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Cultural Ecosystem Services and Sense of Place Diagnostic Model for Heritage Cities in the Global South

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Abstract

Compound crises of heritage cities in the global south led to the destruction of both physical and intangible assets, as well as the processes and relationships that sustain them; nevertheless, while there is more awareness regarding the importance of intangible heritage, regeneration approaches after the crisis period still focus on tangible losses, while the intangible cultural aspects are often overlooked in planning, especially under conditions of restricted field access. This paper proposes a remote-first CESSOP diagnostic model (CSDM), integrating CES and SOP in four decision-focused products: Crisis Pressure Profile (CPP), Biocultural Asset Map (BAM), CESSOP Vulnerability Matrix (CSV), and modeling and Action Typology and Priority Pathways (ATPP), rather than adopting an existing framework. The Cultural Ecosystem Services and Sense of Place Diagnostic Model (CESSOP Diagnostic Model). The CSDM is new; it is a theoretically constructed, theoretically grounded, crisis-sensitive diagnostic methodology designed for heritage cities under conditions of data scarcity and restricted field access. This approach includes aspects of document research, open-source data, environmental morphological intelligence, social networks and remote participation inputs, supported with embedded confidence rating. The methodology is illustrated by a study of old Sana'a, Yemen, and it is applied in cases when there are few opportunities for direct observation.

Keywords: CES; Sense of Place; crisis urbanism; biocultural heritage; historic urban landscape; old Sana'a

1. Introduction

Urban regeneration is defined technologically, involving the maintenance of existing constructions, repair of facades, and improvements to infrastructure. Such an interpretation assumes particular importance during crises, since in such situations the extent of physical damage can be measured, financed, and acted upon [1,2]. However, heritage involves more than physical structures. It is an active process of meaning making, wherein identity, memory, social ties, and culture are maintained through markets, paths, ritual performances, and public spaces [3–6]. If the relational components are also lost along with physical deterioration, regeneration may be socially futile: people do not return, trust is not rebuilt, and cultural life does not restart even when buildings are restored [7,8].

Intangible losses become mostly unnoticeable during crisis situations. For example, even if a street remains intact in its physical structure, the culture of crafts associated with

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it could be lost. Similarly, a market could reopen but fail to regain its community cohesion and safety [8,9]. It is more than an indirect consequence; it will decide whether regeneration is sustainable socially and politically. In addition, planning approaches have been unable to integrate culture due to lack of fieldwork research [10,11].

In most cases, two ways of filling this gap can be applied. Cultural Ecosystem Services (CES) represent a systematic method to evaluate the non-material values related to such aspects as heritage, identity, inspiration, and cohesion [12–15]. In turn, the concept of Sense of Place (SOP) explains how people develop relationships with their environment based on identification, attachment, and use [16–18]. Despite their similarity, these concepts have rarely been used together within the framework of space-making instruments. This challenge is exacerbated in the Global South, where large sections of crisis-affected heritage cities are neglected by CES studies [19,20]. Such contexts combine rich biocultural systems with governance fragility and constraints in resources and access to data [21–23] where standard methods can be challenging to apply.

The purpose of this study is to address these gaps by using a model of diagnosis, a crisis-capable and remote-first model, referred to as the CESSOP Diagnostic Model (CSDM), where both CES and SOP are brought together under one “diagnosis-to-action” framework. The outputs from the CESSOP diagnostic model are four main ones: (i) Crisis Pressure Profile (CPP); (ii) Biocultural Asset Map (BAM); (iii) CESSOP Vulnerability Matrix (CSVM); and (iv) Action Typology and Priority Pathways (ATPP). Following the historic urban landscape approach by UNESCO [23], this model makes an operational use of culture without conflating measurements and classification.

Against this backdrop, this study addresses three research questions:

- RQ1: How can Cultural Ecosystem Services (CES) and Sense of Place (SOP) be integrated into a spatially explicit, crisis-applicable diagnostic framework for heritage cities in the Global South?
- RQ2: What methodological steps are required to construct a model that operates under conditions of restricted field access and severe information scarcity?
- RQ3: How can such a model translate multi-dimensional cultural meaning assessments into actionable, spatially prioritized intervention decisions?

2. Theoretical Framework

2.1. Cultural Ecosystem Services (CES): From Typology to Actionable Evidence

In this regard, CES offers an organized system to measure non-tangible place-based values like identity, cohesion, heritage values, and social practices. Though originally coined within the millennium ecosystem assessment (MEA) [12], subsequent studies have made a clear distinction between experiential values (such as esthetic values, recreation values), and relational values (identity, social cohesion values) which are co-produced as a result of the interaction between human beings and their environment [13,24].

Nevertheless, CES has been poorly operationalized in spatial planning, especially in situations of crisis and information scarcity [25,26]. Even though the scope of CES was extended to incorporate relational values through various conceptual frameworks such as IPBES, the conversion of this concept to decision-support instruments is still inadequate [19,21,22].

Under conditions of crises, CES cannot be considered an additional advantage but should be regarded as a constituent element of resilience because disruptions to markets, rituals, and social processes necessarily result in the loss of social organization and cultural significance [8,27]. Thus, the role played by CES explains its presence in the CPP and CSVM modules.

2.2. Sense of Place: Affect, Meaning, and Commitment

A Sense of Place (SOP) is a concept that illustrates how people develop attachments to places not only by virtue of their physical qualities. SOP is derived from humanistic geography [3,28], but it was later adopted in environmental psychology. SOP encompasses the connections between personal identity, emotions, and behavior in relation to a particular location. This concept is categorized into person, process, and place by Scannell and Gifford [16].

Empirical evidence demonstrates that SOP has direct effects on heritage preservation, community resilience, and stewardship behavior [18,29,30]. In this study, the construct of SOP is conceptualized into three basic elements—emotion, meaning, and commitment—to differentiate between affective bond and involvement.

Nevertheless, most empirical analyses on SOP concentrate on static settings. Under crisis conditions, the affective bond can remain stable, strengthen, or break down, resulting in a latent or controversial relationship with the environment [31,32]. It is crucial to capture such nuances, and the current framework operationalizes SOP into measurable indices grounded in crisis conditions.

2.3. Integration Rationale: CES and SOP as Complementary Diagnostics

While CES and SOP tackle connected yet different problems, with CES identifying non-material resources offered by the environment, and SOP quantifying their significance as perceived through identity, memory, and action, the two tend to correspond in stable conditions but can diverge in times of crisis when meaning may endure even as delivery fails, or attachment may survive physical disconnection, manifesting its latent potential [8,21,33].

Combining CES and SOP within one diagnostic tool enables differentiation between them and thus prevents the assumption of heritage damage being solely tangible and cultural connection being immutable. It also addresses calls for a relational perspective accounting for values generated collaboratively through practice [34–36] and fits into socio-ecological resilience theory [37,38], where resilience is viewed as the ability to cope with stress, maintain identity, and transform, necessitating knowledge of what is affected and what cultural processes remain possible to aid recovery [8,27].

To better position the proposed framework within existing scholarship, a structured comparison was conducted between the CSDM and established approaches, including the UNESCO historic urban landscape (HUL) framework, ICOMOS heritage assessment approaches, heritage values and character assessment (HVCA), culture counts, and previous CES–SOP studies. The comparison demonstrates that while previous approaches have addressed Cultural Ecosystem Services, Sense of Place, or heritage vulnerability separately, none integrate these components within a unified, remote-first diagnostic workflow specifically designed for crisis-affected heritage environments with explicit uncertainty assessment and spatial prioritization mechanisms.

The case for integrating CES and SOP rests on three convergent scientific foundations:

- **Foundation I: Relational CES ontology**—The notion of CES as relational values emanating out of human relationships to practices and landscapes has become more prominent recently [13,24,34–36]. As a result, evaluation of such CES requires attention to be paid to the issues of social meaning, attachment, and commitment, which are essential to research into SOP wellbeing [16–18]. In the CSDM, this relation is achieved through the use of the Biocultural Value Score (BVS).
- **Foundation II: Vulnerability science in socio-ecological systems**: according to Turner et al. [39], vulnerability arises out of exposure, sensitivity, and adaptive capacity. In terms of CSDM, exposure corresponds to CPS; whereas, BVS stands for cultural sen-

sitivity (number of values at stake). The relationship between these variables can be formulated as:

$$\text{CMCI} = \text{CPS} \times \text{BVS}. \quad (1)$$

- Foundation III: For adaptive governance of the commons—CSDMs [37,40] support the notion of spatial diagnosis and evidence-based policy making under uncertainty. This concept finds its application in the CSDM framework based on modularity of the framework, the certainty annotations provided by the framework, and also the differentiation into remote-first and field-calibrated approaches. No other framework incorporates the concepts of CES and SOP in such a novel way, which makes this the main contribution of the current research.

2.4. Why Old Sana'a?

Old Sana'a was selected as an illustrative case because it represents one of the world's most significant historic urban landscapes affected by prolonged conflict and restricted accessibility. As a UNESCO World Heritage Site, it embodies a rich combination of tangible heritage and intangible cultural values while facing severe threats from armed conflict, environmental degradation, and limited conservation capacity [24,41,42]. These conditions make conventional field-based assessment methods difficult to implement and therefore provide an appropriate context for demonstrating the potential of a remote-first diagnostic framework. The case is presented solely to illustrate the analytical workflow of the proposed CSDM rather than to generate validated empirical findings or site-specific management recommendations. Consequently, old Sana'a serves as a representative example for examining how documentary evidence, spatial information, and remote data sources can be integrated into a transparent and transferable diagnostic methodology for heritage cities experiencing restricted field access.

3. Materials and Methods

3.1. Research Design and Epistemological Position

Development of the CESSOP Diagnostic Model (CSDM)

A conceptually based model-building approach which draws upon a combination of systematic literature review as shown in (Figure 1), theory synthesis, systematic indicator derivation, and illustrative case analysis was used to develop the CESSOP diagnostic model [43]. In adopting this approach, the research has taken a post-positivist mixed-evidence perspective where both quantitative measures of space and qualitative measures of culture play a role [14,44]. There were no primary empirical datasets created; rather, the model was developed using publicly accessible secondary data sources and demonstrated through an illustrative, non-empirical case study of old Sana'a, Yemen.

3.2. Model-Building Steps

Unlike existing heritage assessment frameworks, the proposed CSDM is specifically designed as a remote-first diagnostic model integrating CES and SOP under conditions of limited field accessibility. Contextual value identification: prior to the application of the CSDM, the local cultural value system should be identified through heritage documentation, historical records, local planning documents, and expert knowledge. This preliminary step ensures that the interpretation of Cultural Ecosystem Services (CES) and Sense of Place (SOP) reflects the socio-cultural, religious, and historical characteristics of the study area before indicator scoring is undertaken. The model was developed in seven sequential, traceable steps as shown in (Figure 1).

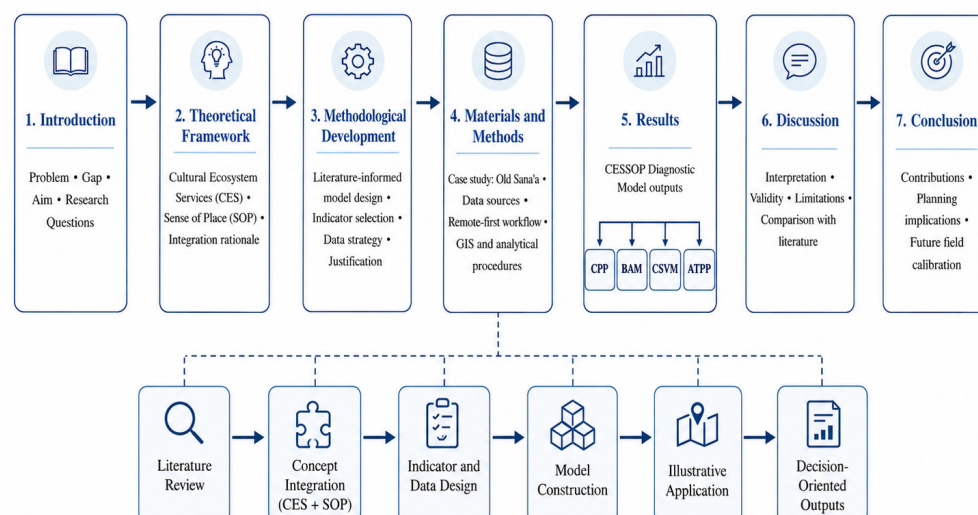


Figure 1. Simplified overall chapter structure and methodological workflow of the study (own figure, 2026).

Step 1—Literature Review and Problem Statement: A literature review was carried out for the following references—heritage crisis framework [45], the Sendai Framework [46], CURE Initiatives by World Bank, UNESCO [2,47], and CES/SOP. To the best of our knowledge, no previous framework has integrated these components within a remote-first, crisis-oriented diagnostic workflow. Existing frameworks such as UNESCO HUL, ICOMOS guidelines, and HVCA approaches primarily rely on field-based assessments and physical condition indicators. While CES and SOP concepts are increasingly integrated into heritage studies, most existing models do not operationalize these constructs in a structured, remote-first diagnostic workflow suitable for crisis conditions with limited access as it shows in Table 1.

Table 1. Conceptual comparison of selected heritage assessment frameworks based on characteristics reported in the literature and the proposed CSDM framework.

Framework	CES/SOP In-Field De- tegration	pence	Crisis Applica- bility	Remote Capa- bility
UNESCO HUL [1,8,23]	Partial	High	Medium	Low
ICOMOS [2,10,47]	Low	High	Medium	Low
HVCA models [21,22,31]	Medium	High	High	Medium
CSDM (this study)	High (inte- grated CES + Low SOP)		High	High (remote- first)

The qualitative ratings presented in Table 2 are based on the documented scope and operational capabilities reported in the cited references. They are intended as a comparative synthesis rather than a quantitative evaluation and serve to position the proposed CSDM relative to existing heritage assessment frameworks.

Table 2. Data Priority Matrix for the CSDM remote-first diagnostic workflow.

Component	Indicator	Primary Source	Proxy Source	Spatial Method	Confidence
CPP—Physical	Building condition	Municipal- ity/UNESCO	Satellite imagery; field photos	Density/overlay	Medium

CPP—Access	Route disruption	Authority/NGO maps	Interviews; network reconstruction	Impedance analysis	Medium
CPP—Socio-economic	Craft and market activity	Craft associations	Remote interviews; proxy mapping	Density change	Low–Medium
CPP—Environmental	Flood susceptibility	Hydrological records	DEM flow accumulation	Weighted overlay	Medium
CPP—Governance	Institutional capacity	Legal/UNESCO documents	Key informant input	Index scoring	Low
BAM	Tangible/intangible assets	Heritage inventories	Remote mapping; diaspore mapping	Point/route/polygon	Medium
CSVM	Status classification	Triangulated evidence	Document analysis; coding	Matrix classification	Variable
ATPP	Priority action rank	CMCI+ status logic	Expert review	Decision matrix	Medium

Step 2—Concept Selection (CES and SOP): CES (Cultural Ecosystem Services) was selected for the conceptualization of the existence of intangible values, such as those related to identity, social bonding, spirituality, heritage values, and knowledge transfer [12,13,33,36]. SOP (Sense of Place) was selected to help understand how people build relationships with certain places. While the humanistic perspective offered by Tuan [3] and Relph [4] on the concept of place as a lived experience is very useful, Scannell and Gifford [13,16], Jorgensen and Stedman [48], and Lewicka [18] have provided practical approaches to understanding place attachment and related attitudes towards place. The selection of CES and SOP is justified, since CES identifies the existence of intangible values, while SOP explains the degree of association with these values.

Step 3—Design Requirements Formulation: The five operational requirements were derived from the gap analysis and critical assessment of existing frameworks: (i) remote feasibility; (ii) cultural sensitivity; (iii) spatial explicitness; (iv) actionability; and (v) transparency under uncertainty. These requirements constrained every subsequent design decision. Full elaboration is provided in Section 3.6.

Step 4—Indicator Selection and Derivation: The indicators were systematically derived from peer-reviewed methodological and empirical literature, then adapted to the specific conditions of crisis-affected heritage cities. For Module 1, pressure indicators were informed by satellite-based damage assessment methods [10,11], urban network analysis, displacement and socio-economic proxy approaches, and GIS-based environmental vulnerability methods. For Module 2, CES bundle categories were derived from established CES typologies, particularly Chan et al. [13,33] and IPBES [36]. For Module 3, SOP dimensions were based on place attachment and place-related attitude frameworks developed by Scannell and Gifford [16,17], Jorgensen and Stedman [48], and Lewicka [18]. The adaptation of these indicators to crisis conditions was guided by Turner et al.'s vulnerability framework [39] and Folke's resilience framework [6,38]. For each indicator, the source literature, adaptation logic, data source, proxy option, and confidence level are specified in the Data Priority Matrix.

Step 5—Data Sources and Collection Strategy: The CSDM incorporates a remote-first approach tailored to situations involving limited field access. In this study, data related to the spatial/physical context will be derived from the UNESCO monitoring report [41], open satellite imagery, heritage inventory information, and relevant spatial databases. Cultural/intangible data will be acquired from ethnographic publications, documentary references, archival information, heritage reports, and cultural documentation that is publicly available. Data for institutional/governance analysis will be gathered from policies, conservation reports, conflict documentation, and expert opinion as needed.

The CSDM, being a diagnostic tool, is also structured to enable a future validation of the model remotely using online structured interviews, diaspora participatory mapping, and photo-elicitation methods if ethical clearance and field access are possible. This does not constitute the actual field methodology of this paper; however, these validation techniques form part of the model design for future validation purposes. All existing and future potential data sources have been compiled into the Data Priority Matrix (Table 3) based on primary sources, proxies, spatial methodologies, and level of confidence for the relevant components of the CSDM.

Table 3. Evidence-to-score translation framework.

Score	Interpretation	Description
0.00	Absent	No evidence identified
0.25	Weak	Limited or isolated evidence
0.50	Moderate	Repeated evidence from multiple sources
0.75	Strong	Extensive evidence with consistent support
1.00	Very Strong	Extensive and unequivocal evidence from numerous independent sources

Step 6—Model Construction and Module Integration: These four modules have been designed in such a way that their application follows an evidence-based diagnostic sequence. The Crisis Pressure Profile (CPP) first defines the crisis conditions affecting the heritage system. The Biocultural Asset Map (BAM) then identifies the cultural assets, practices, and meanings that may be exposed to these pressures. The CESSOP Vulnerability Matrix (CSVM) evaluates how vulnerable each asset is, while the Action Typology and Priority Pathways (ATPP) translates this diagnosis into spatially prioritized planning actions. The scoring criteria are informed by vulnerability science [39], socio-ecological resilience theory [6,38], and place attachment scholarship [16,18,48]. In this way, each module builds on the previous one, creating a transparent evidence chain from crisis conditions to practical intervention priorities.

Step 7—Illustration Case Test Site Selection: The test site chosen for illustration is that of Old Sana’a in Yemen. This illustration case is just what it is meant to be. That is, no field data have been collected. The purpose of choosing this particular example case study is to illustrate the reasoning process and outputs that result from using this approach without much information.

3.3. Case Study Selection: Old Sana’a, Yemen

The example of old Sana’a was chosen for the illustrative purposes because it satisfied four conditions: (i) its recognition as a UNESCO World Heritage Site along with significant research concerning its biocultural importance [41,42]; (ii) its current state of crisis as well as limited possibilities to work with the site in practice that makes it perfectly suitable for representing the model’s area of application; (iii) the presence of reliable secondary literature including UNESCO monitoring reports, academic works, and heritage inventories, as well as open spatial datasets and archive materials; and (iv) the typological diversity of the case, with the simultaneous presence of tangible built heritage and intangible cultural practices in conditions of crisis.

3.4. Indicator Derivation: Source Literature and Adaptation Logic

The indicators were developed through a deductive–adaptive process. Established empirical and methodological literature provided the initial indicator families, while the final indicator structure was refined to address crisis conditions, restricted field access, data scarcity, and the specific heritage context of Old Sana’a:

- Physical Pressure: Derived from satellite-based damage-assessment methods [10,11]; adapted using weighted density classification for compound-crisis built environments.
- Accessibility Pressure: Derived from urban network analysis and pedestrian accessibility research; adapted using impedance analysis for crisis-related movement restrictions.
- Socio-economic Pressure: Derived from displacement and economic-contraction proxy studies [8,22,49]; adapted for data-scarce contexts using mixed-evidence triangulation.
- Environmental–Climatic Pressure: Derived from DEM-based GIS vulnerability methods (slope, flow accumulation); adapted to the earthen construction materials characteristic of Old Sana’a.
- Governance–Institutional Pressure: Derived from institutional capacity frameworks [50]; adapted through expert-informed indexing for fragmented authority under conflict.
- CES Bundle Categories: Derived from Chan et al. [13,33] and IPBES [36] typologies; cross-referenced with UNESCO Intangible Cultural Heritage categories [41].
- SOP Dimensions (affect, meaning, commitment): Derived from Scannell and Gifford’s tripartite model [16,17]; operationalized using Lewicka’s measurement approaches [18].

Transference from literature into context-specific applications corresponds to the theoretical paradigm of Turner et al. [50]. In the CSDM, the CPP reflects the exposure component, while the BVS reflects cultural sensitivity or value of the cultural resource. Adaptive capacity is an integrated part of ATPP by providing alternative action strategies. The linkages ensure that the indicators chosen have a firm grounding in theory.

3.5. Data Sources and Confidence Assessment

Given the model’s remote-first design requirement, data collection follows a tiered confidence strategy:

- Tier 1 (High confidence): Spatially explicit open data—UNESCO World Heritage records [41], open street map network data, DEM-based topographic analysis. These form the quantitative spatial backbone of Module 1 (CPP).
- Tier 2 (Medium confidence): Documentary and archival data—heritage inventories, damage reports, ethnographic literature, historical plans. These populate the biocultural asset layer (Module 2/BAM).
- Tier 3 (Lower confidence): Remote and proxy data—structured interviews with community members and diaspora; proxy indicators such as activity-density changes and market documentation. These inform the qualitative dimensions of CES and SOP assessment (Module 3/CSVM).

All data sources are systematically documented in the Data Priority Matrix (Table 3), which specifies for each module component: the primary source, proxy alternatives, the spatial method applied, and the assigned confidence level. This confidence-tagging system directly implements Design Requirement 5 (Disclosure under uncertainty), elaborated in Section 3.6.

3.6. GIS Analytical Workflow

The process of spatial analysis methodology is based on a four-module structure. Module 1 (CPP) deals with five pressure domains that are analyzed separately using specific GIS techniques designed for that particular pressure domain, including physical pressure measured by weighted damage density obtained by satellite images and documents;

accessibility pressure, which is calculated by reconstruction of networks and impedance; and environmental pressure, computed by slope and flow accumulation from DEM. The values of each pressure domain are scaled to a range of [0, 1] and combined with a composite pressure equation (Equation (1)). While tangible resources, such as markets, ritual sites, crafts workshops, and cisterns, are mapped under Module 2 (BAM) with reference to heritage inventories and historic plans, the intangible cultural uses of various places are determined by virtue of participation and document-based data and categorized using CES and SOP. The computation of BVS follows the method prescribed by Equation (2). Spatial results from Module 1 and module 2 are then combined in module 3 (CSVM), wherein the CMCI will be determined according to the formula in Equation (3). GIS analyses shall be done using open-source software like QGIS 3.40 (Bratislava), PostgreSQL/PostGIS or pgRouting.

3.7. Design Requirements for a Crisis-Ready Diagnostic Tool

Based on the theoretical synthesis presented above and critical assessment of current heritage risk frameworks such as UNESCO's HUL [45], Sendai Framework [46], World Bank UNESCO CURE Framework [47], and post-conflict heritage risk assessment studies [22,23,40], the following design criteria were determined for the CSDM:

- Remote feasibility: The process must be capable of operating with open data about space, remote sensing, proxy methods, documentation, and participatory processes, without the necessity of field presence continuously.
- Culture sensitive: The indicator categories should be compatible with more than just Euro-American valuation systems and not apply any external typologies that misinterpret heritage values [20,26,35].
- Explicitly spatial: The outputs must be maps or explicit spatial classifications; not just qualitative descriptions, in order to allow spatial prioritization of regeneration efforts.
- Actionable: Each diagnostic outcome should have a clear route towards decision-making, in order to ensure the link between diagnosis and intervention [2,47].
- Disclosure under uncertainty: The process should distinguish explicitly between what is measurable with certainty (physical damage density, network metrics), and what is known with different degrees of certainty (CES–SOP status categories).

The above criteria altogether define the CSDM process as one of diagnostic staging: remote-first diagnostics remote validation field calibrations when possible. Not as a substitute for field work, but rather an opportunity to define a principled pathway that allows for early decision support [2,10].

3.8. Data Priority Matrix

The data strategy distinguishes between preferred data sources, proxy alternatives as it shows in Table 2, spatial methods, and confidence levels. This is essential for making the remote-first methodology transparent.

3.9. Operational Scoring Protocol and Evidence Translation Framework

To improve transparency, replicability, and methodological consistency, the Cultural Ecosystem Services and Sense of Place Diagnostic Model (CESSOP Diagnostic Model) employs an explicit evidence translation framework that converts qualitative documentary evidence into standardized numerical scores. A five-point ordinal scale was adopted because it provides sufficient granularity for qualitative assessment while maintaining interpretability and reducing coder ambiguity.

3.9.1. Evidence-to-Score Translation Scale

Qualitative evidence was converted into normalized scores ranging from 0.00 to 1.00 using the following ordinal scale shown in (Table 3):

This scoring framework was designed to facilitate transparent conversion of qualitative documentary evidence into standardized indicators. For example, spiritual value was assigned a score of 1.00 only when multiple independent sources consistently identified a heritage asset as possessing strong religious, ritual, or sacred significance.

3.9.2. Operationalization of Cultural Ecosystem Services (CES)

CES indicators were operationalized through documentary evidence extracted from heritage inventories, historical archives, conservation reports, academic publications, and cultural documentation as it shows in (Table 4).

Table 4. CES indicators and illustrative documentary evidence sources.

CES Indicator	Illustrative Documentary Evidence Source
Spiritual Value	Religious records, sacred-site inventories, pilgrimage documentation
Identity Value	Heritage statements, cultural narratives, symbolic representations
Memory and Herit-	Historical archives, conservation records, documented historical as-
age	sociations
Educational Value	Research publications, interpretive materials, educational references
Esthetic Value	Heritage assessments, landscape evaluations, visual documentation

Higher scores were assigned when multiple independent documentary sources consistently supported the identified cultural value.

3.9.3. Operationalization of Sense of Place (SOP)

Because direct field surveys were not conducted, Sense of Place dimensions were inferred through documentary evidence representing long-term human-place relationships as it shows in (Table 5).

Table 5. SOP dimensions and illustrative documentary evidence sources.

SOP Dimension	Documentary Evidence (Illustrative Application)	Primary Evidence (When Available)
Attachment	Historical continuity, cultural narratives, long-term community presence documented in archival and heritage sources	Online questionnaires/perception surveys
Meaning	Symbolic significance described in heritage documents and literature	Online questionnaires/perception surveys
Commitment	Conservation initiatives, stewardship records, legal protection, community participation records	Questionnaire items

Higher scores were assigned when documentary sources demonstrated persistent and well-documented links between communities and the heritage landscape.

In the suggested model of CSDM, SOP has been operationalized through an adaptable evidence model. In conditions of restricted access, the dimensions of SOP can be derived through the documentation of evidence, which indicates the existence of long-term interactions between people and place in terms of historicity, culture, heritage, conservation, and values. However, with the availability of primary data, SOP dimensions could

also be assessed directly through questionnaires and online community surveys. Thus, the documentary method is not to be considered as an alternative but a remote assessment operation.

3.9.4. Documentary Triangulation Procedure

To reduce dependence on any single source category, each Cultural Ecosystem Services (CES) and Sense of Place (SOP) indicator was evaluated through documentary triangulation using three independent evidence sources as you can see in (Figure 2): historical and archival records (H); institutional and heritage management documents (M); academic and technical literature (S).

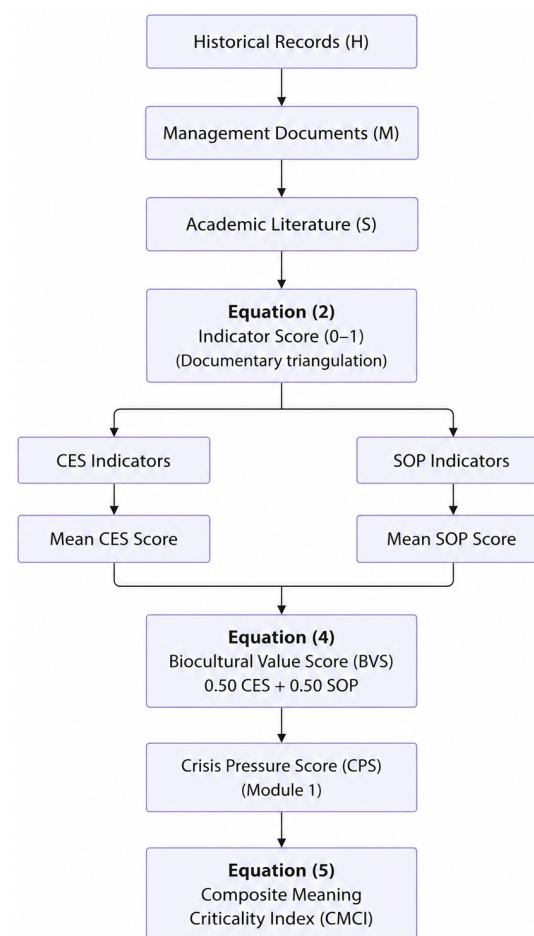


Figure 2. CSDM computational workflow (own figure, 2026).

Each evidence source was independently assessed using the standardized five-level scoring rubric described in Section 3.9.1 and normalized to the interval (0, 1). In the absence of empirical calibration data, equal weighting was adopted to derive the final score for each individual indicator:

$$\text{Documentary Triangulation Score. Score final} = (H + M + S)/3 \quad (2)$$

where H = historical evidence scores; M = management documentation score; S = scholarly evidence scores.

Where one evidence category was unavailable, the final score was calculated using the arithmetic mean of the remaining available evidence sources.

$$\text{For example: Score} = (H + M)/2$$

The resulting indicator scores constitute the inputs for the CES and SOP dimensions. Individual CES indicators are subsequently aggregated to obtain the overall CES score,

while SOP indicators are aggregated to obtain the overall SOP score. these aggregated dimension scores are then combined through Equation (4) to calculate the Biocultural Value Score (BVS), which is subsequently integrated with the Crisis Pressure Score (CPS) to derive the composite meaning criticality index (CMCI). Figure 2 summarizes the complete scoring workflow.

3.9.5. Weighting Assumptions and Sensitivity Scenarios.

In the absence of empirical calibration data and expert-derived weighting coefficients, equal weighting was adopted as a transparent and conservative assumption during the conceptual development stage. This approach minimizes subjective bias while maintaining methodological transparency. Future empirical applications may employ expert elicitation, delphi methods, analytic hierarchy Process (AHP), statistical calibration procedures.

To illustrate the robustness of the framework, conceptual sensitivity scenarios were developed as it is shown below in (Table 6).

Table 6. Conceptual Sensitivity Scenarios.

Scenario	CES Weight	SOP Weight	Relative Ranking Stability
S1	0.50	0.50	Baseline
S2	0.60	0.40	High consistency
S3	0.40	0.60	High consistency

Because the illustrative application does not employ empirical data, these scenarios serve only as demonstrations of future sensitivity testing procedures and should not be interpreted as empirical results

3.9.6. Confidence Assessment

The confidence associated with each indicator was classified according to the quality, quantity, and consistency of available evidence as it shows below in (Table 7).

Table 7. Confidence Classification Framework.

Confidence Level	Description
High	Multiple independent and highly reliable sources
Medium	Several consistent sources with moderate uncertainty
Low	Limited evidence or substantial uncertainty
Variable	Confidence dependent on data availability and context

3.9.7. CSVM Classification Rules

The cultural significance vulnerability matrix (CSVM) employs a conceptual classification scheme to categorize heritage assets according to their composite diagnostic scores. However, the CSVM classification statuses cannot be arrived at strictly on the basis of the CMCI cut-offs. CMCI provides a diagnostic tool for the cultural meaning criticality whereas the actual status of CSVM is derived through interpretation within the cultural significance vulnerability matrix (Figure 5). The matrix takes into account the degree of cultural significance and the extent of crisis pressure in identifying the current state of cultural continuity. Hence, the five CSVM states—stable, eroding, contested, latent, and collapsed are conceptual state changes and not numerical classifications as it shows below in (Table 8).

Table 8. CMCI criticality levels.

CMCI Range	Indicative Criticality	CSVM Status *
0.00–0.20	Very Low	Determined using the CSVM transition matrix
0.21–0.40	Low	Determined using the CSVM transition matrix
0.41–0.60	Moderate	Determined using the CSVM transition matrix
0.61–0.80	High	Determined using the CSVM transition matrix
0.81–1.00	Very High	Determined using the CSVM transition matrix

* CSVM status is determined using the conceptual transition matrix (Figure 5) and should not be interpreted as a direct threshold classification based solely on CMCI values.

Final CSVM categories are assigned through the state-transition logic illustrated in Figure 5 rather than by CMCI thresholds alone. These thresholds are conceptual and intended to demonstrate the classification logic of the proposed framework. Future empirical calibration studies may refine these boundaries.

3.9.8. Inter-Coder Reliability Procedure

To improve methodological reliability, future empirical applications should employ independent dual coding followed by consensus reconciliation. Inter-coder agreement may subsequently be evaluated using reliability statistics such as Cohen’s kappa coefficient.

3.9.9. Methodological Limitations

The proposed scoring framework is intended as a transparent diagnostic procedure rather than a validated empirical measurement instrument. Although explicit scoring criteria and documentary triangulation improve procedural consistency, the resulting scores remain dependent on the availability, quality, and contextual interpretation of documentary evidence.

Accordingly, the present study should be interpreted as a conceptual and methodological demonstration of the CSDM framework rather than as a validated empirical assessment tool.

4. Results: The CESSOP Diagnostic Model (CSDM)

The CESSOP Diagnostic Model (CSDM) is the main product of this research. This product was achieved by applying the methodological approach consisting of seven steps described in Section 3. The CESSOP Diagnostic Model incorporates the CES classification, the SOP three-level structure, and the field of crisis vulnerability into a four-module diagnostic tool. The following subsections provide detailed descriptions of the model’s components. The illustrative application presented here demonstrates the procedural sequence of the CSDM rather than a fully calibrated empirical implementation

4.1. Model Overview and Logical Architecture

The CSDM process involves four modules and yields four integrated products as is shown in (Figure 3). Each module relies on the output from the previous one: the Crisis Pressure Profile explains the context in terms of pressures, the Biocultural Asset Map locates existing cultural values and practices, the CESSOP cultural meaning criticality index assesses the condition of each of the CESSOP components in view of those pressures, and the action typology turns diagnosis into action priorities. Each module draws on three triangulated documentary evidence sources, including historical records, institutional documents, and scholarly literature.

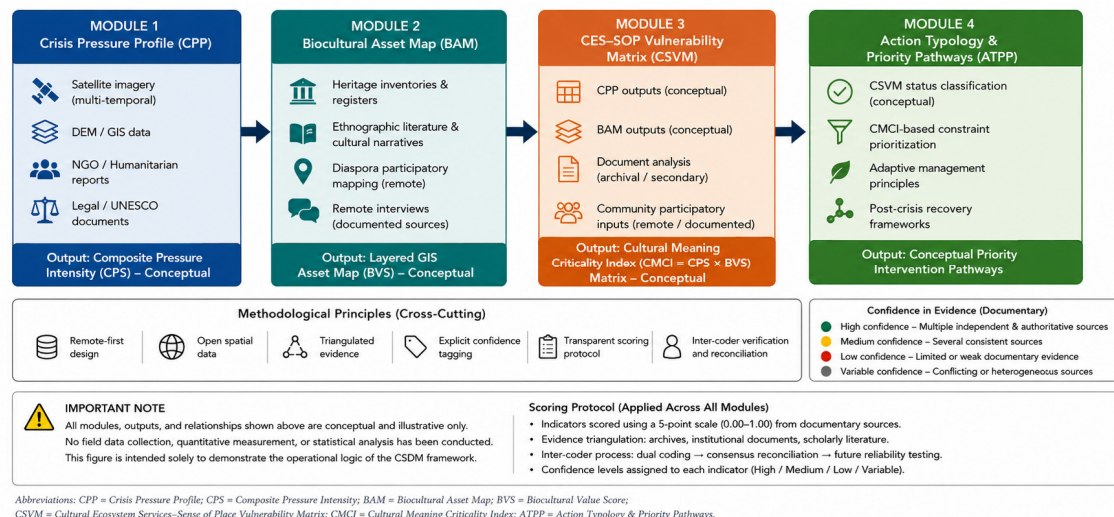


Figure 3. Conceptual workflow of the CSDM (Illustrative—not an empirical assessment) (own figure, 2026).

The design of the model is modular and adaptable in relation to data: each module operates as a self-sufficient unit even when incomplete information is available, and the complexity of the analysis depends on the quality of the data. This model addresses the theoretical problem found in the resilience literature: how to develop methodologies that work under uncertainty but are still clear in their limitations [38,46,50].

4.2. Module 1: Crisis Pressure Profile (CPP)

Purpose: To identify and spatially represent the main crisis pressures affecting cultural meaning, everyday practices, and heritage continuity.

As indicated in Figure 3 the CPP treats crisis as a compound system rather than a purely physical damage condition. Five pressure domains are assessed:

- Physical pressure includes : building damage, infrastructure disruption, and service interruption. Also, accessibility pressure: movement restrictions, blocked routes, and reduced pedestrian connectivity. And, socio-economic pressure: displacement, livelihood contraction, decline of craft activity, and tourism loss.
- Environmental–Climatic Pressure: flood susceptibility, heavy rainfall exposure, heat stress, and material deterioration.
- Governance–Institutional Pressure: fragmented authority, weak enforcement capacity, limited funding, and regulatory constraints.

All pressure indicators are normalized to a 0–1 scale and combined as:

$$\text{Crisis Pressure Score (CPS)} \text{ CPS}_i = \sum(w_j \times P_{j,i}), \text{ where } \sum w_j = 1 \quad (1)$$

Here, CPS_i is the composite Crisis Pressure Score for spatial unit i ; $P_{j,i}$ is the normalized pressure value for domain j ; and w_j is the domain weight. The CPP output is a confidence-tagged composite pressure map supported by individual pressure layers.

Output. As it shows in the (Figure 4) the CPP produces a composite spatial pressure map, supported by domain-specific layers and confidence-tagged assessments, forming the analytical basis for subsequent vulnerability and intervention analysis.

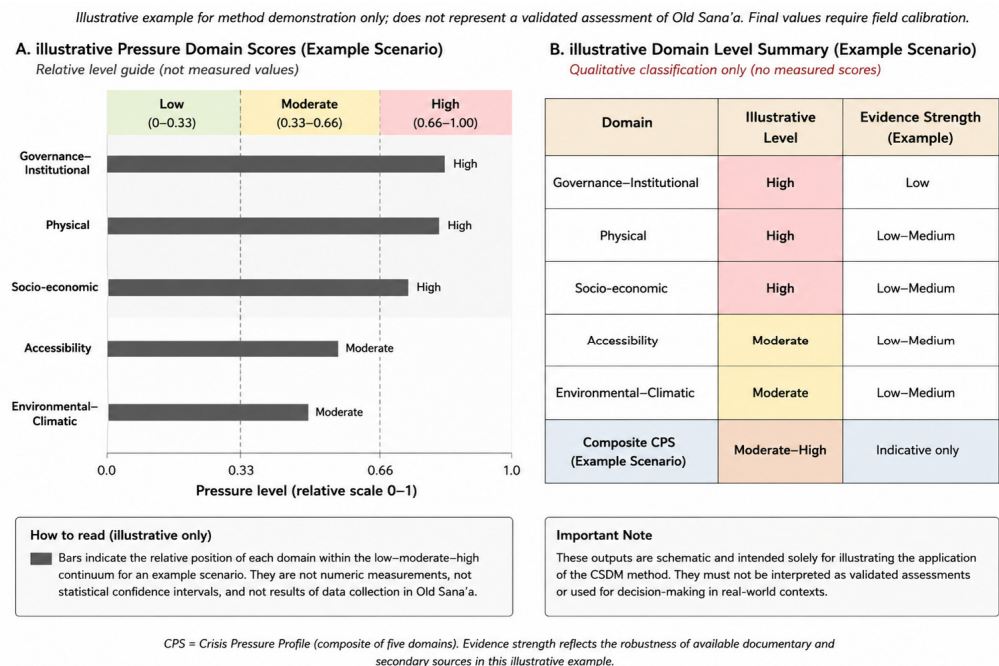


Figure 4. Conceptual illustration of the Crisis Pressure Profile (CPP) workflow. The figure demonstrates the analytical logic of the framework and does not represent empirical measurements (own figure, 2026).

4.3. Module 2: Biocultural Asset Map (BAM)

Purpose: To identify priority areas for protection by locating where heritage assets, cultural practices, and environmental context intersect, as illustrated in Figure 5. The BAM integrates two linked layers:

- Tangible spatial anchors: markets, alleyways, ritual spaces, procession routes, craft buildings, cisterns, gates, and visual landmarks.
- Intangible cultural functions: rituals, crafts, food practices, social routines, knowledge transmission, and place narratives.

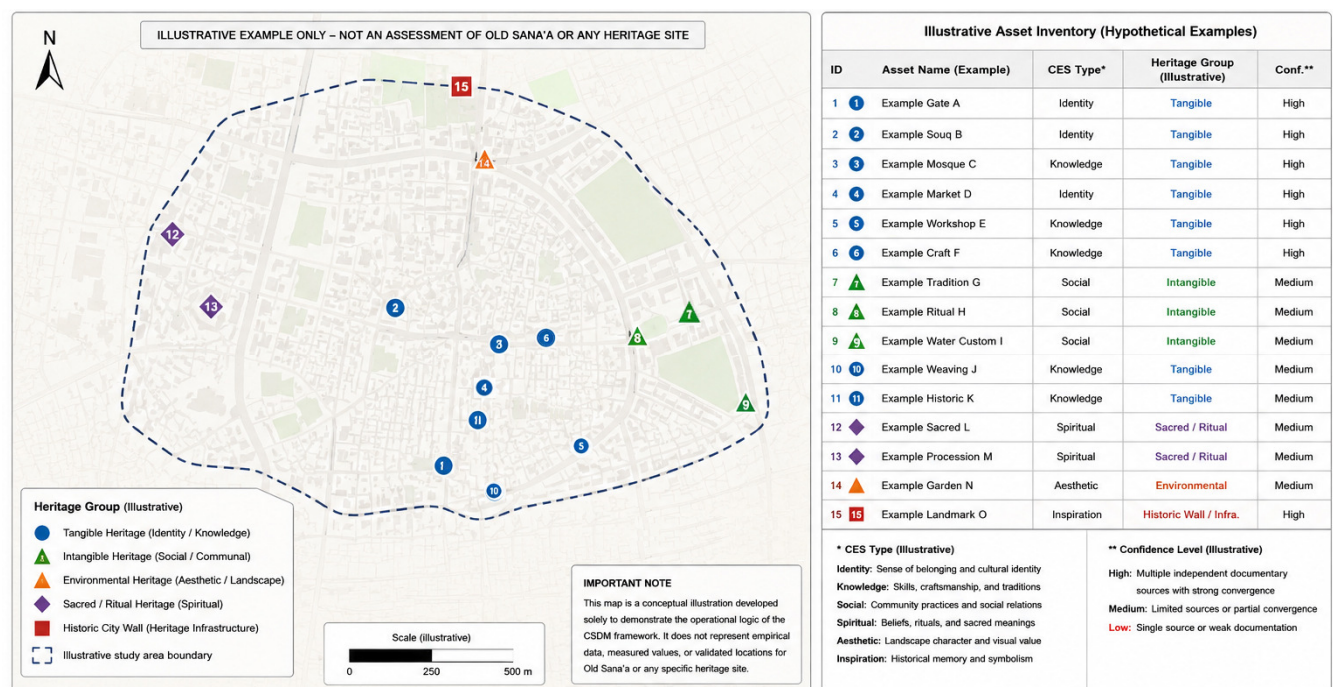
Each asset evaluated using the Normalized CES and SOP scores that have been obtained through the process of documentary triangulation as described in Section 3.9.4. The CES score represents the average of all CES scores, while the SOP score is the average of all SOP scores. Both the dimensions are then combined to obtain the Biocultural Value Score (BVS), calculated as:

$$\text{Biocultural Value Score (BVS)} \\ \text{BVS} = 0.50 (\text{CES score}) + 0.50 (\text{SOP score}) \quad (2)$$

The BAM output is a spatial asset layer showing which places carry high cultural value and therefore require attention when exposed to crisis pressure.

4.4. Module 3: CESSOP Vulnerability Matrix (CSVM)

Purpose: To convert mixed documentary evidence into a structured diagnosis of the status of each cultural value and place–attachment relationship. The cultural significance vulnerability matrix (CSVM) employs five conceptual status categories: stable (S), where cultural values and associated practices remain active; eroding (E), where cultural values remain significant but their associated practices are weakening; contested (C), where values are affected by competing narratives, conflicting claims, or restricted access; latent (L), where values persist primarily in collective memory or diaspora communities but are no longer actively expressed in place; and collapsed (Col), where both cultural values and



associated practices have been severely disrupted and require reactivation rather than simple physical restoration.

Figure 5. Conceptual Biocultural Asset Map and illustrative asset inventory (hypothetical example) (own figure, 2026).

The composite meaning criticality index (CMCI), defined in Equation (1), combines the Crisis Pressure Score (CPS) and the Biocultural Value Score (BVS) to determine the overall level of cultural meaning criticality for each assessed asset. The resulting CMCI values are subsequently interpreted using the CSVM classification framework.

The index is conceptualized as a measure of cultural meaning criticality rather than vulnerability in the classical disaster-risk sense. Following Turner et al. [50], vulnerability assessment requires the explicit inclusion of adaptive capacity. Since the present study aims to identify zones where cultural significance and crisis pressure simultaneously converge, the proposed indicator is more appropriately interpreted as a criticality or priority index [50].

Several aggregation approaches were considered, including additive, geometric mean, minimum operator, and multiplicative formulations. The multiplicative approach was selected because it emphasizes the interaction effect between crisis pressure and biocultural significance. Under this logic, high criticality emerges only when both dimensions are simultaneously elevated. In contrast, additive formulations may compensate for low values in one dimension with high values in another, potentially obscuring critical conditions. The multiplicative structure therefore functions as a conservative diagnostic mechanism intended to identify areas where high cultural value and high crisis pressure coincide, consistent with the conceptual vulnerability framework proposed by Turner et al. [39].

The equal weighting of CES and SOP components within the Biocultural Value Score (BVS) was adopted as an initial theoretical assumption because no empirical evidence currently exists to support differential weighting in crisis-affected heritage contexts. Equal weighting is commonly used in exploratory multi-criteria assessment frameworks when empirical calibration is unavailable. The weighting scheme should therefore be regarded as provisional and subject to future calibration through expert elicitation, participatory assessment, or sensitivity analysis [6,51].

As it shows in Figure 6 high CMCI values indicate high cultural value under high crisis pressure and therefore identify priority intervention zones. The CMCI should be interpreted as a decision-support score, not as a final empirical measurement when based on remote-first data.

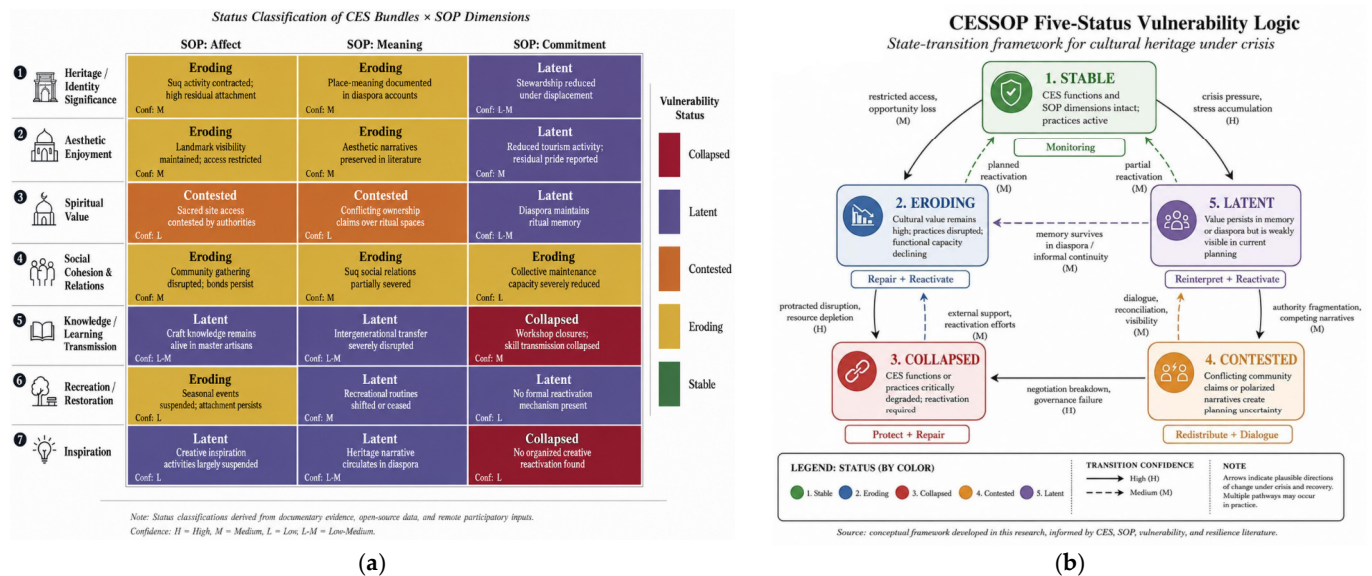


Figure 6. Conceptual demonstration of the cultural site vulnerability matrix (CSVM) and vulnerability transition logic. (a) Illustrative mapping of CES–Sense of Place relationships under crisis conditions. (b) Conceptual five-status vulnerability transition framework illustrating the operational logic of the CSDM. Both panels are schematic and are provided solely to demonstrate the conceptual workflow of the proposed framework. (Own figure, 2026). Note: All vulnerability states and transitions shown in this figure are hypothetical examples designed solely to illustrate the operational logic of the CSDM framework. No field data, stakeholder surveys, or statistical analyses were used to generate these classifications.

4.5. Module 4: Action Typology and Priority Pathways (ATPP)

Purpose: To translate diagnostic findings into feasible planning actions as it shows in Figure 7. The ATPP links CSVM status categories to five intervention families:

- **Protect:** emergency stabilization and safeguarding of practice-critical places.
- **Repair:** targeted restoration of everyday infrastructure, routes, and buildings linked to cultural practice.
- **Reactivate:** support for craft activity, local events, market functions, and community maintenance.
- **Reinterpret:** remote documentation, diaspora co-curation, and memory mapping when access is limited.
- **Redistribute:** equity-oriented measures to address exclusion, unequal access, and contested benefits.

The Old Sana’a application presented in this study serves exclusively as a conceptual demonstration of the operational logic of the proposed framework. No empirical field surveys, statistical analyses, or validated heritage assessments were conducted. All outputs are illustrative and intended solely to demonstrate methodological procedures.

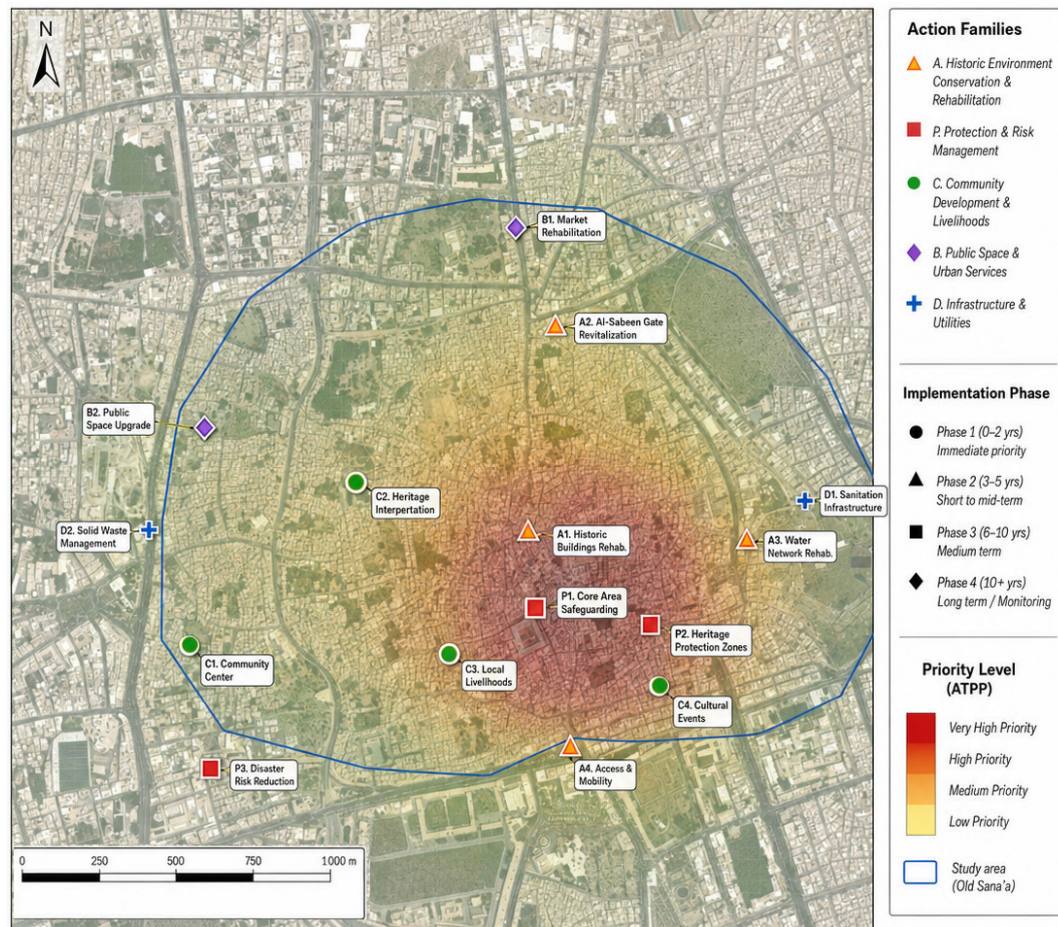


Figure 7. Hypothetical workflow diagram (ATPP). In this figure, the action pathways have been prioritized on the basis of spatial criteria following the CESSOP process diagnosis process, including action families, implementation phases, and priorities. It is important to highlight that the results presented here are purely indicative (own figure, 2026).

4.6. Illustrative Application: Old Sana'a, Yemen

This section demonstrates how the CSDM can be applied to old Sana'a under restricted-access conditions. The application is illustrative: it does not claim new field-derived empirical findings. Instead, it tests the internal logic of the model using literature, open-source data, UNESCO documentation, and confidence-tagged interpretation.

4.6.1. Case Study Justification: Why Old Sana'a

Old Sana'a is selected because it combines exceptional architectural, social, and symbolic heritage values with compound crisis pressures, including conflict damage, infrastructure decline, displacement, declining craft economies, environmental exposure, and fragmented governance. Its dense tower-house fabric, historic suqs, mosques, Maqashim, craft workshops, and water systems make it suitable for testing a model that links tangible heritage with intangible cultural meaning.

4.6.2. Example of Priority Pathways Old Sana'a

The illustrative application suggests two planning horizons:

- Short-term (0–12 months): protect high-value damaged nodes, restore pedestrian access to key suq corridors, and document threatened practices through remote participatory tools.

- Medium-term (12–36 months): reactivate craft micro-economies, repair practice-critical buildings, and establish inclusive benefit-sharing mechanisms for recovery actions.

4.7. Future Sensitivity Testing Framework

As the present study is intended to demonstrate the conceptual architecture and operational workflow of the proposed CSDM framework rather than to provide a calibrated empirical application, a formal sensitivity analysis was not performed. Future applications using empirical datasets should incorporate sensitivity testing to evaluate the robustness of model outputs under alternative weighting scenarios, aggregation functions, and confidence assumptions.

Potential sensitivity tests may include:

- Varying the CES–SOP weighting ratios (e.g., 30/70, 50/50, 70/30);
 - Comparing alternative aggregation operators (multiplicative, additive, geometric mean);
- Testing different confidence-weighting schemes;
- Evaluating the influence of adaptive-capacity indicators in the criticality assessment model.
 - Such analyses will enable calibration of the framework for different cultural and crisis contexts and represent an important direction for future methodological validation.

5. Discussion

This study puts forward the Cultural Ecosystem Services and Sense of Place Diagnostic Model (CSDM) as a remote-first approach to measuring the cultural value of heritage cities facing crisis situations. In lieu of providing an empirically validated assessment of the same, the research aims to develop a theoretical and practically sound methodology for diagnosing heritage value through Cultural Ecosystem Services, Sense of Place, and heritage vulnerability. The following section will examine the evidence base and methodology of the suggested model critically, tackle the ethical aspects of remote heritage evaluation in areas affected by conflict, note the existing limitations of the methodology in addition to the possible improvements, assess the transference and scalability potential of the developed framework in a range of heritage sites, and outline the future directions for the advancement of a dynamic CSDM. Different from UNESCO's historic urban landscape method [1,45,52]—the heritage values and character assessment method [2,22], and culture counts [26,53] approach—the proposed cultural-site diagnostic method (CSDM) incorporates Cultural Ecosystem Services with a document-derived indicator of Sense of Place in one diagnostic process that is remote-first in nature and tailored to heritage cities impacted by conflict and site inaccessibility.

5.1. Validity and Evidential Standards

The validity of the status classification in the CSDM is based on triangulation: status classifications need to be verified by evidence that converges from two or more evidence streams (the spatial-documentary evidence streams and the participatory evidence stream). If there is convergence, it enhances confidence; but where there is divergence, it is taken as a hypothesis for further testing in the field.

Confidence tagging ensures the absence of any misjudgment of precision owing to the visibility of data quality for the user. It is especially relevant in the context of planning processes, where users might mistake visual appeal on the map for certainty. As per

Turner et al. [39], uncertainty should not discourage spatial analysis; it is an integral component of spatial analysis.

5.2. Ethical Dimensions

There are distinct ethical responsibilities attached to remote research of heritage cities affected by crises. Any process of participation will have to be carried out in full compliance with anonymity and do no harm. There should be no publication of the specific location of the participants or other information which might put the informants in danger [53]. “Redistribute” constitutes an essential ethical responsibility and not just an option. There needs to be equal consideration of access and benefits along with preservation responsibilities.

5.3. Limitations and Staged Upgrading

These limitations in the present version of the iteration become clear from the following list:

- (i) Remote sensing is limited by representational bias since diasporic or connected individuals are over-represented relative to poorer, older, or non-migrants who retain their unique value systems; future field work will need to compensate for this limitation.
- (ii) The use of proxies such as night lights, satellite damage maps, or floods inferred from DEMs leaves room for error, but this will be addressed in part using confidence tagging.
- (iii) The classification scheme is based on subjective evaluation of the evidence, which will require evaluation of the inter-rater reliability in field calibration.

In order to update the present model through an incremental process, the following protocol will be followed: (i) remote diagnosis according to the results of this study; (ii) remote validation using further interviews and diaspora mapping; (iii) targeted field calibration on uncertain classifications; (iv) field testing and implementation through the platform.

5.4. Transferability and Scalability

Though applied to old Sana’a, CSDM is explicitly designed for transferability. Key structural adjustments needed to adapt the model to different contexts include recalibrating environmental pressures according to the particular environmental risks of those places (such as earthquakes instead of floods); changing the types of crises used to define pressures according to the relevant stresses in a given place; and redefining the CES categories based on local, non-European–American values systems [20,26].

5.5. Future Development: Toward a Dynamic CSDM

A future extension of the CSDM could develop the model into a dynamic monitoring framework capable of tracking cultural meaning over time. This extension may include time-sensitive indicators such as changes in crisis pressure, biocultural value, cultural practice continuity, and resilience capacity.

This dynamic formulation is not implemented in the present paper because it requires longitudinal data, repeated observations, and field calibration. Therefore, the current study remains focused on the first-stage remote diagnostic function of the CSDM, while temporal modeling is identified as a future research direction.

Response to RQ1: The study demonstrates that Cultural Ecosystem Services and Sense of Place can be systematically integrated within a remote-first diagnostic framework for crisis-affected heritage contexts.

Response to RQ2: The proposed CSDM framework establishes an operational workflow linking cultural significance assessment, crisis pressure evaluation, and spatial prioritization under conditions of restricted field access.

Response to RQ3: The study demonstrates a conceptual pathway for transforming multidimensional cultural significance assessments into spatially explicit intervention priorities through the CSVM and ATPP modules.

6. Conclusions

The regeneration of heritage in times of crisis should not just depend on the scale of physical damage. Cultural values, place attachment, and interaction between people are vital considerations to make judgments regarding the degree of social revitalization following such a process. This diagnostic model, referred to as the CES–SOP model, provides a structured way to incorporate these considerations into a planning process during times of access restrictions. This study presents a conceptual implementation of the CSDM diagnostic chain rather than a fully empirically validated application.

This diagnostic model makes five notable contributions to existing scholarship. One, it defines and quantifies an integrated concept of Cultural Ecosystem Services and Sense of Place in times of crises. Two, it spatializes cultural meanings through an innovative asset-mapping approach suited to remote, first-order use. Three, it accounts for uncertainty in the design phase through confidence tagging and information pathways. Four, it connects diagnosis to actions through an action typology based on rules. Five, it provides a scalable and replicable framework suited to environments characterized by lack of data and restricted access, common among crisis-stricken heritage cities in the Global South.

The illustrative application demonstrates the potential feasibility of the proposed framework under conditions of restricted field access. In this example, areas characterized by high cultural meaning, but low commitment indicate critical heritage assets where conservation efforts should prioritize sustaining cultural continuity alongside physical recovery. Although the illustrative application demonstrates the complete logical workflow of the proposed diagnostic framework, empirical parameterization and validation remain the subject of future research. Future work will evaluate the framework through online participatory surveys, expert assessment, and applications across multiple heritage cities.

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Data Availability Statement: No new field-based empirical datasets were generated in this study. The illustrative application relies on publicly available documentary, spatial, and secondary sources, as identified in the Data Priority Matrix. The methodological workflow and model-scoring structure are available from the corresponding author upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript

CES	Cultural Ecosystem Services
SOP	Sense of Place
CSDM	CESSOP Diagnostic Model
CPP	Crisis Pressure Profile
BAM	Biocultural Asset Map
CSVM	CESSOP Vulnerability Matrix
ATPP	Action Typology and Priority Pathways
CPS	Crisis Pressure Score
BVS	Biocultural Value Score
CMCI	Cultural Meaning Criticality Index
GIS	Geographic Information System
DEM	Digital Elevation Model
HUL	Historic Urban Landscape

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