesopotamian, South Asian, Mediterranean, Mesoamerican, Andean, Indigenous North American, African, Oceanic, and Australian traditions where appropriate source access, linguistic expertise, and community-guided research are available. Indigenous oral traditions are often active systems of historical knowledge, law, place, kinship, and ceremonial responsibility. They cannot be treated as detached data points for externally imposed conclusions [23, 24].

Each corpus entry must identify language, textual or performance history, date range, geographic setting, translation, scholarly commentary, known contact pathways, and exact passage. A coding unit is not an entire “mythology” or “civilization.” It is a specified textual, oral, ritual, or performative unit.

The codebook defines prior order, rupture, survivor or carrier, renewal, and temporal architecture through observable criteria. Every coding decision retains its source, exact passage or performance locator, translation where applicable, category assignment, and reasoning. The designation “uncertain” follows a published decision rule rather than a coder’s intuition. Competing interpretations, translation choices, and unresolved classifications remain visible in the corpus.

For oral and Indigenous traditions, the codebook must be developed with relevant knowledge holders, language specialists, and, where applicable, the community authorized to interpret or transmit the material. It must distinguish publicly shareable evidence from restricted knowledge and must not require disclosure of restricted ceremonial content as a condition of methodological inclusion. A coding decision may identify the existence of a custodial or performative structure without reproducing knowledge that the relevant community does not authorize for publication.

Sensitivity analyses are mandatory. Findings must be recalculated after removing traditions with known contact, after using alternative translations, after changing category thresholds, and after separating late written redactions from independently attested oral or ritual transmission.

Within the framework, mythic comparison is an extension module that tests whether symbolic and narrative continuity can be specified through source history, chronology, transmission, contact control, and documented coding under the published codebook. Its result concerns the evidential structure of a proposed continuity claim and remains analytically distinct from claims about construction authorship, material chronology, or technical capability.

Illustrative Pilot Corpus

The pilot is not a statistical result. It demonstrates transparent coding.

The Sumerian King List contains an explicit pre-flood order. It records eight kings in five cities ruling for 241,200 years, followed by the flood and the re-establishment of kingship in Kish. Prior order, rupture, renewal, and numerical temporal architecture are present. A human survivor or carrier is not established in the selected text and is coded absent [25].

Plato's Atlantis account presents an explicit model of civilizational rupture, lost records, and mediated memory. The narrative reaches Athens through a transmission chain from Egyptian priests, through Solon and the elder Critias, to Critias; later geographical identifications belong to reception history rather than providing evidence of Plato's original referent (Timaeus 20d–25d; Critias 108e–121c) [26].

The Vishnu Purana, particularly Book I, Chapter III, presents yugas, manvantaras, days and nights of Brahma, dissolution, and renewal. Prior order, rupture, renewal, and numerical deep time are present. A specific human survivor transmitting knowledge through every dissolution is not established in the selected passage and is coded uncertain [27].

Hesiod's Works and Days contains successive races or ages: gold, silver, bronze, heroic, and iron. Prior order is present. A singular global rupture is not explicit and is coded uncertain. A surviving carrier is absent. Renewal is absent. Numerical deep time is absent. This is a necessary partial and negative case rather than a confirmation of a full cyclic pattern [28].

Voluspa presents creation, destruction, survival, and renewal. Prior order and rupture are present. Lif and Lifthrasir are explicit survivors. Renewal is present through the emergence of a transformed world. Numerical deep time is absent [29].

The Popol Vuh presents successive creations and failed forms of humanity before the emergence of present humanity. Prior order, termination of earlier creations, and renewal are present. A human survivor carrying institutional continuity from one destroyed humanity into the next is not established in the selected narrative and is coded absent. Numerical deep time is absent [30].

The Maya Long Count provides explicit large-scale calendrical architecture. It is coded as numerical and calendrical deep time. It is not, from the calendar alone, coded as proof of a prior destroyed world, a flood, survivors, or renewal. This negative control prevents a numerical time system from being improperly transformed into catastrophe evidence [31].

Extension Module II: Symmetrical Audit Protocol for Technical Claims

Questions about ancient electrochemical devices, unusual material composition, sound effects in monumental architecture, mineral resonance, illumination, ventilation, drilling, cutting, or astronomical alignment should not be dismissed because they are unusual. Nor should they be admitted because they are striking.

The six conditions are not exceptional hurdles applied only to unconventional proposals. They are symmetrical audit dimensions for every technical explanation, including ramp models, sled and haulage models, rope-pulling systems, internal-ramp proposals, counterweight systems, and any alternative account. The first dimension is provenance: the relevant object, feature, trace, or architectural element must have secure provenance, stratigraphy, and dating. The second is physical feasibility: the proposed operation must be physically specified rather than invoked as a general possibility. The third is contextual fit: materials, users, energy source, maintenance, associated objects, and plausible purpose must fit the wider construction system. The fourth is archaeological traces: residue analysis, use-wear, microstructure, chemical composition, wear patterns, construction scars, and contextual association must be reported where the proposed mechanism predicts them. The fifth is predictive performance: experimental replication must reproduce an effect compatible with the archaeological configuration, not merely demonstrate a modern possibility, and rival explanations must be tested under comparable conditions. The sixth is uncertainty: missing traces, preservation limits, alternative explanations, and unresolved operations must be stated rather than absorbed into an assertion of completion.

No explanation is required to begin with complete confirmation in all six dimensions. Archaeological records are often incomplete, and the loss of organic materials, temporary works, labour records, and use traces affects conventional and unconventional proposals alike. But no explanation may be treated as final where its open dimensions are not identified. A ramp model is not validated merely because ramps are

plausible in general; it must be assessed for route geometry, material volume, construction sequence, traces, throughput, and compatibility with the relevant monument. The same requirement applies to every competing account.

Where expected archaeological traces are absent, the framework does not automatically classify the proposed mechanism as unsupported. It first asks whether the absence is taphonomically diagnostic. The hypothesis must specify the trace it predicts. A taphonomic analysis must then address the trace's material composition, expected deposition, exposure, disturbance history, erosion, reuse, excavation history, and probability of survival or recovery. Only where this analysis shows that the predicted trace would probably not survive, or could not reasonably be expected to be recovered, may the Evidence State Matrix record the status taphonomically non-diagnostic.

This status is not a substitute for evidence. It does not turn an absent ramp, rope, scaffold, wooden sled, earthen platform, organic binding material, labour record, or use trace into confirmation of a proposed mechanism. It means that absence cannot count against the mechanism on that particular evidential dimension. The hypothesis must then be assessed through the remaining dimensions: biomechanical or physical feasibility, route geometry, load path, material volume, construction sequence, throughput, contextual fit, comparative predictions, and explicit residual uncertainty.

A biomechanical model used under this replacement standard must specify the masses, coefficients of friction or mechanical resistance, slope or lift geometry, force requirements, work-team assumptions, anchoring points, materials, sequence of operations, and time requirements. It must be possible to identify what observation would distinguish it from a competing explanation. A mechanism that is merely physically possible remains compatible but unverified. A mechanism that fails the modelled requirements is contradicted. A mechanism that survives the modelled requirements but lacks direct traces because such traces are demonstrably non-preservable remains taphonomically non-diagnostic, not directly documented.

This symmetry prevents a double standard. The framework neither dismisses an unusual hypothesis because it is unusual nor protects a conventional hypothesis because it is familiar. It compares explanations on the same evidential record, specifies which predictions each explanation makes, and records where the archaeological evidence supports, fails to support, is taphonomically unable to decide, or contradicts those predictions.

Objects sometimes described as ancient batteries illustrate the distinction. The possibility of generating voltage under modern experimental conditions is not equivalent to demonstrating ancient electrical use. Their original configuration, archaeological context, associated equipment, and practical function require independent analysis before they can support a technological claim.

The same standard applies to illumination in enclosed ancient spaces. The absence or presence of soot, oxygen constraints, airflow, reflective surfaces, lamp traces, oil residues, and wall alteration must be systematically sampled and reported. A difficulty in one proposed lighting method does not prove another technology. It identifies a research problem.

Acoustic and vibrational claims require architectural measurement, material analysis, repeatable sound testing, environmental controls, and historically plausible use context. Mineral-resonance claims require equally strict physical and archaeological evidence. Conventional construction proposals are audited by the same dimensions: provenance, physical feasibility, contextual fit, archaeological traces, predictive performance, and uncertainty. These technically contested questions form an extension module: they test whether the same evidential disciplines remain operative for unusual proposals while retaining each conclusion within its own material, contextual, and predictive record.

The Modern Regression Thought Experiment

The possibility of regression does not require a claim that ancient societies experienced modern forms of warfare. Contemporary civilization itself provides the analytical model.

A severe systemic rupture involving war, energy failure, ecological breakdown, disease, supply-chain collapse, and educational disruption could leave roads, buildings, machinery, books, data centres, and fragments of technical language while destroying the operational capacity to maintain power grids, manufacture semiconductors, refine specialized materials, reconstruct global logistics, or interpret technical archives.

Later communities could inherit objects they partly understand but cannot reproduce. They could reuse buildings for different purposes, mythologize ruins, retain names without technical meanings, and create new complex societies from incomplete remains.

This demonstrates that material survival and technical survival are separate variables.

Falsification

Spiral History is falsifiable at the level of each mechanism and at the level of the overall framework.

The technological-discontinuity mechanism fails in a particular case if the apparent decline is fully explained by sampling bias, chronological error, resource depletion, or a stronger alternative explanation.

The monumental-inheritance mechanism fails in a particular case if alleged later reception is disproven by re-dating, failed provenance analysis, or contextual reassessment.

The Transmission-Bridge Hypothesis fails when alleged continuity depends only on broad symbolic resemblance; when chronological linkage, an identifiable transmission mechanism, or a concrete continuity marker is absent; or when contrary evidence defeats the proposed bridge. In oral contexts, it also fails when the proposed temporal sequence, custodial mechanism, or formal marker cannot be independently specified or is rejected by the relevant evidence and community context. Multiple superficial similarities cannot compensate for the failure of a necessary condition.

The mythic deep-time hypothesis fails if a published-codebook, contact-controlled comparison reveals no structure beyond ordinary narrative recurrence, translation bias, genealogical relatedness, or selective sampling.

The Capability Profile Framework fails as a useful method if independent applications do not improve clarity, reproducibility, or discrimination among competing construction hypotheses; if the Evidence State Matrix cannot be independently recoded from its published source record and decision rules; if taphonomic assessments cannot distinguish genuinely non-diagnostic absence from ordinary lack of support; or if the numerical metric does not remain stable under transparent changes in reference group, uncertainty treatment, and inclusion criteria. It fails at an individual site if a complete, positively evidenced construction chain accounts for the full measured profile and later local groups demonstrably reproduce the relevant capability.

The overall Spiral History model would be weakened if material persistence, operational capability, public symbolic memory, restricted transmission, and later reception consistently remained coupled through periods of disruption.

Validation Pathway and Scope Conditions

Independent application proceeds through a fixed validation pathway. A research team preregisters the reference population, eligibility criteria, variables, uncertainty treatment, and robust alternative estimators before calculating A_i . The Evidence State Matrix is applied from the published codebook and source record. Each application publishes its coding sheet, source locators, decision rules, taphonomic assessments where relevant, and reasoned resolutions of contested classifications. Cross-regional replication then tests whether a capability-specific contrast recurs where chronology, preservation, and survey quality are independently defined. Appendix E establishes reproducible implementation of the metric on a published $N=13$ Old Kingdom corpus. Independent external validation requires separately assembled comparison corpora and

independent coding teams. The framework is evaluated capability by capability: convergent results strengthen a specified attribution or discontinuity inference, while divergent results identify a boundary condition or a revision requirement. Orientation remains a surveying measure; its interpretation is integrated with the separate evidence states for procurement, fabrication, logistics, handling, placement, symbolic transmission, and later reception.

CONCLUSION

Spiral History adds an evidential layer to research on collapse, resilience, and cultural evolution. It provides a procedure for distinguishing material survival, technical continuity, later reception, symbolic memory, and restricted transmission.

Its central contribution is the Rule of Temporal Attribution. Later use establishes later use. Original construction, original function, and uninterrupted technical understanding require their own evidence.

Its operational contribution is now equally explicit. Numerical variables are tested with a defined reference distribution, propagated uncertainty, resampling intervals, and sensitivity analysis. The simulated proof of concept demonstrates the mathematical operation of the metric; the extended Old Kingdom dataset tests its empirical archaeological application. Qualitative and categorical evidence is coded through an Evidence State Matrix that preserves the difference between direct documentation, convergent inference, compatibility, absence of documented support, taphonomically non-diagnostic absence, and contradiction.

Technical explanations, conventional and unconventional alike, are audited through the same six dimensions.

Spiral History assigns each proposition to the evidence capable of deciding it. Monumental precision remains a variable-specific measurement; mythic material is assessed through transmission, chronology, and corroboration; construction questions are assessed through logistical and material evidence; and attribution follows from demonstrable evidence. The framework specifies the observations capable of revising each result and analyzes later reception independently of original construction and function.

The Giza calculation demonstrates the numerical workflow but does not validate a standardized orientation effect with an $N=2$ reference group. The simulated $N=16$ calculation demonstrates that the formula can handle uncertainty, dispersion, confidence intervals, and sensitivity analysis in practice. The expanded Old Kingdom dataset determines whether the orientation metric yields a stable quantitative contrast in archaeological data.

History is neither an uninterrupted ascent nor simple repetition. Capacities emerge, concentrate, fragment, survive unevenly, become reinterpreted, and can return in altered form. A scientific history of that process begins by refusing to confuse survival with continuity.

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Data Availability Statement

All numerical inputs, extraction rules, uncertainty assumptions, code, and results underlying the simulated and empirical proof-of-concept analyses are included in Appendices C–E. No proprietary dataset was used.

Conflicts of Interest

The author declares that there is no conflict of interest.

AI Usage Statement

Artificial intelligence-assisted tools were used for language editing and readability improvements. The author reviewed and edited all output and takes full responsibility for the accuracy, originality, integrity, and scholarly content of the final manuscript. No artificial intelligence system is listed as an author.

Institutional Review Board Statement

Not applicable. This theoretical study did not involve human participants or animals.

Informed Consent Statement

Not applicable.

Appendix A: Orientation Pilot Calculation and Extension Protocol

The direct orientation pilot uses the four reported side deviations for Khufu, $-3.6'$, $-3.4'$, $-0.5'$, and $-3.7'$, whose mean absolute deviation is $2.8'$. Khafre's reported side deviations, $-3.8'$, $-4.0'$, $-5.8'$, and $-4.2'$, yield $4.5'$. Menkaure's reported mean absolute deviation is approximately $22.0'$. With later Giza successors Khafre and Menkaure as the preregistered descriptive reference set, the arithmetic median is $13.25'$ and the sample dispersion is $12.37'$. Coding precision as the negative of absolute angular deviation gives the mechanical point-estimate calculation $A_i^{(o)orientation} = 10.45/12.37 = 0.84$.

This computation is reported as a descriptive screen only. It preserves the exact numerical relation within the immediate Giza comparison but does not supply a statistically meaningful reference distribution. The calculation is not a validated A_i result because two monuments cannot establish stable population dispersion and because the compact summary inputs do not supply harmonized monument-level uncertainty terms. Appendix D therefore adds a separate real-data computational demonstration with $N=17$ separately identified architectural units, an explicit uncertainty term, and sensitivity analyses. That demonstration validates implementation of the metric, not a regional historical inference. The extended analysis must replace the provisional treatment with the published survey-error model or clearly derived uncertainties for every monument.

The extension dataset must define the chronological reference population before analysis, distinguish original architectural segments from reconstructed or eroded segments, publish all raw side-level measurements, and record why any monument or side is excluded. It must compute A_i for each numerical variable separately, report uncertainty propagation and confidence intervals, and provide sensitivity analyses for alternative reference groups and dispersion estimators. It must include leave-one-out analyses and must not aggregate the results into a universal rank. The purpose is to identify capability-specific contrasts, not to manufacture a civilizational hierarchy.

Appendix B: Evidence State Matrix Codebook

The Evidence State Matrix has one row for each construction phase and operational module and one cell for each claim tested. A cell begins with secure provenance and context, secure temporal allocation, direct relevance to the claimed mechanism, independent confirmation, and an explicit assessment of whether predicted traces are taphonomically recoverable. Direct documentation is assigned only when a source or securely contextualized physical record directly bears on the operation. Convergent inference is assigned when independent evidence lines jointly support an operation without directly documenting it. Compatible

but unverified is assigned when the evidence permits but does not establish the operation. No documented support is assigned when the available record contains no evidence for the proposed operation and no taphonomic analysis shows that relevant traces should be absent. Taphonomically non-diagnostic is assigned only when expected traces are specified and their likely loss or non-recovery is demonstrated through an explicit taphonomic assessment. Contradicted is assigned when evidence conflicts with the claimed operation, its necessary sequence, or its physical conditions.

The codebook requires each cell to retain the source, location, date or phase assignment, evidence type, reasoning, taphonomic assessment where relevant, coder identity, and any dissenting code. Reproducibility is operationalized through documentary traceability: every categorical assignment must identify the applicable decision rule, the supporting source and precise locator, the alternative state considered where classification is contested, and the reason for its exclusion. The complete coding sheet and source record therefore permit each classification to be inspected, challenged, and independently recoded from the same published criteria. The framework compares qualitative evidence through a transparent state system rather than through an unexamined numerical surrogate.

Appendix C: Simulated Quantitative Proof of Concept

The simulated dataset demonstrates the operation of A_i . It is not presented as archaeological evidence, as a reconstruction of the Old Kingdom, or as a claim about Khufu. Its purpose is limited and explicit: to show the treatment of a defined reference distribution, measurement uncertainty, resampling intervals, and sensitivity analysis alongside the empirical Old Kingdom corpus validation.

The simulated reference group contains sixteen independent monument-level orientation deviations, expressed as mean absolute angular deviation from cardinality in arc minutes: 2.9, 3.4, 4.1, 4.8, 5.2, 5.7, 6.3, 6.9, 7.2, 8.0, 8.5, 9.1, 10.0, 10.8, 11.7, and 12.6. The values are deliberately synthetic and fully published so that every calculation is reproducible. Their median is 7.05', and their sample dispersion is 2.959'.

For the demonstration, the target monument has a mean absolute angular deviation of 2.8'. Precision is coded as the negative of angular deviation, so the target value is $x_i, M = -2.8'$, while the reference median is $\tilde{x}_i, R = -7.05'$. The illustrative target-measurement uncertainty is $u_i, M = 0.25'$, and the uncertainty of the reference summary is $u_i, R = 0.35'$. The point estimate is therefore:

$$A_i (\text{simulation}) = [-2.8 - (-7.05)] / \sqrt{(0.25^2 + 0.35^2 + 2.959^2)} = 1.42$$

The calculation was evaluated through 100,000 seeded non-parametric bootstrap resamples of the sixteen reference values. Within each resample, Gaussian draws are made for the target value with standard deviation $u_i, M = 0.25'$ and for the reference median with standard deviation $u_i, R = 0.35'$. The resulting 95 percent simulation interval for A_i is 0.74 to 2.43. The interval remains on the more precise side of the synthetic reference distribution.

The leave-one-out analysis recalculates the estimate after removing each one of the sixteen synthetic reference monuments. The resulting values range from 1.33 to 1.55. The calculation is therefore not driven by one simulated case. This result establishes the mathematical proof of concept: the metric can incorporate uncertainty, report an interval rather than a point estimate alone, and reveal whether a contrast is sensitive to individual reference observations.

The simulation does not validate an archaeological conclusion. That task belongs to the extended Old Kingdom dataset. The simulation validates the computational procedure; the empirical dataset tests whether the procedure remains informative when applied to real monument-level measurements, preservation conditions, survey uncertainties, and historically defined reference populations.

Reproducibility procedure. The simulation uses NumPy default_rng with seed 20261001. It draws 100,000 reference samples of size sixteen with replacement, recomputes the median and sample standard deviation (ddof=1) for every draw, and then draws the target and reference-median values from their stated Gaussian

uncertainty distributions. It recalculates A_i for each draw. The 2.5th and 97.5th percentiles of the resulting 100,000 A values are reported as the percentile interval. The leave-one-out range is recomputed after excluding each of the sixteen values in turn. These steps are sufficient to reproduce the numerical outputs without any unpublished data or discretionary tuning.

```
import numpy as np
ref = np.array([2.9,3.4,4.1,4.8,5.2,5.7,6.3,6.9,7.2,8.0,8.5,9.1,10.0,10.8,11.7,12.6])
target, u_m, u_r = 2.8, 0.25, 0.35
def score(m, s): return (m - target) / np.sqrt(u_m**2 + u_r**2 + s**2)
point = score(np.median(ref), np.std(ref, ddof=1))
rng = np.random.default_rng(20261001); med = np.empty(100000); sd = np.empty(100000)
for k in range(100000):
    b = rng.choice(ref, len(ref), replace=True)
    med[k], sd[k] = np.median(b), np.std(b, ddof=1)
target_draw = rng.normal(target, u_m, 100000)
reference_draw = rng.normal(med, u_r)
boot = (reference_draw - target_draw) / np.sqrt(u_m**2 + u_r**2 + sd**2)
interval = np.quantile(boot, [0.025, 0.975])
loo = [score(np.median(np.delete(ref, j)), np.std(np.delete(ref, j), ddof=1)) for j in range(len(ref))]
point, interval, min(loo), max(loo)
```

Appendix D: Empirical Computational Proof of Concept

This appendix supplies the requested empirical proof of concept for the quantitative metric. It uses published Total Station deviations from cardinality (DFCs) reported for the Khufu complex by Nell and Ruggles [20]. The authors report survey-grid and plate-bearing accuracy at approximately 0.3 arc minutes and distinguish the number of measured points supporting each fitted alignment. The source also warns that three-point fits require additional caution. The target is Khufu's published mean absolute DFC of 2.8'; a lower absolute DFC represents greater cardinal precision.

The real-data reference set contains $N=17$ separately identified architectural units from the Khufu complex: the mortuary temple, KQ2, seven eastern-cemetery mastaba units, three southern-cemetery mastabas, and five western-cemetery mastaba units. The unit of analysis is therefore the architectural structure, not an individual wall or side. One absolute DFC is selected for each unit by a rule fixed before calculation: use the published combined long-axis fit where available; where the source reports two longer-side fits, use their mean absolute DFC; where only one diagnostic fit is published, use that fit. This prevents repeated sides of one mastaba from being counted as separate reference observations. The source values based on three survey points are retained and explicitly marked quality B rather than silently discarded. A quality-A sensitivity analysis retains only units with at least four points.

The full $N=17$ unit-level reference set has a median absolute DFC of 38.0' and sample dispersion $s_{i,R}=62.497'$. Reference-summary uncertainty $u_{i,R}$ is estimated by 100,000 bootstrap resamples of the seventeen units (seed 20261001): $u_{i,R}=29.474'$, the bootstrap standard deviation of the reference median. This term is not the same quantity as $s_{i,R}$. The dispersion records heterogeneity among the individual architectural units; $u_{i,R}$ records finite-sample uncertainty in estimating their median. Both remain in A_i because the metric is an uncertainty-aware comparative index, not a conventional z statistic. The target's measurement uncertainty is conservatively set to $u_{i,M}=0.300'$, following the reported survey accuracy. With precision coded as $x=-|DFC|$, the empirical point estimate is:

$$A_i \text{ (empirical)} = [-2.8 - (-38.0)] / \sqrt{(0.300^2 + 29.474^2 + 62.497^2)} = 0.509$$

Unit-resampled percentile interval. Repeating the unit-level bootstrap 100,000 times and recalculating the score gives a 95% percentile interval of 0.339 to 1.812 (median resampled score 0.540). Leave-one-unit-out point estimates range from 0.465 to 0.655. The stricter quality-A sensitivity set contains ten units with at least four underlying survey points; its bootstrap is separately recomputed, including its own reference-summary uncertainty. It yields $A=1.503$ and a positive 95% resampling interval of 0.799 to 2.894. The full and quality-A analyses therefore demonstrate that the metric remains executable when preservation quality is made explicit. Neither result is evidence that one dynasty, culture, or construction system possessed a globally superior capability, because this proof-of-concept set is site-bound rather than a regional chronological control population.

Reproducible empirical procedure. Table D1 is the complete input. The code below calculates the full unit-level score, its bootstrap interval, the quality-A sensitivity score, and the leave-one-unit-out range. It uses one preselected value per architectural unit and exposes every lower-quality estimate. A future historical test must pre-register a broader, independent Old Kingdom comparison population and retain this same audit trail.

```
import numpy as np
units = np.array([1,15,18,33,27,18,161,57,91,33.5,27,38,106,188,163.5,140,136], float)
quality_a = np.array([1,15,18,33,27,18,57,33.5,27,38], float); target, u_m = 2.8, 0.300
def bootstrap(x):
    rng=np.random.default_rng(20261001); med=np.empty(100000); sd=np.empty(100000)
    for k in range(100000): draw=rng.choice(x,len(x),replace=True);
    med[k],sd[k]=np.median(draw),np.std(draw,ddof=1)
    return med, sd
med,sd=bootstrap(units); u_r=np.std(med,ddof=1)
score=lambda x,u: (np.median(x)-target)/np.sqrt(u_m**2+u**2+np.std(x,ddof=1)**2)
a_point=score(units,u_r); a_boot=(med-target)/np.sqrt(u_m**2+u_r**2+sd**2)
loo=[score(np.delete(units,j),u_r) for j in range(len(units))]
med_a,sd_a=bootstrap(quality_a); u_r_a=np.std(med_a,ddof=1)
a_quality=score(quality_a,u_r_a); a_boot_a=(med_a-target)/np.sqrt(u_m**2+u_r_a**2+sd_a**2)
a_point,np.quantile(a_boot,[.025,.5,.975]),min(loo),max(loo),a_quality,np.quantile(a_boot_a,[.025,.975])
```

Table D1. Unit-level real-data reference input. One preselected DFC per separately identified architectural unit. Quality A: at least four points; quality B: three-point fit retained transparently. Source: Nell and Ruggles [20].

Architectural unit	Preselected fit	Absolute DFC (arc min)	Survey points	Quality
Khufu mortuary temple	East	1	4	A
Queen's pyramid KQ2	East	15	4	A
Mastaba EC 1a 1b	West combined	18	6	A
Mastaba EC 1c 1d	West combined	33	7	A
Mastaba EC 2a 2b	West	27	5	A
Mastaba EC 3c 3d	West combined	18	6	A
Mastaba EC 3e	North	161	3	B
Mastaba EC 4c 4d	West combined	57	4	A
Mastaba EC 4e	North	91	3	B
Mastaba SC 1	East and west mean	33.5	5 and 5	A

Mastaba SC 3	East and west mean	27	4 and 5	A
Mastaba SC 4	East and west mean	38	7 and 5	A
Mastabas WC 2b 3b	North	106	3	B
Mastaba WC 2e	West	188	3	B
Mastaba WC 3a	North and west mean	163.5	3 and 3	B
Mastaba WC 4a	North and west mean	140	3 and 3	B
Mastaba WC 4b	West	136	3	B

APPENDIX E:

Old Kingdom Pyramid Corpus Implementation Validation

Appendix E provides an empirical implementation validation of the orientation metric on a defined Old Kingdom corpus. The corpus contains thirteen separately identified pyramids with reported cardinal-orientation data: Djoser, Sekhemkhet, and Khaba; Meidum, Bent, and Red under Snofru; Khufu; Djedefre; Khafre; Menkaure; Sahure; Neferirkare; and Unas [20, 32, 33]. The unit of analysis is one primary pyramid, not a wall segment. Every pyramid is evaluated once as the target against the remaining twelve pyramids. The resulting thirteen-fold analysis tests reproducible execution, bounded-uncertainty propagation, and sensitivity across an empirical N=13 corpus.

The entry rule is fixed before calculation. For every pyramid, x_i , orientation is the negative of the mean absolute deviation from cardinality across all reported base-side values. When only one side is reported, that value is used. Table E1 records each published symmetric error margin and its exact source locator. Every bootstrap draw uses a uniform distribution bounded by that reported $\pm$ margin. For the metric denominator, the corresponding standard uncertainty is the half-range divided by $\sqrt{3}$. This preserves the bounded meaning of the published measurement margins while propagating their uncertainty consistently. The precision-restricted Khufu sensitivity analysis excludes the three degree-rounded Third-Dynasty entries and tests whether the result depends on those lower-resolution inputs.

For each fold, 100,000 non-parametric bootstrap resamples draw twelve reference pyramids with replacement, apply the published bounded error margin to every sampled reference value, and independently draw the target from its own bounded uncertainty interval. The score uses the reference median, the reference dispersion, and the bootstrap standard deviation of the reference median. The latter expresses finite-sample uncertainty; the dispersion expresses heterogeneity among pyramids. Khufu's fold has a reference median absolute DFC of 23.713', a reference dispersion $s_i, R=220.767'$, and $u_i, R=34.878'$. With $u_i, M=0.173'$, its point estimate is:

$$A_i (\text{Old Kingdom, Khufu}) = [-2.8 - (-23.713)] / \sqrt{(0.173^2 + 34.878^2 + 220.767^2)} = 0.094$$

Khufu's propagated 95% bootstrap interval is 0.054 to 0.546, with a median resampled score of 0.111. The complete thirteen-fold results appear in Table E2. Their signs accord with the predeclared sign convention: a pyramid more precise than its twelve-pyramid reference median receives a positive score, and a less precise pyramid receives a negative score. Khufu, Khafre, Bent, and Red retain positive lower 95% bounds in the complete corpus. The precision-restricted Khufu sensitivity analysis, which excludes the three degree-rounded entries, produces $A_i=1.360$ with a 95% interval of 0.420 to 2.277. The positive directional classification is therefore preserved under the principal data-quality restriction, while the change in magnitude shows that the score is sensitive to reference-corpus composition.

The validation target in Appendix E is the metric: it demonstrates reproducible calculation on a real N>10 corpus, complete target-by-target application, explicit bounded-uncertainty propagation, and a predeclared data-quality sensitivity test. Table E2 records the sign-consistency check defined by the metric's orientation convention, and the code below reproduces both the full corpus and the restricted Khufu sensitivity

calculation with fixed seeds. The historical application is then governed by the same metric together with an independently specified chronological comparison population. That design makes the metric and the historical inference fully inspectable.

Reproducible Old Kingdom corpus procedure. The following code calculates every leave-one-pyramid-out fold, samples both reference and target uncertainty from their published bounded margins, produces Table E2, and reproduces the restricted Khufu sensitivity calculation. The variable values are absolute deviations; the numerator is written as reference median minus target so that a positive result denotes greater target precision.

```
import numpy as np
names=np.array(['Djoser','Sekhemkhet','Khaba','Meidum','Bent','Red','Khufu','Djedefre','Khafre','Menkaure','Sahure','Neferirkare','Unas'])
pyramids=np.array([180.000,660.000,510.000,24.425,10.200,8.700,2.800,48.700,4.450,22.250,23.000,30.000,17.250])
margin=np.array([30.0,30.0,30.0,0.4,0.2,0.2,0.3,1.0,0.3,1.0,10.0,10.0,0.2]); B=100000
def score(ref,ref_h,target,h,seed):
    u_m=h/np.sqrt(3); rng=np.random.default_rng(seed); j=rng.choice(len(ref),(B,len(ref)),replace=True);
draw=ref[j]+rng.uniform(-ref_h[j],ref_h[j])
    med,sd=np.median(draw,axis=1),np.std(draw,axis=1,ddof=1); u_r=np.std(med,ddof=1)
    target_draw=np.random.default_rng(seed+10000).uniform(target-h,target+h,B)
    point=(np.median(ref)-target)/np.sqrt(u_m**2+u_r**2+np.std(ref,ddof=1)**2)
    boot=(med-target_draw)/np.sqrt(u_m**2+u_r**2+sd**2); return point,np.quantile(boot,[.025,.5,.975])
results=[score(np.delete(pyramids,k),np.delete(margin,k),pyramids[k],margin[k],20261002+k) for k in
range(len(pyramids))]
for name,(point,interval) in zip(names,results): print(name,point,interval)
keep=np.array([3,4,5,7,8,9,10,11,12]) # excludes the three degree-rounded Third-Dynasty entries and
Khufu
khufu_restricted=score(pyramids[keep],margin[keep],pyramids[6],margin[6],20261008);
print(khufu_restricted)
```

Table E1. Old Kingdom pyramid corpus and input provenance. Mean absolute DFC is calculated as indicated in the final column. Published symmetric $\pm$ error margins are used as bounded bootstrap half-ranges; their standard-uncertainty equivalents are $\text{margin}/\sqrt{3}$.

Pyramid	Mean absolute DFC (arc min)	Published $\pm$ error margin (arc min)	Source table and extraction
Djoser	180.000	30.0	[33], Table 1; reported side value
Sekhemkhet	660.000	30.0	[33], Table 1; reported side value
Khaba	510.000	30.0	[33], Table 1; reported side value
Meidum	24.425	0.4	[33], Table 1; mean sides
Bent Pyramid	10.200	0.2	[33], Table 1; mean sides
Red Pyramid	8.700	0.2	[33], Table 1; reported E-side value
Khufu target	2.800	0.3	[20], Table 1b; mean sides
Djedefre	48.700	1.0	[33], Table 1; mean sides
Khafre	4.450	0.3	[20], Table 3b; mean sides

Menkaure	22.250	1.0	[20], Table 5c; mean courses
Sahure	23.000	10.0	[32], Table 1; reported value
Neferirkare	30.000	10.0	[32], Table 1; reported value
Unas	17.250	0.2	[33], Table 1; mean sides

Table E2. Complete leave-one-pyramid-out implementation validation of the orientation metric. Each interval includes reference resampling and independent bounded uncertainty draws for reference and target values. The final column records the sign convention and is not an independent external validity criterion. An indeterminate classification is assigned when the 95% bootstrap interval crosses zero; under the specified resampling and uncertainty model, the direction of the target's deviation from the reference median is therefore not resolved. Displayed values are rounded to three decimal places.

Target pyramid	A_i point estimate	95% bootstrap interval	Sign-consistency check
Djoser	-0.699	-5.085 to -0.439	less precise
Sekhemkhet	-4.334	-27.573 to -2.766	less precise
Khaba	-2.590	-21.051 to -1.611	less precise
Meidum	-0.008	-0.197 to 0.347	indeterminate
Bent	0.060	0.013 to 0.415	more precise
Red	0.067	0.026 to 0.425	more precise
Khufu	0.094	0.054 to 0.546	more precise
Djedefre	-0.116	-0.789 to 0.220	indeterminate
Khafre	0.086	0.047 to 0.496	more precise
Menkaure	0.007	-0.154 to 0.360	indeterminate
Sahure	0.002	-0.191 to 0.352	indeterminate
Neferirkare	-0.033	-0.338 to 0.327	indeterminate
Unas	0.029	-0.058 to 0.378	indeterminate

REFERENCES

1. Tainter, J. A. (1988). *The Collapse of Complex Societies*. Cambridge University Press.
2. McAnany, P. A., & Yoffee, N. (Eds.). (2010). *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire*. Cambridge University Press.
3. Butzer, K. W. (2012). Collapse, environment, and society. *Proceedings of the National Academy of Sciences*, 109(10), 3632–3639. DOI: 10.1073/pnas.1114845109
4. Middleton, G. D. (2017). *Understanding Collapse: Ancient History and Modern Myths*. Cambridge University Press.
5. Mesoudi, A. (2011). *Cultural Evolution: How Darwinian Theory Can Explain Human Culture and Synthesize the Social Sciences*. University of Chicago Press.
6. Henrich, J. (2015). *The Secret of Our Success: How Culture Is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter*. Princeton University Press.
7. Miton, H., & DeDeo, S. (2022). The cultural transmission of tacit knowledge. *Journal of the Royal Society Interface*, 19(195), 20220238. DOI: 10.1098/rsif.2022.0238
8. Andocides. (1998). *Antiphon and Andocides*. Edited and translated by Michael Gagarin and Douglas M. MacDowell. University of Texas Press.
9. Burkert, W. (1987). *Ancient Mystery Cults*. Harvard University Press.
10. Mylonas, G. E. (1961). *Eleusis and the Eleusinian Mysteries*. Princeton University Press.
11. Staal, F. (1986). *The Fidelity of Oral Tradition and the Origins of Science*. North-Holland.
12. Witzel, M. (2003). Vedas and Upaniṣads. In G. Flood (Ed.), *The Blackwell Companion to Hinduism* (pp. 68–101). Blackwell.
13. Erb-Satullo, N. L. (2021). Technological rejection in regions of early gold innovation revealed by geospatial analysis. *Scientific Reports*, 11, 20255. DOI: 10.1038/s41598-021-98514-7
14. López Luján, L., & De Anda Rogel, M. (2017). Teotihuacan en Mexico-Tenochtitlan: Descubrimientos recientes, nuevas perspectivas. *Estudios de Cultura Náhuatl*, 54, 17–60.
15. Wilke, A., & Moebus, O. (2011). *Sound and Communication: An Aesthetic Cultural History of Sanskrit Hinduism*. De Gruyter.

16. Krippendorff, K. (2018). *Content Analysis: An Introduction to Its Methodology* (4th ed.). Sage.
17. Tallet, P. (2017). *Les Papyrus de la Mer Rouge I: Le Journal de Merer*. Institut français d'archéologie orientale.
18. Sheisha, H., Kaniewski, D., Marriner, N., Djamali, M., Younes, G., Chen, Z., El-Qady, G., Saleem, A., Véron, A., & Morhange, C. (2022). Nile waterscapes facilitated the construction of the Giza pyramids during the 3rd millennium BCE. *Proceedings of the National Academy of Sciences of the United States of America*, 119(37), e2202530119. DOI: 10.1073/pnas.2202530119
19. Scheuring, S. A. (2025). Construction of the Great Pyramid with pulley-like systems using counterweights on sliding-ramps. *npj Heritage Science*, 13, 473. DOI: 10.1038/s40494-025-02018-w
20. Nell, E., & Ruggles, C. (2014). The orientations of the Giza pyramids and associated structures. *Journal for the History of Astronomy*, 45(3), 304–360. DOI: 10.1177/0021828614533065
21. Assmann, J. (2011). *Cultural Memory and Early Civilization: Writing, Remembrance, and Political Imagination*. Cambridge University Press.
22. Hadot, P. (1995). *Philosophy as a Way of Life: Spiritual Exercises from Socrates to Foucault*. Blackwell.
23. Atalay, S. (2012). *Community-Based Archaeology: Research with, by, and for Indigenous and Local Communities*. University of California Press.
24. Vansina, J. (1985). *Oral Tradition as History*. University of Wisconsin Press.
25. Electronic Text Corpus of Sumerian Literature. (2006). The Sumerian king list: translation, text 2.1.1. University of Oxford. URL: <https://etcsl.orinst.ox.ac.uk/section2/tr211.htm>. Accessed: 1 October 2026.
26. Plato. (1997). *Timaeus and Critias*. Translated by Donald J. Zeyl. In J. M. Cooper (Ed.), *Plato: Complete Works*. Hackett.
27. Wilson, H. H. (Trans.). (1840). *The Vishnu Purana: A System of Hindu Mythology and Tradition*. John Murray.
28. Hesiod. (1978). *Works and Days*. Edited with prolegomena and commentary by M. L. West. Clarendon Press.
29. Larrington, C. (Trans.). (2014). *The Poetic Edda (Revised ed.)*. Oxford University Press.
30. Tedlock, D. (Trans.). (1996). *Popol Vuh: The Definitive Edition of the Mayan Book of the Dawn of Life and the Glories of Gods and Kings (Revised ed.)*. Simon and Schuster.
31. Coe, M. D., & Van Stone, M. (2005). *Reading the Maya Glyphs (2nd ed.)*. Thames and Hudson.
32. Spence, K. (2000). Ancient Egyptian chronology and the astronomical orientation of pyramids. *Nature*, 408, 320–324. DOI: 10.1038/35042510
33. Puchkov, A. (2023). Multi-star target model for astronomical orientation of the Old Kingdom Egyptian pyramids. *Shodoznavstvo*, 91, 3–68. DOI: 10.15407/skhodoznavstvo2023.91.003