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Computational Decision Support for Historic Hospital Adaptive Reuse: Development and Internal Verification of HARP v1.1

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Abstract

The adaptive reuse of historic hospitals requires comparing prospective functions against inherited architectural configurations, heritage constraints and contextual conditions, often under incomplete documentation. This study develops and internally verifies HARP v1.1, a hospital-specific rule-based decision-support framework designed to make preliminary reuse assessments transparent and traceable. Drawing on 43 comparative cases, 15 supplementary cases and iterative architectural modelling, the framework connects evidence-supported inputs, derived indicators and conditional rules to eight prospective reuse directions. Rule-normalised compatibility scores are reported separately from Evidence Adequacy. The original 19 software-conformance tests were passed, and deterministic replay reproduced the Pirot reference assessment. Mixed Use ranked first in the reference assessment, while sensitivity analyses and alternative scoring controls identified modelling dependencies that could have affected the rankings. The developmental coding pilot informed protocol refinement; a separate, focused, independent-coder check of the final 35 inputs for Pirot yielded 32/35 exact agreements (91.4%; unweighted Cohen's $\kappa = 0.859$), with three one-level disagreements. The findings demonstrate the implementation consistency and reproducibility of the reference assessment, while the framework's traceable computational structure supports the inspection of its assumptions and dependencies. Further evaluation across independent assessments and additional hospital cases is needed. HARP v1.1 is proposed as a research prototype for preliminary architectural screening and briefing, rather than as a validated predictor of optimal reuse.

Keywords: adaptive reuse; historic hospitals; decision-support systems; architectural decision support; rule-based modelling; evidence traceability; sensitivity analysis; reproducibility

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1. Introduction

Historic hospital buildings and complexes form a distinct category of built heritage because their spatial organisation are shaped by medical routines, ward structures, sanitary requirements, service routes, circulation hierarchies and relationships between buildings and open space. When healthcare activity is relocated, reduced or discontinued, possible future uses remain conditioned by this inherited spatial and operational organisation [1–5]. The resulting task combines heritage and architectural assessment with an early-stage decision problem in which heterogeneous evidence must be translated into a transparent comparison of alternative reuse trajectories before detailed feasibility and design studies are undertaken.

Adaptive-reuse research has developed assessment and decision-support approaches combining heritage, environmental, social, economic, functional and technical criteria. Architectural/physical and historical–cultural conditions recur as intrinsic foundations of reuse assessment, with functional compatibility, structure and layout, spatial flexibility and site/context conditions among the most frequent factors [6]. Stakeholder-based research further shows that reuse challenges operate across building, site and urban scales and extend to institutional and regulatory conditions [7], while decision criteria vary by project stage, placing early screening before later feasibility, design and investment decisions [8]. Related evaluation studies have applied multidimensional, energy-related and heritage-focused criteria [9–15], alongside post-occupancy and automated assessment approaches [16,17].

A parallel line of research concerns decision-support systems (DSS) and design decision-support systems (DDSS) in architecture and building renovation. Architectural DDSS structure complex early-stage decisions in which several criteria and alternative trajectories must be considered concurrently [18]. Renovation research similarly identifies decision support as relevant to building diagnosis, the generation and evaluation of alternatives and the prioritisation of subsequent interventions [19]. Computational architectural DSS formalise design variables and performance criteria for systematic comparison [20], while heritage-focused DSS extend structured multicriteria support across spatial and stakeholder scales [21]. For such systems, the quality of the decision-support process depends not only on the final ranking but also on the transparency of the assessment object, input evidence, inference structure, uncertainty or evidence status and reproducibility of the computational output. Within the broader civil-engineering decision chain, HARP functions as a front-end pre-design and pre-feasibility DSS, structuring architectural and contextual reuse alternatives before structural, fire-safety, building-services, energy, regulatory and economic evaluation.

A methodological review focused on industrial heritage identifies fragmentation and uneven evaluation within that specific adaptive-reuse research domain [22]. Existing approaches range from general building-level opportunity or reuse-versus-demolition models [23,24] to multicriteria selection among candidate uses [25–29]. A relevant type-specific precedent for institutional buildings combines expert elicitation, hierarchical weighting, fuzzy consensus and sensitivity analysis to prioritise functional categories [30].

Hospital-focused research identifies ward organisation, tract configuration, daylight, structural repetition, circulation, access and relationships between buildings and open space as conditions that can influence future adaptation [1–4]. A preceding comparative study of 43 international realised hospital-reuse cases developed a structured coding framework, four hospital layout forms (HLFs) and recurrent reuse directions [31]. Those findings provide an empirical and typological development basis; in HARP v1.1 they inform construct and rule formation, while prospective compatibility is determined from case-specific evidence under the version-locked rule structure. These findings define the methodological need addressed here: a hospital-specific computational framework that combines domain-specific architectural knowledge with case-specific evidence to compare prospective reuse directions while keeping the evidence and reasoning pathway visible.

Table 1 positions the present research relative to selected decision-oriented adaptive-reuse approaches. The comparison addresses the decision problem and analytical basis, assessment boundaries, evidence handling, output structure and evaluation status. The examples are intended to represent recurring methodological types rather than provide an exhaustive review.

Table 1. Decision-support positioning of HARP v1.1 relative to selected adaptive-reuse approaches.

Approach	Decision Problem and Analytical Basis	Boundary, Evidence, Output and Evaluation Status
Langston et al. [23]	General building-level adaptive-reuse opportunity based on age, expected life and six obsolescence dimensions.	Individual building; potential and timing output; evidence quality is embedded within the strategic reuse-opportunity model.
Bullen and Love [24]	Reuse-versus-demolition decision model for existing built assets, centred on practitioner viability and decision process.	Project-level decision-process output grounded in practitioner-based decision research.
Vehbi et al. [25]	Expert-weighted architectural, cultural, social, legal, environmental and economic assessment of compatible uses for one historic hospital.	Single-property case application; expert-weighted ranked use alternatives supported by the multicriteria assessment.
Li et al. [30]	Expert-elicited functional decision model for institutional buildings of control and reform, including hospitals; fuzzy expert consensus, hierarchical weighting and weight-based sensitivity analysis.	Single-property case application; ranked functional categories supported by expert/fuzzy consensus and weight-sensitivity analysis.
Historic-building reuse-selection multicriteria decision analysis (MCDA) [26–29]	Multi-objective and multicriteria selection among alternative uses for historic buildings using weighted decision criteria, extended in more recent work to the prioritisation of intervention strategies.	Property- or project-specific case applications; ranked reuse alternatives or intervention strategies; evaluation procedures vary by study.
HARP v1.1	Hospital-specific, rule-based framework for the prospective comparison of adaptive-reuse compatibility, developed through comparative case evidence, iterative model development and rule formalisation.	Declared assessment boundary; evidence-supported comparative profiling with separate application-level Evidence Adequacy reporting; intended for early-stage screening and briefing. The present study reports internal verification; independent-user evaluation and external validation form subsequent stages.

Unlike approaches based solely on flat weighted scoring, HARP structures decision support through an explicit dependency architecture in which evidence-supported primitive inputs propagate through indices, derived indicators, thresholds, conditional modifiers and typological starting values to the final reuse-direction profiles. Its methodological contribution lies not in ranking alone, but in making the evidence-to-decision pathway explicit, traceable and reproducible.

The present study develops the Hospital Adaptive Reuse Profiler (HARP) v1.1 for prospective comparison of reuse directions in historic hospitals. The framework connects a declared assessment unit and evidence-supported primitive inputs with traceable rule dependencies, compatibility profiling and separate Evidence Adequacy reporting. This creates an inspectable evidence-to-decision structure for early-stage architectural screening and briefing.

The study examines HARP v1.1 at the development and internal verification stage, focusing on specification–implementation conformity, reproducibility, inspectability and local model sensitivity. Three research questions guide the investigation: (1) how can comparative architectural evidence be operationalised within a prospective rule-based structure for comparing adaptive-reuse directions; (2) how can the assessment boundary, input ontology and dependency pathways be formalised so that reasoning from documented evidence to output remains traceable and reproducible; and (3) what properties of the locked HARP v1.1 specification can be established through post-lock internal verification and diagnostic examination before subsequent independent validation and user-oriented evaluation? The reported procedures comprise developmental coding and ontology refinement, dependency tracing, predefined software-conformance tests, deterministic replay, local input-sensitivity analysis and targeted structural controls.

Abbreviations used in the manuscript are listed at the end of the article.

2. Materials and Methods

2.1. Research Design and Methodological Workflow

The study employed an iterative research and development approach to translate architectural knowledge about historic hospital buildings and complexes into a rule-based framework for preliminary adaptive-reuse assessment. Comparative case evidence, relevant literature, architectural analysis and model-development iterations informed the identification of assessment criteria, architectural constructs and computational relationships.

The research followed four stages (Figure 1): (1) the establishment of the developmental evidence base; (2) the definition and refinement of the assessment unit, architectural constructs and input parameters; (3) the formal specification, implementation and version locking of HARP v1.1; and (4) post-lock verification and diagnostic examination. Developmental procedures informed the model's structure and rules, whereas post-lock procedures examined the implementation and behaviour of the fixed specification without modifying it.

HARP assessments operate within a declared spatial boundary, which may encompass an individual historic hospital building, a coherent building group, a defined zone or an entire complex. This boundary establishes the scope of architectural documentation, typological classification, input coding and calculation. The developmental corpus, the Niš model-development case and the Pirot post-lock reference assessment served distinct methodological purposes, detailed in the following sections.

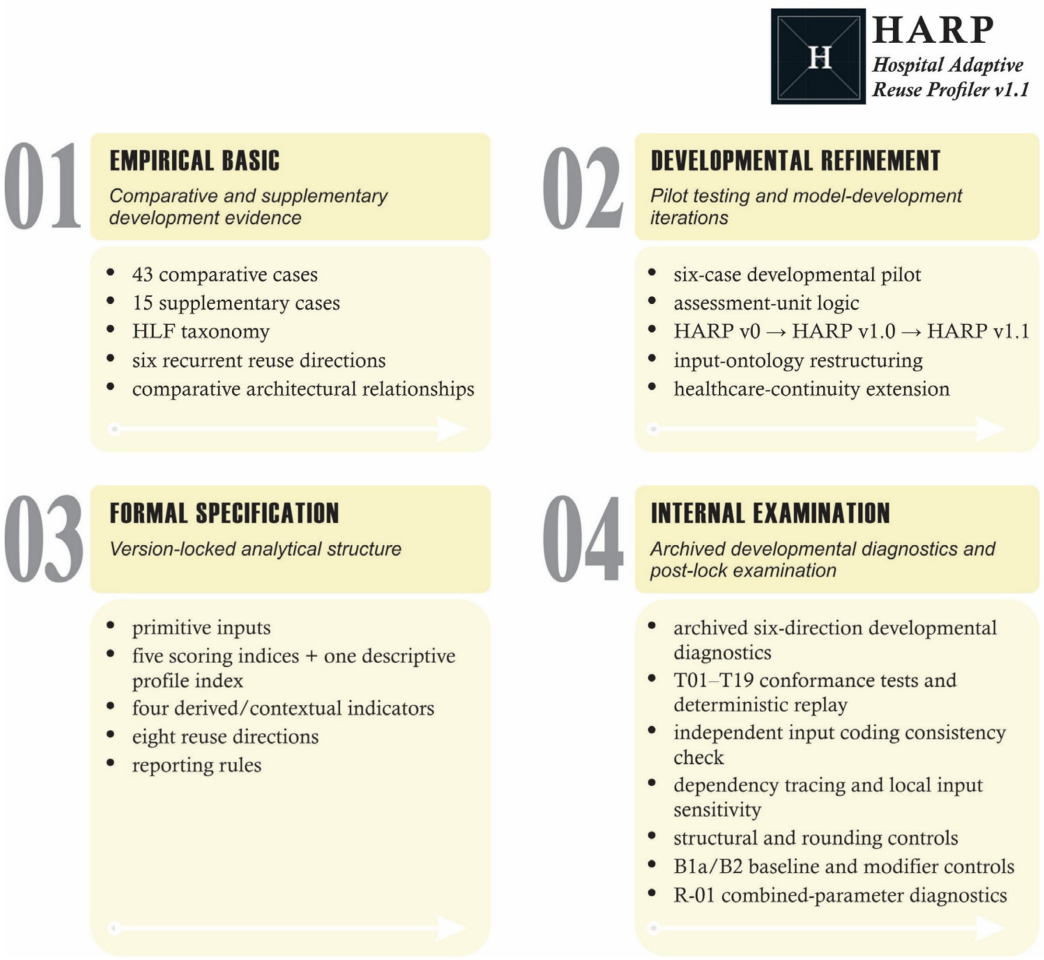


Figure 1. Four-stage HARP v1.1 development workflow, version lock and post-lock examination. Source: Authors' diagram.

2.2. Developmental Evidence and Framework Development

2.2.1. Comparative and Supplementary Development Evidence

The developmental evidence base comprised 43 international cases of realised hospital adaptive reuse from a preceding comparative study [31] and 15 supplementary cases purposively selected to broaden the geographical, typological, functional and complex-scale conditions examined. The 43 comparative cases supported the identification of recurrent hospital layout forms, realised reuse categories and architectural relationships, while the 15 supplementary cases broadened the evidence considered during construct refinement and rule development. Together, these 58 cases informed the architectural structure and prospective programme space of HARP rather than serving as a statistical training or calibration dataset.

Four hospital layout forms (HLFs)—Hospital Village, Pavilion, Block and Campus—provided the typological starting framework (Figure 2). The cases were not independently assessed using the final 35-input HARP v1.1 instrument, and numerical coefficients were not estimated or optimised from the developmental corpus. Selection and exclusion counts for the supplementary cases were not systematically recorded. Case registers and the selection rationale are documented in Supplementary Tables S1 and S2.

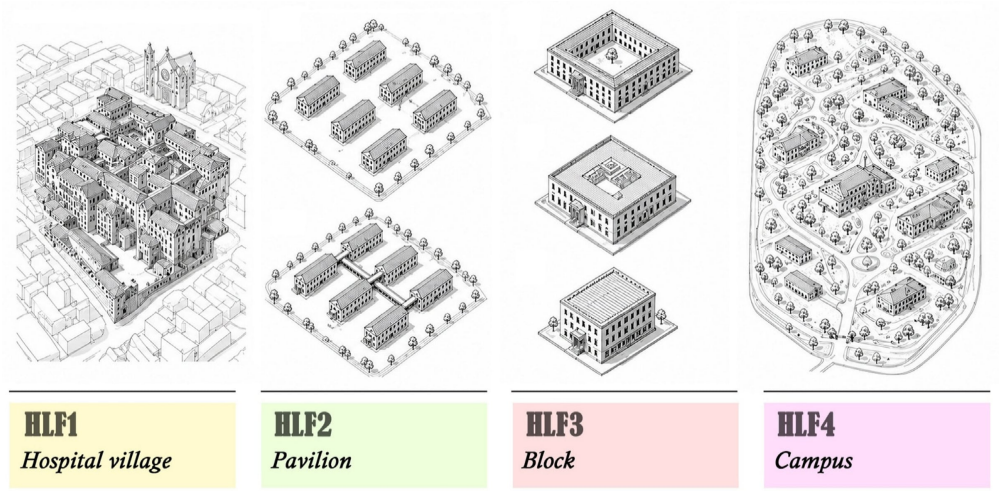


Figure 2. Hospital layout forms used as the typological starting layer: HLF1 Hospital Village, HLF2 Pavilion, HLF3 Block and HLF4 Campus. Source: HLF taxonomy based on [31]; diagram newly drawn by the authors.

2.2.2. Developmental Coding Pilot and Niš Model-Development Iterations

The initial HARP v0 model comprised six prospective reuse directions and an eleven-parameter case-specific coding module, with HLF defaults providing typological starting values. A formative two-coder pilot was conducted on six purposively selected cases from the original 43-case comparative corpus, representing different hospital configurations, assessment scales and levels of documentary completeness. The pilot therefore comprised 66 coding decisions and did not constitute an additional case sample.

Each parameter was rated on a three-point ordinal scale or recorded as Unassessed, with a corresponding evidence status (Ready, Provisional or Unassessed), supporting Evidence IDs and a written justification. The principal researcher prepared the coding guide and shared documentary evidence packages. A second architect independently assessed the same cases without access to the principal researcher's ratings. Agreement was calculated from the original pre-reconciliation ratings using exact agreement, agreement within one ordinal level, linear and quadratic weighted Cohen's kappa [32], and evidence-status agreement. Discrepancies were subsequently reviewed against the declared assessment boundary, documentary evidence and applicable scoring rules to refine the coding protocol. The procedure and original coding records are provided in Supplementary Tables S3 and S9.

Two subsequent model-development iterations examined the four oldest historic buildings within the active University Clinical Centre Niš complex. The first assessed consistency across individual-building, coherent-group, defined-zone and wider-estate boundaries, including the alignment of typological classification, measurements, evidence and coded inputs. The second examined physical, institutional and operational continuity with active healthcare functions. Both iterations informed refinement of the assessment protocol and model structure before version locking. Their developmental findings are presented in Section 3.1.

2.2.3. Construct Review and Input-Ontology Refinement

The initial eleven-parameter module was reviewed against four criteria: construct specificity, evidence traceability, scale stability and dependency clarity. Each parameter was examined for its architectural meaning, documentary basis, applicability across assessment boundaries and role within the calculation structure. Parameters were retained, decomposed, replaced or redistributed as appropriate, resulting in the final 35-input ontology

and its defined relationships with derived indicators and reuse directions. The principal transformations are reported in Section 3.1 and Table 2.

Table 2. Transformation of the developmental eleven-parameter module into HARP v1.1.

Developmental Construct	Final HARP v1.1 Treatment	Analytical Consequence
Ward layout adaptability	Retained as wardAdaptability.	Direct case-specific morphology input.
Daylight/tract adaptability	Retained as daylightTract.	Direct morphology and functional-openness input.
Tract-configuration clarity	Redistributed across specific spatial pathways.	Clarifies the distinct roles of ward, daylight, subdivision, access and ensemble conditions.
Structural system flexibility	Retained as structuralFlexibility.	Direct morphology and functional-openness input.
Floor area potential	Replaced by actual area data and derived site-scale logic.	Makes the assessment boundary and quantitative basis explicit.
Plot/site potential	Decomposed into openSpace, landscape, newConstruction and site metadata.	Separates physical capacity, landscape value and expansion conditions.
Access/circulation potential	Decomposed into independentAccess, publicAccessClinical, carAccess and contextual variables.	Distinguishes non-equivalent access conditions and active-campus constraints.
Subdivision potential	Retained as subdivision.	Direct morphology, functional-openness and mixed-use input.
Phased development potential	Retained as phased.	Direct site, regeneration and mixed-use input.
Ensemble/campus adaptability	Retained as ensembleAdaptability.	Direct morphology and mixed-use input.
Heritage sensitivity/value	Replaced by historical, preservation, memory, representativeSpaces, narrativePotential and sensitivity; heritageStatus separate.	Differentiates significance, surviving fabric, identity, interpretation potential and intervention constraint.

Developmental sensitivity and structural examinations informed successive model revisions before the HARP v1.1 specification was locked. These included six-direction template ablation, input and coefficient sensitivity, and analyses of Provisional scoring (Supplementary Tables S5–S7 and S10). The archived 148 single-coefficient perturbations concerned an earlier six-direction HLF1 model and were not treated as robustness evidence for the final eight-direction specification.

A retrospective coefficient-evolution audit documented changes between developmental variants and the locked specification, distinguishing retained, redistributed, removed and non-comparable numerical terms and dependencies. This documentary audit did not involve optimisation or modification of the locked numerical rules.

2.3. HARP v1.1 Formal Specification and Implementation

2.3.1. Assessment Unit, Typology and Evidence Protocol

Each HARP v1.1 assessment is conducted for a declared spatial unit: an individual historic hospital building, a coherent building group, a defined zone or an entire complex. This boundary determines the buildings and additions included in the assessment and provides a consistent basis for typological classification, architectural documentation, measurements and input coding. Site-related parameters may consider the wider setting where explicitly documented.

The inherited spatial organisation of the assessment unit is classified into one of four hospital layout forms (HLFs): Hospital Village, Pavilion, Block or Campus. Hybrid configurations are classified using the decision hierarchy provided in Supplementary Table S3. HLF establishes the typological starting context before case-specific scoring.

Architectural evidence is documented through a structured register identifying sources, their spatial coverage, supported parameters, relevant facts, reliability and limitations. Each assessment also records case metadata: original healthcare function (OHF), hospital layout form (HLF), urban position (UP), heritage status (HS), architectural style (AS) and case-metadata reliability (DR). DR describes the reliability and traceability of case identification, typological classification and metadata, independently of application-level Evidence Adequacy.

Evidence Adequacy evaluates the documentary basis of the assessment through three required evidence groups—location/site, layout/plan and heritage/visual—each scored from 0 to 3. An assessment is classified as Incomplete if a required group is blank or unassessed; Low if all groups are assessed but at least one has no usable evidence; and High if all three groups score at least 2 and the required whole-unit coverage is complete. The whole-unit coverage requirement applies to grouped, whole-complex and HLF4 assessments. Other complete assessments are classified as moderate. Detailed criteria are provided in Supplementary Tables S3 and S4.

Evidence Adequacy is reported separately from compatibility scores and does not modify their calculation or ranking. A leading alternative supported by moderate or low evidence therefore requires further documentary confirmation rather than being interpreted as an established feasibility or design recommendation. An optional fourth evidence group records technical-condition information, including structural condition, building services, fire safety and general physical condition, for a separate preliminary feasibility/risk review.

2.3.2. Analytical Structure and Decision-Support Outputs

HARP v1.1 translates documented architectural and contextual characteristics into comparative compatibility profiles for eight prospective reuse directions. Its analytical structure connects 35 scored primitive inputs with five composite scoring indices: Location Value Index (LVI), Site Potential Index (SPI), Morphological Flexibility Index (MFI), Heritage Value Index (HVI) and Regeneration Potential Index (RPI). A separate Functional Openness Index (FOI) provides descriptive information without contributing to the final compatibility scores.

Four derived or contextual indicators—Cultural Potential Score (CPS), Mixed-Use Capacity (MUC), Cultural Anchor Potential (CAP) and Healthcare Continuity Index (HCI)—represent additional relationships between inherited conditions and prospective functions. HCI addresses continuity with healthcare-related institutional activities, including medical education and clinical training, without restricting the University/Education direction to healthcare-related education.

The framework compares eight reuse directions: Culture/Museum/Public Cultural Use, Hotel/Tourism, Housing/Residential, University/Education, Office/Public Administration, Mixed Use, Medical Research/Training and Health/Social Care/Rehabilitation. The first six correspond to broad realised-use categories identified through comparative research, while the latter two were introduced during the Niš model-development iterations as prospective healthcare-continuity extensions. Programme-demand inputs represent documented contextual or institutional relevance within the declared assessment setting.

Each reuse direction is evaluated through a specified combination of primitive inputs, composite indices, derived indicators and HLF starting values. Direction-specific coefficients represent the relative emphasis assigned to architectural, spatial, heritage, contextual and

programme requirements. Thresholds govern specified indicator calculations and reporting decisions, while conditional modifiers adjust scores when predefined conditions are met.

The numerical structure was developed through comparative architectural evidence, the relevant literature, iterative modelling and architectural reasoning. Within composite indices, equal contributions were retained where the available evidence did not support a defensible hierarchy among constituent inputs. At the final scoring level, direction-specific coefficients express modelled priorities associated with the defining requirements of each prospective reuse function. For example, the largest direct coefficients are assigned to CPS for Culture/Museum (28/100), LVI for Hotel/Tourism (24/100), MFI and demandEducation for University/Education (20/100 each), HCI for Medical Research/Training (28/100), and MUC for Mixed Use (28/100). HLF starting values represent limited typological predispositions, while conditional modifiers provide bounded heuristic adjustments rather than measured percentage effects.

Parameterisation was further informed by developmental examinations of HLF starting configurations, coefficient sensitivity and heritage-related weighting assumptions, with changes between model versions documented through a retrospective coefficient-evolution audit. Construct selection and relative priorities were thus architecturally informed, while exact numerical values were specified through explicit modelling conventions rather than statistical calibration against realised reuse outcomes. Their rationale, provenance, dependencies and version-lock status are documented in Supplementary Table S4.

The dependency structure allows an architectural characteristic to influence a reuse-direction score directly and indirectly through composite indices or derived indicators. These pathways represent different relationships within the assessment but are not independent contributions. Consequently, the effective influence of a primitive input may exceed its nominal direct coefficient. Repeated pathways and effective input weights are documented in Supplementary Table S4.

Three-point scored inputs use a 1–3 ordinal scale treated computationally as equally spaced values. This is an operational assumption and does not imply empirically equal differences in architectural compatibility. Selected composite indices and derived indicators are rounded and constrained to the 1–3 range at specified stages before entering subsequent calculations, while HCI follows its threshold rule. Intermediate rounding formed part of the locked specification; its influence was examined separately through the full-precision propagation control documented in Supplementary Table S11.

For each reuse direction, active indices, derived indicators, direct inputs and HLF components contribute to a weighted raw score. Applicable conditional modifiers are applied cumulatively without intermediate rounding, after which the modified score is normalised against the reference value of 300 and constrained to the 0–100 reporting range:

$$R_j = \sum_i w_{ij} z_i;\ R_j^* = R_j \prod_q m_{jq};\ S_j = \mathrm{clamp}\left[\mathrm{round}\left(\frac{100 R_j^*}{300}\right), 0, 100\right].$$

Here, R_j is the raw score for reuse direction j; w_{ij} is the weight assigned to active input or derived indicator i for direction j; z_i is its coded value; m_{jq} is the q-th conditional modifier applied to direction j; and S_j is the final normalised compatibility score. The reference value of 300 corresponds to the maximum unmodified weighted sum under the three-point coding structure and a total coefficient weight of 100. Conditional modifiers may produce higher intermediate values before final score limiting. Uniform minimum and midpoint input values correspond approximately to normalised scores of 33 and 67, respectively, subject to applicable modifiers.

In HARP, compatibility denotes context-adjusted reuse compatibility: the rule-based alignment of inherited architectural, spatial, heritage and site conditions with contextual and programme-demand requirements for the declared assessment unit. The resulting

0–100 scores are rule-normalised comparative indices, not probabilities, empirically validated suitability percentages or predictions of project performance.

The outputs support dense ranking, ties, score margins and interpretive tiers. Directions within 0–3 points of the highest score form the leading tier; secondary alternatives are 4–8 points below the maximum with a score of at least 70. First-to-second margins are classified as near-tied (0–3), close or multi-scenario (4–8), or well differentiated (greater than 8). These thresholds are version-specific interpretive conventions.

Compatibility profiles are presented alongside Evidence Adequacy and any separate preliminary feasibility/risk findings. They support architects, planners, heritage professionals and multidisciplinary teams in comparing alternatives during initial architectural screening and briefing, before detailed conservation, technical, regulatory, economic and design evaluation. Figure 3 summarises the relationship between architectural evidence, the computational structure and the resulting decision-support outputs.

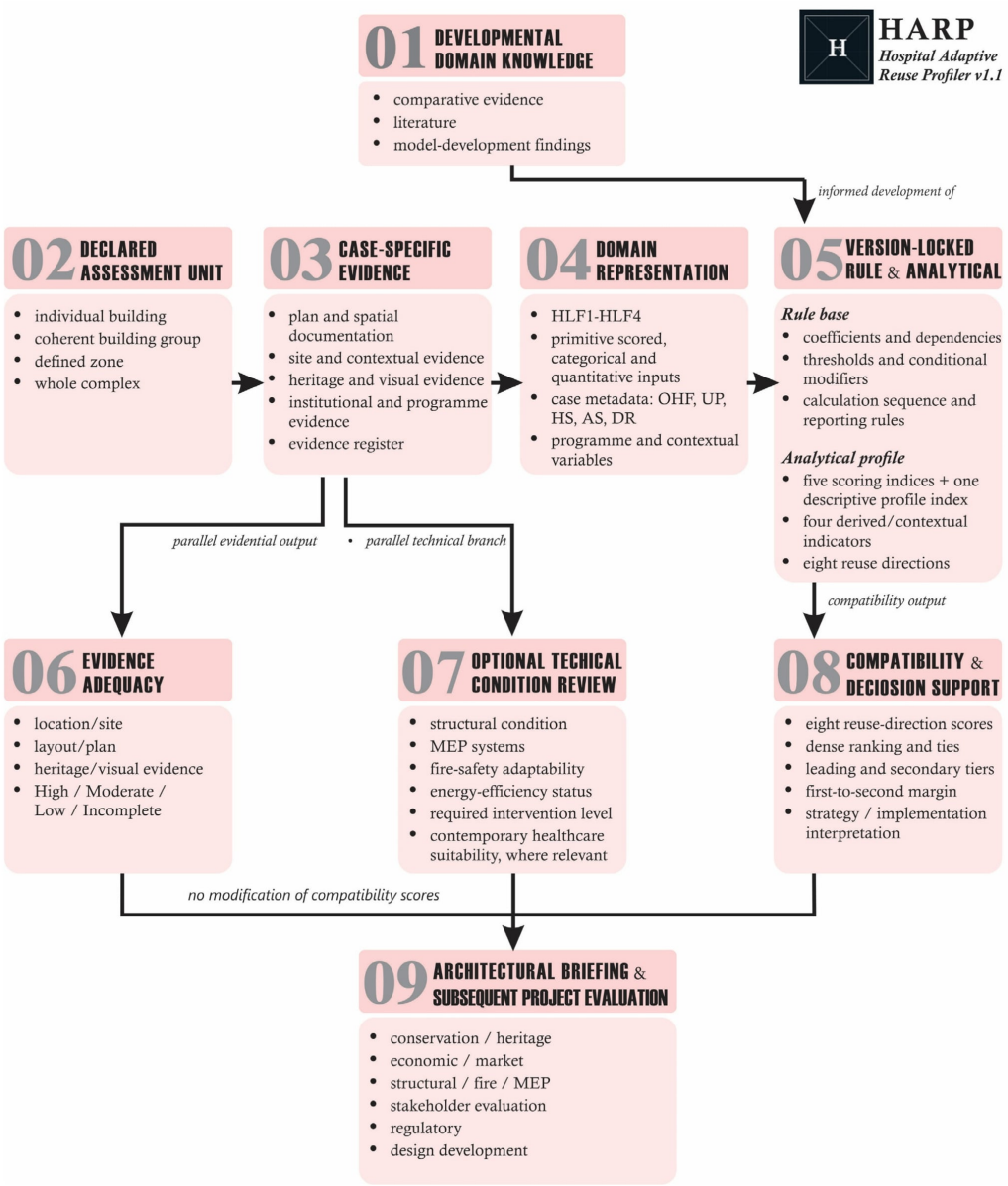


Figure 3. HARP v1.1 analytical architecture linking architectural evidence, rule-based compatibility assessment and subsequent decision-support activities. Source: Authors' diagram.

2.3.3. Software Implementation and Reproducibility Infrastructure

HARP v1.1 was implemented as a client-side application using HTML, CSS and JavaScript. Assessment data are retained locally during normal use, while optional external research submission operates separately with user consent. The canonical JSON field structure supports saved assessment profiles, archived source/input records and deterministic replay.

The locked implementation is identified as build HARP-v1.1-FATC-20260801-b03. Supplementary Files S1–S3 provide the self-contained software release, canonical JSON field specification and archived Pirot source/input record. The version-locked Zenodo archive and institutional software page are cited in Reference [33]. The corresponding source directory is preserved in Software Heritage under SWHID swh:1:dir:2aeda3ff61069aaaff0e9ad64706e9aeb3929921.

2.4. Post-Lock Verification and Diagnostic Examination

2.4.1. Reference Case and Internal Verification Procedures

The former hospital complex in Pirot, Serbia, comprising five buildings classified as HLF2 Pavilion, served as the post-lock reference assessment. The institutional and archival histories of healthcare in Pirot provide historical context for the reference case [34,35]. Its archived source/input record was retained unchanged and recalculated using the version-locked HARP v1.1 specification. The Pirot assessment was not used to define, calibrate or modify the final coefficients, thresholds, dependencies or reporting rules.

The examination distinguished software verification from architectural validation. Verification assessed whether the implementation followed the specified calculation and reporting rules, while the architectural appropriateness of compatibility rankings required subsequent independent evaluation [36].

Internal verification comprised 19 predefined software-conformance tests (T01–T19) and the deterministic replay of the archived Pirot assessment. The tests covered HCI thresholds, ranking and tier classification, strategy reporting, Evidence Adequacy, inactive elements, saved-profile persistence and the complete calculation sequence. Expected outputs were established from the locked rule specification, archived reference records or applicable invariance criteria. For T19, intermediate and final values were independently recalculated from documented pre-rounding values, modifier sequences, normalisation and rounding rules before comparison with application outputs. The original T01–T19 conformance results are documented in the archived verification records and Supplementary Table S4. The additional executable verification package supports the independent rerunning of T02–T16 and the Pirot numerical replay, with partial checks for T01, T18 and T19. The original T17 result is preserved in the archived verification records but is not re-executed by the current scripts.

Deterministic replay applied the unchanged archived Pirot inputs to reproduce the reference calculation and reporting outputs. Test definitions, expected and observed values, and their provenance are documented in Supplementary Table S4; the reference assessment and replay records are provided in Supplementary Table S8 and File S3.

2.4.2. Independent Coding of the Final Input Instrument

A focused independent-coder check examined the consistency of the architectural input assessment using the final 35-input HARP v1.1 instrument. An architect not involved in developing the scoring model independently evaluated the Pirot reference case using the same documentary evidence package and coding guidance, without access to the archived HARP ratings.

The original ratings were compared without modifying the locked assessment. Exact agreement, unweighted Cohen's kappa, and linear and quadratic weighted kappa were calculated as descriptive measures of coding consistency, with weighted statistics included to examine the sensitivity of agreement estimates to the ordinal rating scale. This post-lock examination was distinct from the earlier six-case developmental pilot and was limited to a single reference assessment; it was not designed to establish general inter-user reliability or validate the architectural suitability of the resulting rankings. The complete comparison and agreement statistics are provided in the supplementary revision package (03_Independent_Coding).

2.4.3. Dependency Tracing and Local Sensitivity

Dependency tracing examined how individual architectural and contextual inputs influenced the eight prospective reuse directions, either directly or through composite indices and derived indicators. Summed pre-rounding pathway coefficients were recorded as indicators of structural influence. Their actual effects remain case-dependent because intermediate rounding, thresholds and conditional modifiers may change the propagated values.

Local sensitivity was assessed through one-at-a-time perturbations of the archived Pirot inputs. Each scored parameter was changed by every admissible adjacent one-level value on the 1–3 scale, while all other inputs remained unchanged. Following each change, the complete dependency structure and all eight compatibility scores were recalculated.

The analysis recorded changes in individual scores, the leading reuse direction and the margin between the two highest-ranked alternatives. This procedure identified inputs capable of affecting the local Pirot assessment, without establishing ranking stability across other hospital configurations [37,38].

2.4.4. Structural and Numerical Controls

Two post-lock controls examined how selected computational assumptions influenced the compatibility profiles without modifying the locked HARP v1.1 specification.

The first examined intermediate rounding. The locked coefficients, dependencies, thresholds and modifiers were retained, while intermediate index and derived-indicator values were propagated at full precision until the final reuse-direction calculation. A comparison with the locked results isolated the effects of intermediate rounding on final scores and rankings.

The second examined repeated dependency pathways. For selected inputs contributing both directly and indirectly to a reuse direction, the direct contribution was set to the neutral midpoint while the original input values were retained in the indirect pathways. The affected scores were then recalculated to isolate the contribution of the selected direct term. This control did not remove all influence of the underlying architectural characteristic or establish the appropriateness of its combined weighting.

The tested terms, calculations and comparative outputs are documented in Supplementary Table S11.

2.4.5. Baseline Comparison and Combined-Parameter Diagnostics

Three additional revision-stage diagnostics examined the behaviour of the locked scoring structure under alternative computational assumptions.

The B1a comparator used equal weighting of unique primitive inputs with unconditional linear dependencies for each reuse direction. Each input–direction relationship was counted once, yielding 112 selected links across the 35-input × eight-direction matrix. Conditional modifiers and separate contextual/HLF scoring components were excluded. Scores were calculated as

$$S_d^{B1a} = \frac{100 \sum_{i=1}^{n_d} x_{i,d}}{3n_d}$$

where S_d^{B1a} was the B1a compatibility score for reuse direction d, $x_{i,d}$ was the original 1–3 rating of selected primitive input i, and n_d was the number of selected unique primitive inputs for that direction. B1a retained the HARP-defined input–direction relationships and therefore served as a simplified structural comparator rather than an independently specified architectural suitability model.

The B2 control retained the locked indices, coefficients, HLF starting values and intermediate rounding while neutralising only the final conditional multipliers. This isolated the contribution of those modifiers to the reference outputs.

The combined-parameter diagnostic (R-01) examined 20 scenarios: eight scenarios with direction-specific weight variations of ±10% and ±20%, followed by within-direction renormalisation, and twelve scenarios combining selected weight changes with changes to the demandMixed and demandEducation inputs. Each scenario was recalculated for the archived Pirot assessment, recording score changes, leading directions and first-place ties without assigning the tied alternatives an artificial order.

All three diagnostics were performed without altering the locked specification. Their purpose was to examine selected dependencies and ranking behaviour in the Pirot reference case, rather than establish empirically optimal parameter values or general robustness across hospital types.

3. Results

3.1. Developmental Findings and Final HARP v1.1 Architecture

The final HARP v1.1 specification combined the restructured input ontology with the Healthcare Continuity Index (HCI) and two additional prospective directions—Medical Research/Training and Health/Social Care/Rehabilitation. Together with the six directions derived from recurrent realised uses in the comparative corpus, these formed the eight-direction framework subsequently version-locked for internal examination.

The preceding comparative corpus of 43 international cases established the initial hospital layout form (HLF) taxonomy, recurrent reuse directions and a developmental set of relationships between inherited hospital organisation and realised reuse [31]. Fifteen supplementary international cases broadened the geographical, functional, typological and scale conditions considered during model development, expanding the developmental evidence base to 58 cases. Together, these materials informed construct definition, programme categories and subsequent rule development.

An audit of the earlier 58-row template workbook showed that its architectural component contained four unique HLF parameter profiles. The 58 rows thus represented a developmental case register linked to shared typological templates, establishing a clear distinction between the development corpus and independent case-specific HARP assessments.

The two Niš model-development iterations produced two further methodological results. The first, considered together with the pilot, led to the formalisation of the assessment unit as an individual building, coherent building group, defined zone or whole complex. HLF classification, measurements, documentary evidence and scored inputs were consequently required to refer to the same declared spatial boundary, marking the transition from HARP v0 to HARP v1.0. The second iteration examined historic buildings that remained physically, institutionally or operationally connected to an active medical centre. This revealed a healthcare-continuity condition that was not fully represented in the initial six-direction programme space and contributed to the transition from HARP v1.0 to HARP v1.1.

The combined developmental evidence led to a substantial restructuring of the input ontology. Six of the eleven developmental parameters were retained as direct scored inputs in HARP v1.1: ward adaptability, daylight/tract adaptability, structural flexibility, subdivision potential, phased-development potential and ensemble/campus adaptability. The remaining five were replaced, decomposed or redistributed to improve construct specificity, evidence traceability, scale stability and dependency clarity. The aggregate floor-area parameter was replaced by explicit area information and derived site-scale logic; plot/site potential was decomposed into separate site-related components; access/circulation potential was divided into distinct access and contextual inputs; tract-configuration clarity was redistributed across specific morphology, daylight, subdivision, access and ensemble pathways; and the single heritage sensitivity/value parameter was replaced by differentiated heritage-related fields, with formal heritage status retained separately. Table 2 summarises these transformations.

The retrospective coefficient-evolution audit showed that the transition from the six-direction developmental model to the eight-direction HARP v1.1 framework involved changes in the input ontology, composite indices and dependency pathways rather than a simple rescaling of an unchanged weighting structure. For example, the developmental Culture/Museum formula assigned HVI a direct weight of 0.35, while variants using 0.15 and 0.00 were diagnostic controls rather than successive optimisation steps. In the locked specification, the direct HVI coefficient was 18/100, with additional heritage-related influence propagated through constructs including CPS and CAP. These differences demonstrate that directly assigned coefficients from successive versions cannot necessarily be interpreted as equivalent measures of the total influence of an architectural characteristic.

3.2. Computational Verification and Independent Input Coding

3.2.1. Internal Verification and Deterministic Replay

All 19 predefined automated implementation checks (T01–T19) were passed. The checks covered HCI calculation, ranking, tier and strategy rules, Evidence Adequacy boundaries, inactive elements, saved-profile persistence and the complete calculation sequence. Their successful execution confirmed conformity between the version-locked HARP v1.1 calculation and reporting specification and its software implementation; in software-testing terms, T01–T19 constituted conformance and regression testing. The reported 19/19 PASS result refers to the original documented conformance verification, whereas the currently executable supplementary checks reproduce T02–T16 and the Pirot numerical results. Additional partial checks are provided for T01, T18 and T19, while the original T17 result remains documented in the archived verification records and is not re-executed by the current scripts.

A deterministic replay of the archived Pirot record reproduced the reference assessment from identical inputs. All 35 scored inputs, five scoring indices and one descriptive profile index, four derived/contextual indicators, eight reuse-direction scores, dense ranking, tiers, Evidence Adequacy and strategy output were reproduced. The replay therefore established the exact repeatability of the archived assessment under the version-locked specification. The complete conformance and replay records are provided in Supplementary Tables S4 and S8 and File S3.

3.2.2. Developmental and Final-Input Coding Consistency

The six-case developmental pilot produced 53 exact numerical agreements among 66 decisions (80.3%); all disagreements were limited to one ordinal level. Linear weighted Cohen's kappa was 0.672, quadratic weighted kappa was 0.716, and evidence-status agreement was 55/66 (83.3%). Disagreements were concentrated in evidence-intensive spatial

judgements, particularly daylight/tract, site and access-related conditions. Reconciliation generated clarification rules for ward adaptability, tract-depth evidence, subdivision, circulation and heterogeneous assessment units. These findings provided formative evidence for the developmental eleven-parameter module and informed refinement of the coding protocol. These pilot statistics do not establish the reliability of the final 35-input instrument [32].

In the separate final-input check for Pirot, exact agreement was observed for 32 of 35 primitive ratings (91.4%; unweighted Cohen's $\kappa = 0.859$). Linear and quadratic weighted Cohen's kappa were 0.881 and 0.908, respectively. The three differences concerned ensembleAdaptability (HARP 3, independent coder 2), demandHousing (1 vs. 2), and demandHotel (1 vs. 2). All three disagreements were limited to one ordinal level.

3.3. Pirot Reference Assessment

The final eight-direction profile for the former hospital complex in Pirot ranked Mixed Use first at 80, followed by Housing/Residential at 76 and Office/Public Administration at 74. The first-to-second margin was four points and was therefore classified as close or multi-scenario. Mixed Use was the sole member of the leading tier. Housing/Residential and Office/Public Administration met the criteria for secondary alternatives, whereas University/Education, with a ten-point gap from the maximum, fell outside the secondary band. For University/Education, HCI specifically reflects healthcare-related institutional continuity, such as medical education or clinical training, rather than general educational suitability; the reuse direction itself remains applicable to broader educational functions. The resulting strategy output was mixed-use regeneration, with phased mixed use as the implementation mode.

Evidence Adequacy was moderate: the three required domain scores were 2 for location/site, 3 for layout/plan and 2 for heritage/visual evidence. The five-building assessment unit had partial whole-unit documentary coverage, placing the profile in the moderate category. The moderate Evidence Adequacy classification indicates that the reference profile should be interpreted in light of the documented coverage limitations; Evidence Adequacy remained analytically independent of compatibility scores and ranking.

The archived Pirot assessment and its associated compatibility profile are presented in Figure 4, with the complete numerical trace provided in Supplementary Table S8.

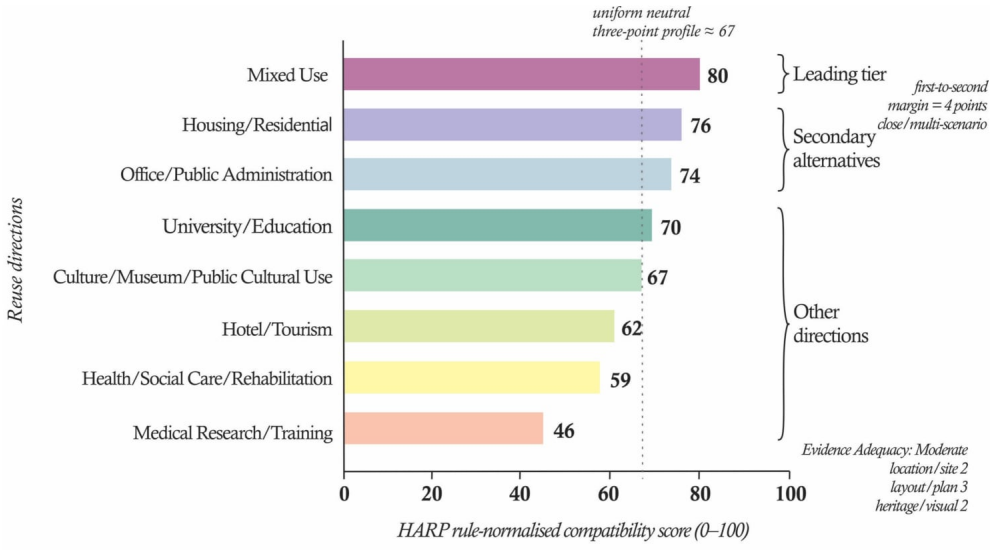


Figure 4. Rule-normalised compatibility profile for the former hospital complex in Pirot; dashed line denotes the reference level of approximately 67. Source: authors' diagram.

3.4. Sensitivity and Structural Diagnostics

The one-at-a-time sensitivity analysis of the Pirot post-lock assessment comprised 52 admissible one-level perturbation scenarios across the final scored input structure. Twenty-nine scenarios changed at least one reuse-direction score, whereas only four (7.7%) changed the first-ranked direction. In all four rank-changing scenarios, Housing/Residential replaced Mixed Use. The rank changes resulted from housing demand increasing from 1 to 2, phased-development capacity decreasing from 3 to 2, structural flexibility increasing from 1 to 2, or ward adaptability increasing from 2 to 3; the resulting first-to-second margins were one or two points. The complete perturbation matrix is provided in Supplementary Table S8.

3.4.1. Results of Structural and Numerical Controls

Relative to the version-locked HARP v1.1 reference baseline, two post-lock diagnostic controls examined selected structural features through counterfactual recalculation without redefining the locked model. Retaining full-precision intermediate values preserved Mixed Use as first-ranked but changed its score from 80 to 84, widening the first-to-second margin from four to eight points while Housing/Residential and Office/Public Administration both remained within the secondary-alternative band. Ranking with unrounded final normalised values alone produced no rank or tier change, locating the observed effect in intermediate discretisation rather than final display rounding.

The repeated-pathway control was more rank-sensitive. Setting only the direct phased-development term in Mixed Use from 3 to the neutral midpoint 2, while retaining its indirect pathways, reduced Mixed Use from 80 to 75, allowing Housing/Residential at 76 to become first-ranked. Other tested direct-term controls did not change the first rank. The detailed structural-control calculations are reported in Supplementary Table S11. Dependency tracing identified eight direct and indirect pathways for phased-development capacity in Mixed Use, seven for collective memory in Culture, and two each for daylight/tract adaptability and subdivision in Housing. These coefficients describe structural pre-rounding influence, not independent causal effects.

3.4.2. Baseline Comparison and Combined-Parameter Diagnostics Results

Revision-stage comparators found Mixed Use first under B1a (76.92), followed by Education (74.36) and Housing (73.33); the ordering of lower-ranked alternatives differed from the locked HARP output, showing sensitivity to structural simplification. B2 reproduced all eight locked Pirot scores because none of the neutralised final multipliers was active in this reference assessment. In R-01, Mixed Use was uniquely first in all eight weight-only scenarios. Across all 20 targeted perturbations, 14 scenarios produced a unique Mixed Use lead, five produced a shared first place and one produced a unique Education lead. These findings describe the behaviour of the Pirot assessment under selected parameter changes and should not be interpreted as evidence of robustness across hospital cases. In the accompanying R-01 CSV, top_direction refers to the first item in the serialised ranking and does not imply a unique winner when the first-place margin is zero; the accompanying tie-resolved summary identifies all joint leaders.

Table 3 summarises internal verification, local sensitivity, structural controls and the additional baseline and combined-parameter diagnostics.

Table 3. Post-lock internal verification and diagnostic results for HARP v1.1.

Procedure	Result	Interpretation
HARP v1.1 automated implementation checks (T01–T19)	19/19 predefined automated checks passed.	The software implementation conformed to the version-locked calculation and reporting rules and reproduced the predefined expected outputs; these checks constitute conformance and regression testing rather than empirical model validation.
Pirot assessment rerun (deterministic replay)	All 35 scored inputs, five scoring indices and one descriptive profile index, four derived/contextual indicators, eight reuse-direction scores and dense ranking were reproduced.	The archived Pirot assessment under the locked specification was rerun from identical inputs and reproduced the same numerical results.
Pirot post-lock assessment sensitivity	4/52 perturbations changed first rank; 29/52 changed at least one reuse-direction score. Housing/Residential replaced Mixed Use in all four first-rank changes.	Single-case one-at-a-time sensitivity test of the version-locked eight-direction HARP v1.1 assessment.
Pirot intermediate-rounding control	Mixed Use remained first at 84; Housing and Office both scored 76 and retained secondary status. The first-to-second margin widened from 4 to 8 points.	Single-case full-precision propagation control using the archived Pirot inputs, including UP3 = 2. Intermediate numerical margins changed, but the first-ranked direction and secondary-alternative membership remained unchanged.
Pirot repeated-pathway control	Setting only the direct phased-development term in Mixed Use from 3 to the neutral midpoint 2, while retaining its indirect paths, changed first rank to Housing 76 vs. Mixed Use 75.	Single-case structural control isolating the direct phased-development contribution while retaining its indirect pathways.
B1a equal-weight primitive-input baseline	Mixed Use 76.92; University/Education 74.36; Housing/Residential 73.33.	Simplified structural comparison retaining HARP-derived input selection; not independent decision validation.
B2 final-modifier ablation	All eight locked Pirot direction scores remained unchanged.	Final conditional multipliers did not affect this archived assessment.
R-01 combined-parameter diagnostics	20 perturbations: 14 unique Mixed Use leads, five first-place ties and one unique University/Education lead; eight weight-only scenarios all retained Mixed Use first.	Targeted single-case parameter sensitivity; does not demonstrate multi-case robustness.

4. Discussion

4.1. HARP as a Domain-Specific Architectural Decision-Support Framework

HARP v1.1 translates comparative architectural evidence and iterative architectural reasoning into a hospital-specific, prospective decision-support structure. The 43 comparative cases and 15 supplementary cases informed the typological framework, initial programme space and construct development [31], without constituting a calibration dataset for nu-

merical coefficients. Literature, architectural judgement and model-development iterations further shaped the input ontology and dependency architecture. The resulting framework applies a version-locked rule structure to case-specific evidence and current programme-demand conditions, rather than treating realised outcomes in the development corpus as prospective predictions.

Architectural and renovation DSS research provided an important methodological foundation for HARP, particularly in structuring complex early-stage decisions through explicit criteria, formalised variables and comparative evaluation of alternatives [18–21]. These methodological principles were combined with hospital-specific architectural and typological knowledge derived from the comparative case study [31] and subsequent model-development iterations. General building-level models such as those of Langston et al. [23] and Bullen and Love [24] address adaptive-reuse opportunities or project-level decision processes, while multicriteria approaches including Vehbi et al. [25], Wang and Zeng [26], Haroun et al. [27], Ribera et al. [28] and Maselli et al. [29] structure the comparison or prioritisation of alternative uses and interventions. Vehbi et al. [25] provides a particularly relevant hospital-specific precedent, using expert-weighted multicriteria assessment to evaluate compatible new uses for a historic hospital, while Li et al. [30] extend type-specific functional decision modelling to the broader category of institutional buildings of control and reform. Within this methodological landscape, HARP formalises a hospital-specific decision-support architecture in which the assessment object is explicitly declared, the domain-specific analytical structure is encoded in a version-locked specification, dependency pathways are traceable, and compatibility and Evidence Adequacy are reported as separate decision-support outputs. Although HARP uses weighted aggregation at the reuse-direction level, it is not implemented as a flat weighted MCDA model: the final profiles arise from a dependency architecture comprising indices, derived indicators, thresholds, conditional modifiers, typological starting values, and traceable direct and indirect pathways.

The principal methodological advance is the operational integration of hospital-specific architectural knowledge, case-specific evidence and explicit computational dependencies within a single reproducible assessment framework, allowing prospective reuse alternatives to be compared through a documented and inspectable reasoning process.

Beyond its ranked output, HARP makes the relationship between documented inputs, propagated dependencies and compatibility profiles inspectable. This permits the examination of assumptions, score margins and rank-critical conditions, without implying that the resulting rankings have been independently validated.

4.2. Formalisation, Traceability and Domain Representation

The declared assessment unit provides a common spatial boundary for typological classification, measurements, documentary evidence and scored inputs. For historic hospital estates comprising buildings, additions and shared site conditions at different scales, this alignment is methodologically important: it reduces the risk that evidence recorded for one spatial extent will be used to assess another. Explicit boundaries and separately supported primitive inputs also make the resulting evidence-to-rule relationships inspectable.

Separating the HLF typological starting layer from case-specific architectural, spatial and contextual evidence prevents a shared hospital layout category from determining an individual assessment by itself. The typological layer represents recurring spatial organisation, whereas the scored evidence differentiates the actual assessment unit. This distinction supports more transparent interpretation of why buildings with a similar inherited form may obtain different prospective reuse profiles.

The extension from six to eight reuse directions also has a representational implication. By introducing HCI and healthcare-continuity directions, the framework distinguishes ongoing medical or institutional relationships from general educational or functional adaptability. It thereby accommodates a hospital-specific condition that cannot be inferred solely from historical layout form or realised reuse categories, while leaving the eventual architectural suitability of these directions to subsequent evaluation.

4.3. Inspectability, Sensitivity and Early-Stage Decision Support

The post-lock procedures establish two complementary but distinct forms of evidence: T01–T19 and deterministic replay examine computational conformity and repeatability, whereas local sensitivity and counterfactual controls expose dependencies of the Pirot rankings on the specified rule structure. Neither form of examination independently establishes the actual suitability of the ranked reuse directions for the assessed hospital complex.

Dependency tracing shows that direct terms and indirect pathways can reinforce one another, rather than acting as independent contributions. The phased-development example demonstrates how a characteristic that enters several pathways can exert more influence than its direct coefficient alone suggests. The repeated-pathway and full-precision controls further show that both the dependency structure and intermediate discretisation can affect score margins and, under selected changes, the leading alternative. These effects are inspectable modelling dependencies, not independently established optimal architectural weights.

The B1a comparator shows how simplifying the scoring structure changes the relative profile without supplying an independent validity benchmark. The B2 isolates the role of final conditional modifiers in the reference calculation. R-01 identifies conditions under which selected weight changes preserve the lead, while combinations of changes can produce first-place ties or reversals. Together with the repeated-pathway and rounding controls, these diagnostics distinguish locally stable from rank-sensitive conditions and provide a documented basis for examining individual model assumptions in subsequent HARP versions. The identification of rank-critical inputs provides an actionable diagnostic outcome: it indicates which architectural or contextual assumptions warrant closer documentary examination before a preliminary reuse profile is taken forward into architectural briefing. Their implications remain specific to the tested Pirot assessment.

For early-stage screening and briefing, the principal value of the compatibility profile lies in keeping competing reuse directions, score margins and evidence-dependent questions visible rather than presenting a single option as a validated design recommendation. In Pirot, the leading Mixed Use direction and the nearby Housing/Residential and Office/Public Administration alternatives exemplify how the profile can structure further comparative architectural inquiry.

Evidence Adequacy provides a separate assessment of the documentary basis. Compatibility describes how the documented characteristics of the assessment unit align with the version-locked rule structure, while Evidence Adequacy reports the strength and coverage of the documentary basis. In Pirot, moderate Evidence Adequacy directed attention toward further survey and documentation needs while leaving the compatibility profile analytically unchanged.

The resulting profile informs subsequent project-specific conservation, structural and fire-safety assessment, regulatory review, market and economic analysis, stakeholder consultation and design development [23–28,39]. These downstream assessments are distinct from the compatibility calculation.

Figure 5 illustrates a conceptual architectural interpretation of the highest-ranked Mixed-Use direction for the former hospital complex in Pirot. The proposed functional

distribution among the buildings was developed by the authors and is not a direct output of HARP v1.1 or a model-validated design solution. The axonometric representation is based on available architectural documentation, photographs and GIS imagery, with surrounding building heights estimated from imagery. The proposed cultural functions aim to preserve and communicate the historical and memorial identity of the complex through exhibitions on the development of healthcare in Pirot (ground floor) and local industry (upper floor), with the adjoining extension serving as exhibition storage. The second main historic building is envisaged for education, presentations and training activities potentially serving nearby industrial facilities and the neighbouring dairy school, while the separate historic single-storey building is proposed for Community/Visitor Services, supporting the everyday needs of visitors and users of the complex. The surrounding industrial zone, neighbouring educational facilities, and immediate proximity of the railway station and a hotel provide a contextual basis for the proposed combination of cultural, educational and service functions, potentially attracting different user groups and supporting complementary activities. The multi-building configuration may facilitate functional differentiation, shared circulation and phased adaptation while retaining the historical identity of the complex. The scenario remains a conceptual interpretation rather than a validated design proposal and requires subsequent feasibility assessment.

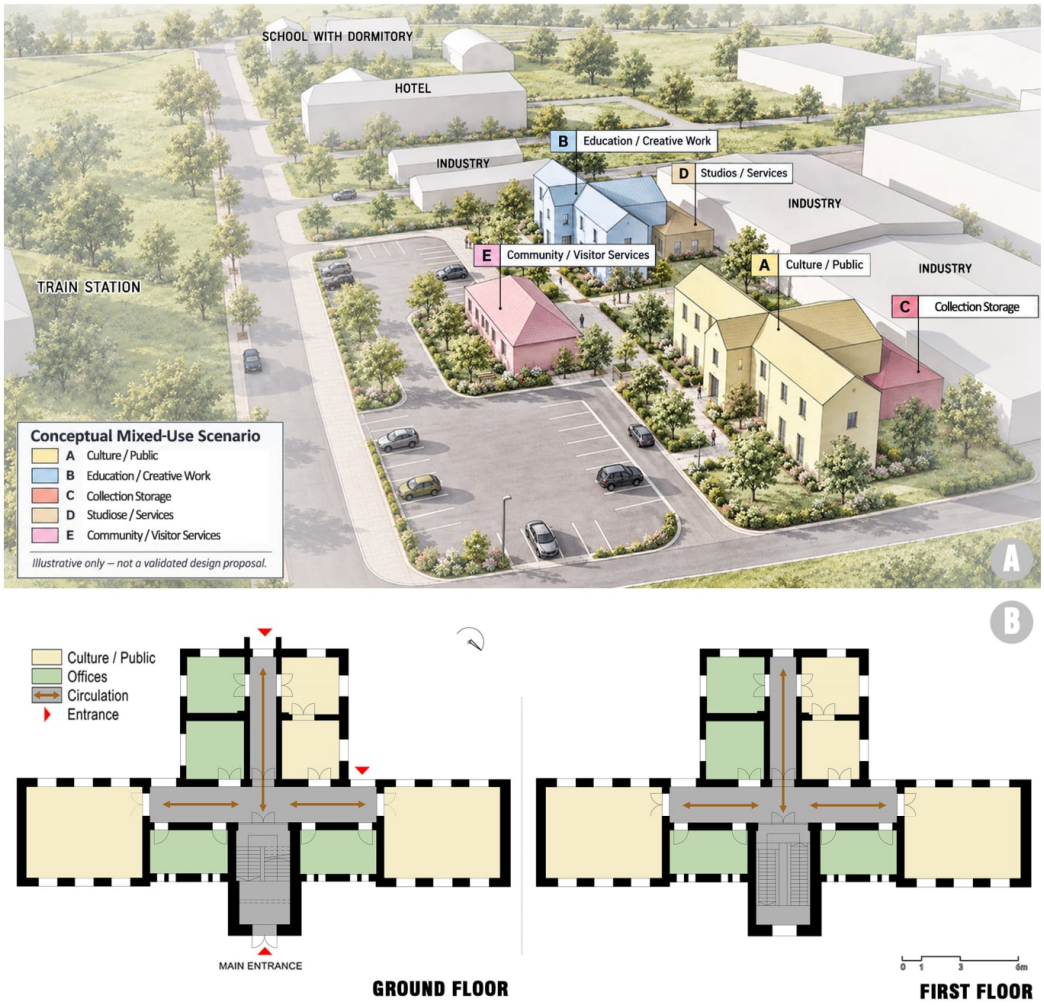


Figure 5. Conceptual Mixed Use scenario for the former hospital complex in Pirot: (**A**) Functional distribution within the mixed-use complex. (**B**) Functional zones within the Culture/Public use. Source: Authors' illustration.

4.4. Evaluation Boundaries and Future Research

HARP v1.1 is presented as a developed and internally verified research prototype for preliminary architectural decision support, while the independent validation of its reuse compatibility assessments remains a subject for future research. Its numerical specification combines architecturally informed coefficients, thresholds, HLF starting values and conditional modifiers within a documented rule structure. The post-lock analyses established implementation conformity and exposed selected dependencies affecting the Pirot rankings but did not determine whether the resulting compatibility profiles accurately represent architectural suitability across different hospital cases. The focused independent-coder check provides preliminary single-case evidence of coding consistency for the final instrument but not general inter-user reliability.

Further research should address these limitations through independent coding across additional hospital cases and HLF classifications, structured architectural expert appraisal, and multi-case robustness assessment across different hospital layouts and documentary conditions. Comparisons with independently specified reference models, as well as alternative parameter settings evaluated across multiple hospital cases, would provide evidence beyond the HARP-derived B1a baseline about the influence and appropriateness of the present rule structure. Beyond numerical and architectural validation, user-oriented DSS evaluation should examine decision consistency, task efficiency, the interpretation of competing alternatives and practical utility in preliminary architectural screening and briefing. These evaluations should also determine whether the observed sensitivities warrant refinement of input definitions, dependency pathways, or numerical weighting in subsequent model versions.

The adaptation to other building typologies represents a separate research direction. Such extensions would require redevelopment of the typological framework, architectural constructs, evidence requirements, reuse alternatives and numerical rules. Research on shopping-mall redevelopment, for example, identifies location, market context, building characteristics, facility management and life-cycle conditions as relevant assessment factors [40]. These studies illustrate the need for building-type-specific knowledge rather than demonstrating direct transferability of HARP v1.1.

Human-centred spatial assessment offers another possible extension at later design stages. Approaches integrating spatial cognition, emotional responses and movement behaviour [41] could complement preliminary compatibility screening when specific reuse proposals are available for evaluation. Such methods would broaden the assessment of user experience without providing retrospective validation of HARP's present coefficients or rankings.

5. Conclusions

This study developed HARP v1.1 as a hospital-specific, rule-based framework for the preliminary comparison of adaptive-reuse directions in historic hospital buildings and complexes. Its main methodological contribution is the formalisation of architectural and contextual evidence into an explicit computational structure connecting a defined assessment unit, evidence-supported inputs, derived indicators and conditional rules with eight prospective reuse directions. The framework makes the evidence-to-decision process traceable and reproducible while reporting compatibility scores separately from Evidence Adequacy.

Original internal verification demonstrated conformity with the locked computational specification through 19 successful conformance tests and deterministic reproduction of the Pirot reference assessment. A focused independent-coder comparison of the final 35 inputs yielded 32/35 identical ratings (91.4%; Cohen's $\kappa = 0.859$), providing preliminary evidence of coding consistency for the reference case. The Pirot assessment illustrated the comparison

of competing reuse directions, while sensitivity analyses and structural controls identified specific input changes, with repeated dependency pathways and numerical assumptions affecting the resulting rankings. These findings establish implementation consistency and reveal selected properties of the model's computational behaviour without independently validating the architectural suitability of its reuse rankings.

HARP v1.1 provides a documented and internally examined research prototype for preliminary architectural screening and briefing. Further research should evaluate coding reliability across additional hospital cases, assess the compatibility rankings through independent architectural expert judgement, and examine model behaviour under alternative parameterisations and decision-support approaches. Such evaluation will help determine the applicability of the framework beyond the present reference case and inform its subsequent development.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/app162110918/s1, Table S1, core comparative dataset; Table S2, supplementary development/refinement dataset and selection protocol; Table S3, developmental case-specific scoring guide and clarification rules; Table S4, HARP v1.1 authoritative specification, provenance, dependency paths, version history and T01–T19 implementation-conformance report with expected-output/oracle provenance; Table S5, archived six-direction HLF-template ablation and input sensitivity; Table S6, archived HLF1 local coefficient sensitivity; Table S7, archived HLF1 template and heritage-control diagnostics; Table S8, Pirot post-lock assessment, replay and input sensitivity; Table S9, six-case independent coding pilot; Table S10, archived developmental Provisional-score sensitivity; Table S11, post-lock structural controls; File S1, HARP v1.1 software release (build HARP-v1.1-FATC-20260801-b03); File S2, canonical JSON field specification; and File S3, archived Pirot source record. The version-locked Zenodo archive and institutional software page are cited in Reference [33]. Additional revision-stage materials are supplied in the accompanying package: the final 35-input Pirot coding rules, both coders' ratings, and unweighted and weighted Cohen's kappa calculations in 03_Independent_Coding, and the B1a/B2 baseline comparisons, R-01 combined-parameter perturbations and RT-03 full-precision replay control in 02_Revision_Diagnostics. The accompanying package also includes executable Pirot replay and selected conformance-check procedures in 04_Executable_Reproducibility, together with the original T01–T19 conformance evidence in 05_Original_20260801_Conformance_Evidence. The executable procedures rerun T02–T16 and the Pirot numerical replay and provide partial checks for T01, T18 and T19. The original T17 result is preserved in the archived verification records but is not re-executed by the current scripts. These analyses do not modify the version-locked HARP v1.1 specification.

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Institutional Review Board Statement: Not applicable. The developmental coding pilot was conducted by two members of the research team, while the subsequent independent assessment of the final 35 inputs for the Pirot reference case was performed by an architect who was not involved in developing HARP. The study involved documentary architectural evidence, coded case data and computational model testing, without collecting identifiable personal data.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets, scoring guide, authoritative specification, pilot materials, replay materials and structural controls are provided in the Supplementary Materials. Supplementary

Table S4 also contains the T01–T19 implementation-conformance report, including test definitions, expected and observed outputs, expected-output/oracle provenance, and test status. Supplementary File S1 contains the self-contained HARP v1.1 software release (build HARP-v1.1-FATC-20260801-b03); File S2 contains the canonical JSON field specification; and File S3 contains the archived Pirot source/input record. Supplementary File S3 is retained unchanged to preserve replay provenance. Legacy labels contained in that archived record reflect earlier development-stage terminology and do not describe the validation status or terminology of the final HARP v1.1 specification. The version-locked Zenodo archive (https://zenodo.org/records/21761638 (accessed on 21 October 2026)) cited in Reference [33] contains the application package, README, version and citation metadata, T01–T19 test inputs and outputs, the Pirot canonical replay, SHA-256 checksums and the software licence. The corresponding source directory is also preserved in Software Heritage under SWHID swh:1:dir:2aeda3ff61069aaaff0e9ad64706e9aeb3929921. Additional executable procedures for the Pirot numerical replay and selected conformance checks, including software requirements and expected outputs, are provided in the accompanying revision package (04_Executable_Reproducibility).

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

Abbreviations

The following abbreviations are used in this manuscript:

HARP	Hospital Adaptive Reuse Profiler
HLF	Hospital Layout Form
HLF1–HLF4	Hospital Village; Pavilion; Block; Campus
LVI	Location Value Index
SPI	Site Potential Index
MFI	Morphological Flexibility Index
HVI	Heritage Value Index
RPI	Regeneration Potential Index
FOI	Functional Openness Index
CPS	Cultural Potential Score
MUC	Mixed-Use Capacity
CAP	Cultural Anchor Potential
HCI	Healthcare Continuity Index
OHF	Original Healthcare Function
UP	Urban Position
HS	Heritage Status
AS	Architectural Style
DR	Case-Metadata Reliability
T01–T19	Predefined automated implementation checks
MCDA	Multicriteria decision analysis

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