Reconnecting Place, Memory, and Self through Adaptive Reuse: Energy Performance of a Vernacular Rammed Earth Structure in Bhutan

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Abstract
This study investigates the adaptive reuse of a dilapidated rammed earth structure at Tandin Ney, Thimphu, Bhutan, transforming it into a low-impact multifunctional contemplative retreat. The project is based on the principles of cultural continuity, material authenticity and minimum environmental disturbance, and reinterprets vernacular construction in the existing footprint to serve Bhutan's Gross National Happiness framework for mental well-being. The mixed-method approach combines three key elements of architectural design development, user perception analysis, and performance-based evaluation. The programmatic elements are integrated into the natural environment to promote contemplative interaction, and validation is carried out qualitatively through surveys of stakeholders, including monastic and non-monastic participants. Dynamic energy simulation with Rhinoceros 3D, using the Honeybee plugin, analyzes thermal performance and energy demand. Results show an energy use intensity of 45-55 kWh/m2/year, and that the indoor comfort level is reached for 70-80% of the occupied hours with no active systems. This high thermal mass of the rammed earth envelope helps to stabilize indoor temperature by keeping it within ±3°C of the extremes. The findings demonstrate a strong convergence between spatial experience, cultural relevance, and environmental performance, proposing a replicable, performance-informed model for adaptive reuse in Bhutan.

Key Words: *Adaptive reuse, Rammed earth, Energy simulation, Thermal performance, Vernacular architecture*

1. INTRODUCTION

The Gross National Happiness (GNH) philosophy of Bhutan provides an alternative development paradigm that goes beyond mere economic growth, highlighting the well-being of its citizens, the environment and cultural heritage. This philosophy increasingly shapes-built environment initiatives, most notably the Gelephu Mindfulness City, rendering architectural heritage protection and adaptive reuse essential to sustainable development.

However, Bhutan is struggling with an ongoing conflict between urbanization and architectural identity. Once essential to the life of rural communities, traditional structures of ramming earth are suffering from degradation and their cultural tales are fading. Instead of treating these structures as lost forever, the purpose of this study is to acknowledge the potential for meaningful transformation and to identify the significant but under-explored resources in these structures.

This paper introduces an adaptive reuse concept for a degraded rammed earth ruin located in the vicinity of the sacred pilgrimage site of Tandin Ney that can be rejuvenated as a multipurpose contemplative space for pilgrims and urbanites. This research does not follow the traditional lines of conservation approach, but brings together aspects of design, user perception and building performance simulation, placing adaptive reuse as a cultural and technical solution. It posits that the low impact adaptations of vernacular architecture in a culturally sensitive manner can be adopted, as it provides a replicable model for sustainable development in Bhutan, which further solidifies cultural identity, fosters psychological health and is consistent with Bhutan's GNH principles.

2. THEORETICAL FRAMEWORK AND BACKGROUND

The design methodology is based upon a blend of meditative architecture, Bhutanese vernacular architecture, theory of adaptive reuse and building performance simulation with a number of relevant precedents from both local and international levels. It is a holistic approach that will help designers make decisions based on measurable environmental effects, spatial experience and cultural significance at the same time.

2.1 Adaptive Reuse and Precedent

The adaptive reuse of buildings is a sustainable solution that extends building lifecycles, reduces environmental footprint and protects cultural heritage (Douglas, 2006). It goes beyond simply reinterpreting the content, and programmatic changes are also woven into the existing structure, establishing a relationship and interplay of past and present (Bullen & Love, 2010). This is what Peter Zumthor has done in the Zinc Mine Museum in Norway, where the site is converted to minimalist buildings with weathered woods and raw materials, in the spirit of the heritage without overpowering it. Likewise, Neyphug Heritage Café at Paro is a typical local example, where the abandoned ruin structure with the material of rammed earth was restored with local material, preservation of traditional architecture, and meeting the new social needs. The case studies highlight the critical need for material integrity, minimal intervention and contextual reverence for effective adaptive reuse projects.

2.2. Vernacular Architecture and Environmental Performance

Bhutanese rammed earth construction is an advanced climate responsive building system that has been developed through centuries of empirical adaptation practices in high-altitude Himalayan climates. There are three characteristics that describe its environmental performance. A dense earthen wall is usually 600 to 900 mm thick, of density around 2050 kg/m³, and has high thermal mass, which absorbs and gradually redistributes the heat gains, blunting diurnal variations which would otherwise force unheated interiors to become uninhabitable. The size and placement of openings is also considered strategically, as openings on the south-facing elevations optimise solar gain, whilst minimising exposure on the colder north-facing walls. Using locally sourced earthen materials not only reduces the building's embodied carbon footprint of manufactured structural systems but also situates the building in its geophysical and ecological context.

These strategies have been scientifically proven in quantitative terms by contemporary building performance research. Hall & Allinson (2009) also conclude that unsterilized rammed earth has a high thermal diffusivity which is appropriate for a climate with significant diurnal temperature fluctuations; moisture sorption of earthen walls also results in hygrothermal buffering which is relevant to the monsoonal climate of Thimphu. The results show that vernacular rammed earth is not an inferior performance solution, but a technically advanced passive climate control solution that is fully in line with the current requirements of low-energy design.

2.3. Contemplative Architecture

Bhutan's vernacular architecture directly responds to topography, climate, and Buddhist principles, featuring robust rammed-earth walls, stone foundations, and timber constructions (Wangchuk, 2008; Penjore, 2017). Contemplative architecture offers design space that fosters reflection and a greater awareness of the environment through the manipulation of light, connection to nature, and the use of natural materials (Plummer, 2020).

Designed by Kéré Architecture from Montana, USA, the Xylem Pavilion is an important open-air building constructed of locally grown pine wood, offering spaces for gathering and solitude. Characterized by diffused light and seamless harmony with the forest, it demonstrates how natural forms evoke deep tranquilly and contemplation. The incorporation of these ideas forms the foundation of this study. The project puts forward the idea that contemplative architectural principles could be applied to the adaptive reuse of traditional Bhutanese buildings to serve two purposes: protect the tangible cultural heritage and meet the intangible human needs for well-being.

3. METHODOLOGY

This research is based on a mixed-method approach organized in four interrelated parts: site documentation and analysis, design development, building performance simulation, and user perception survey. The components are sequentially structured yet mutually reinforcing, where findings from each stage progressively shape subsequent design and analytical decisions.

This integrative structure positions adaptive reuse not merely as a preservation exercise but as a simultaneously cultural and performative design strategy.

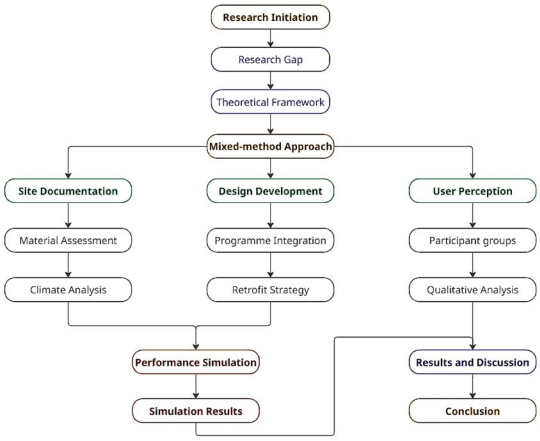

Fig. 1: *Methodology Chart (Source: Author)*

3.1. Site Documentation and Precedent Analysis

The spatial attributes, structural integrity and material composition of the existing ruin were documented through a comprehensive on-site assessment. A key precedent study of the Zinc Mine Museum, Xylem Pavilion, and Neyphug Heritage Café was also carried out to identify architectural learnings for material authenticity, minimal intervention and cultural sensitivity.

Figure 1: a) Site context, b) Existing Ruin (Source: Google Earth Pro)

3.2 Design Development

Based on the preliminary analysis, a design concept was developed in an iterative process. The proposal focused on interventions with low impact inside the ruins' footprint, with the use of local materials and passive design, creating a contemplative space with multiple functions.

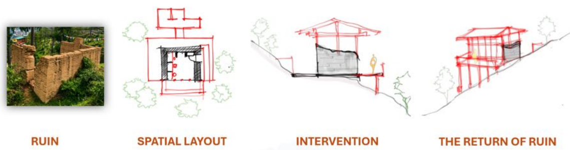

Fig. 2*: Design Iteration (Source: Author)*

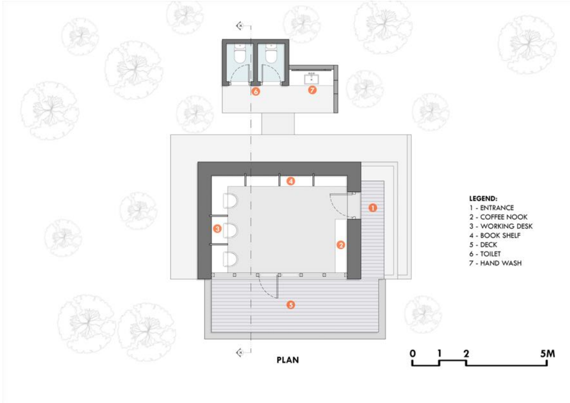

Fig. 3: *Spatial Layout (Source: Author)*

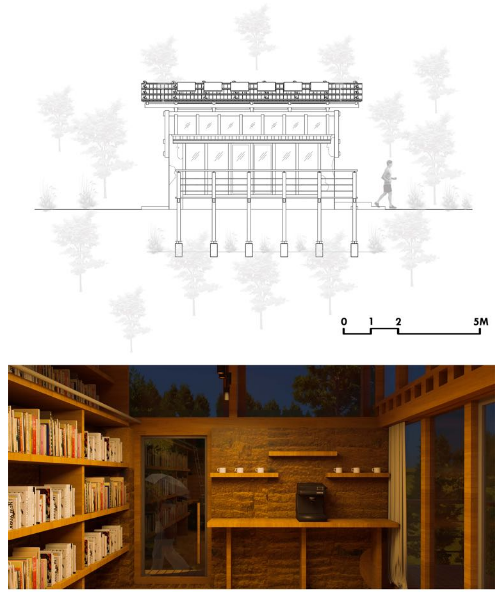

Fig. 4: *a) Elevation, b) Coffee corner (Source: Author)*

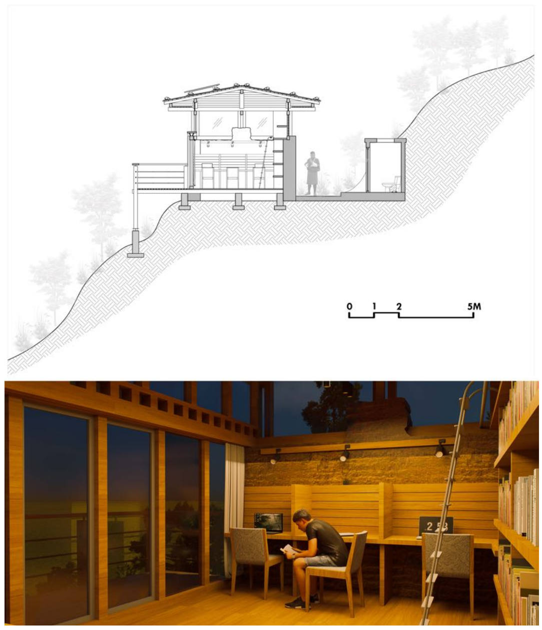

Fig. 5: *a) Section, b) Work nook (Source: Author)*

***Fig. 6**: Side View (Source: Author)*

***Fig. 7:** Side View (Source: Author)*

3.3 Performance Simulation

Thermal performance was assessed with Rhinocorus 3D and the Honeybee plugin, coupled with EnergyPlus as the simulation engine. The workflow allows the envelope parameters to be varied parametrically within a single calibrated geometric model, ensuring consistency for all the simulation scenarios (U.S. Department of Energy, 2022). Climate data were obtained from an EnergyPlus Weather (.epw) file, calibrated for Thimphu using meteorological data obtained from the National Centre for Hydrology and Meteorology of Bhutan.

The hygrothermal mass of the rammed earth walls is taken into account in the thermal model by using the material properties measured on site: material density 2050 kg/m³, specific heat capacity 920 J/kgK and the thermal conductivity of 0.72 W/mK. Thermal mass in rammed earth buildings is well recognized as being one of the key elements for passive thermal stability and comfort (Hall & Djerbib, 2004; Minke, 2012). The heat gained due to the internal gain from occupants is modelled as 80W per person at a maximum of 8 persons. Some lighting and equipment loads are not included as the programme is very minimal technology. The following five simulation scenarios are analyzed: Baseline; Roof Insulation only; Airtightness Improvement only; Glazing Upgrade only; and Combined Retrofit.

The three elements of thermal performance include indoor temperature variation from season to season, passive thermal stability, as indicated by the percentage of hours in the adaptive comfort zone according to ASHRAE 55-2020 (ASHRAE, 2020), and energy demand, namely energy use intensity (EUI), in kWh/m²·yr. In addition, a one-at-a-time sensitivity analysis is conducted, changing the infiltration rate (0.3 to 1.8 ACH), roof U-value (0.20 to 0.60 W/m²K), and the glazing U-value (1.0 to 3.5 W/m²K) to see which of these parameters is most critical to the thermal performance.

3.4 User Perspective Survey

A user perception survey was carried out in a structured way to validate the design concepts and also to assess the cultural and functional relevance. The survey aimed to gather quantitative and qualitative data from a selected sample of relevant stakeholders representing a diversity of perspectives from the monastic, academic, professional and local community.

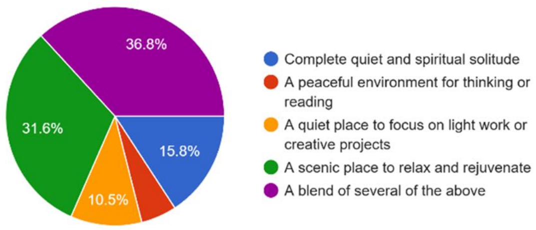

***Fig. 8:** Concept Validation Survey (Source: Author)*

4. RESULTS AND DISCUSSION

4.1. Environmental Performance

The building is still heating dominant all year round, with a peak demand from October to March. The minimum monthly heating demand in January was 479.5 kWh and in December it was 405.5 kWh, dropping to 106.0 kWh in July. This seasonal trend is typical of high annual heating degree days (3759.89 °C-day) and a very low cooling degree day value (0.04 °C-day), which is indicative of a lack of cooling demand. Individual retrofit measures resulted in the largest reductions overall, with roof insulation reducing annual heating demand from 3168.0 kWh to 2552.0 kWh, or 19.4%. A comparable reduction of 15.3% was found, reducing annual demand to 2684.0 kWh, when the airtightness was improved. The roof heat loss and air leakage had much greater impact on the building performance than the window glazing, with only a 6.9% reduction, from 2948.0 to 2850.6 kWh, for the glass upgrade.

The lowest heating demand was obtained in the combined retrofit scenario, with a total demand of 2134.0 kWh per year, which is a 32.6% reduction from the baseline. The decrease in cross seasons is consistent, which indicates a synergic effect of these three measures: roof insulation, air tightness and upgraded glazing, as the association of these three measures has a greater effect, than any one of them individually, on improving the thermal stability of the building.

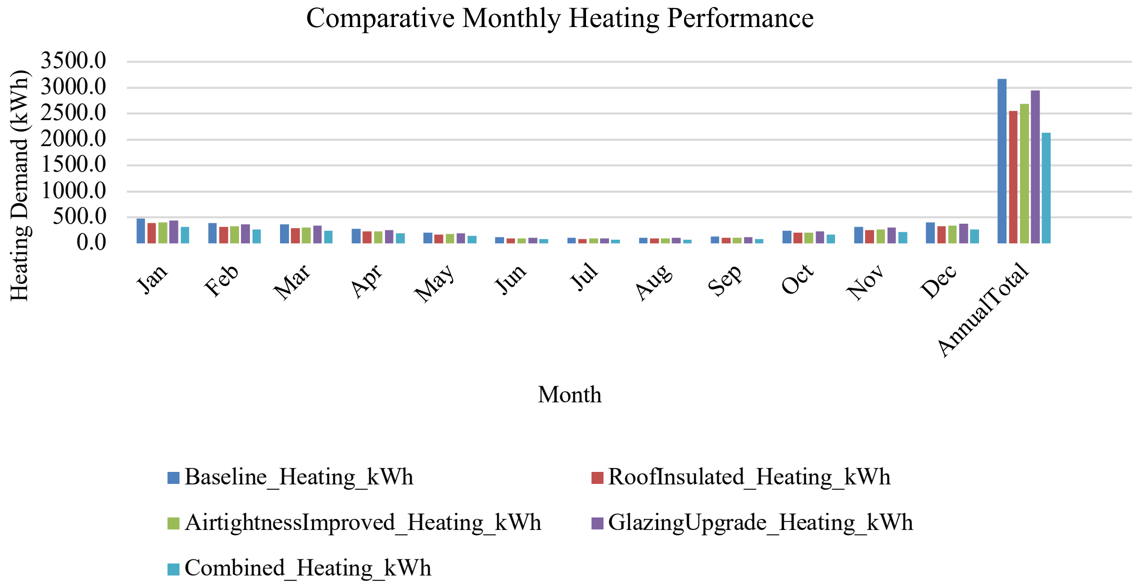

***Fig. 9**: Monthly heating demand by retrofit scenario, showing that roof insulation is the most effective individual intervention, while the combined strategy provides the greatest overall reduction (Source: Author)*

4.2. Annual Energy Use Intensity

The difference in annual energy use intensity (EUI) also confirms that the combined retrofit strategy is superior. The baseline recorded was at 72.0 kWh/m2·yr. The individual measures ranked with the lowest reduction in energy use were airtightness improvement (61.0 kWh/m²·yr) and the upgrade of the glazing (67.0 kWh/m²·yr), whereas roof insulation achieved the greatest reduction (58.0 kWh/m²·yr).

The combined scenario resulted in an EUI of 48.5 kWh/m²·yr, which is a 32.6% reduction compared to the baseline and is within the research objectives' target range of 45 to 55 kWh/m²·yr. Most importantly, this performance is delivered entirely through passive envelope improvements (not mechanical conditioning) and therefore maintains the authenticity of the material of the rammed earth structure, whilst making a meaningful contribution towards a reduction in operational energy consumption.

The result is that this has proved that low energy consumption and cultural integrity are not mutually exclusive goals, but can be achieved together in a sensitive adaptive reuse approach.

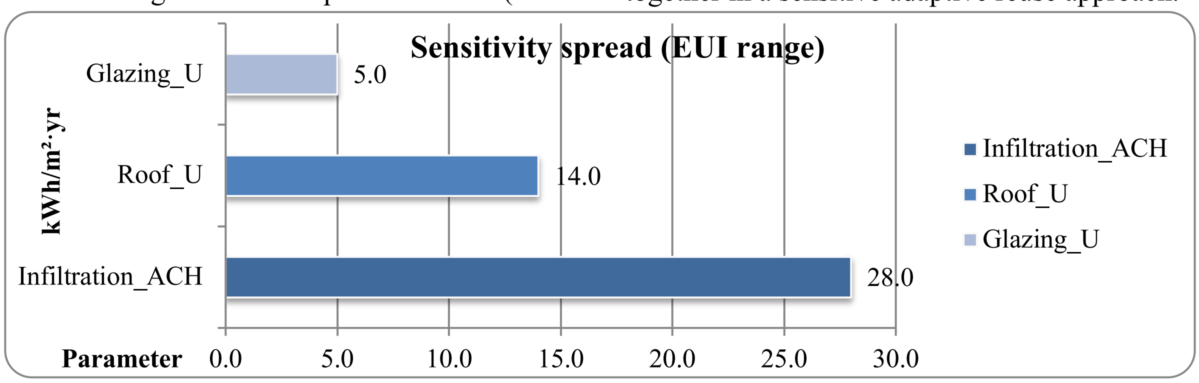

***Fig. 10:** Annual EUI by retrofit scenario, illustrating that the combined strategy provides the greatest reduction in energy demand (Source: Author)*

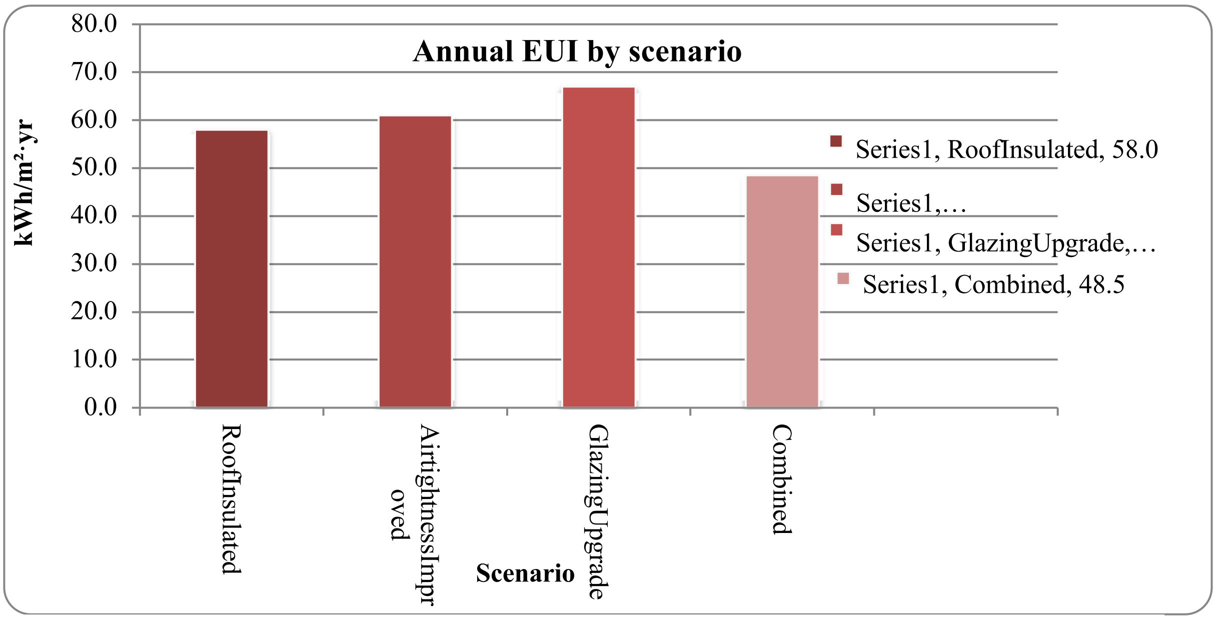

Fig. 11: *Sensitivity spread of annual EUI, showing that infiltration and roof insulation are the most influential retrofit parameters (Source: Author)*

4.3. Sensitivity Analysis

The results of the sensitivity analysis show that the most important parameter affecting annual energy performance is the infiltration rate, which gave an EUI range of 28.0 kWh/m²·yr over the range of the tested parameters. This is an indication that the major source of heat loss in the current building is the uncontrolled air leakage. The second most important was roof thermal transmittance, with an EUI spread of 14.0 kWh/m²·yr, and the third most important was the thermal transmittance of the glazing, which had a relatively small spread of 5.0 kWh/m²·yr.

The results of this study confirm the results of the monthly and annual analyses and always make it clear that airtightness and roof insulation is superior to glazing enhancements in terms of the retrofit priority. In the context of vernacular rammed earth buildings in Bhutan, where loss of heat through the building envelope in winter is a major part of the performance, this hierarchy implies that future interventions should be directed towards enhancing the air tightness of the building envelope, before investing in higher-cost fenestration interventions.

4.4. Validation of Design Intent

The survey results provide good empirical support for the objectives of the design. The quantitative information showed high values in all of the variables related to the equilibrium and cultural sensitivity of the design. It is felt that the overall concept successfully combines the traditional culture with the modern needs. This overwhelming consensus verifies that the project fulfils its primary objective. This is supported by the qualitative responses from the participants. A monastic response noted that these harmonious spaces are "universally appealing and can 'foster tranquility and contemplation'", while a design specialist commented on the "fusion of contemporary retreat with the site's cultural heritage".

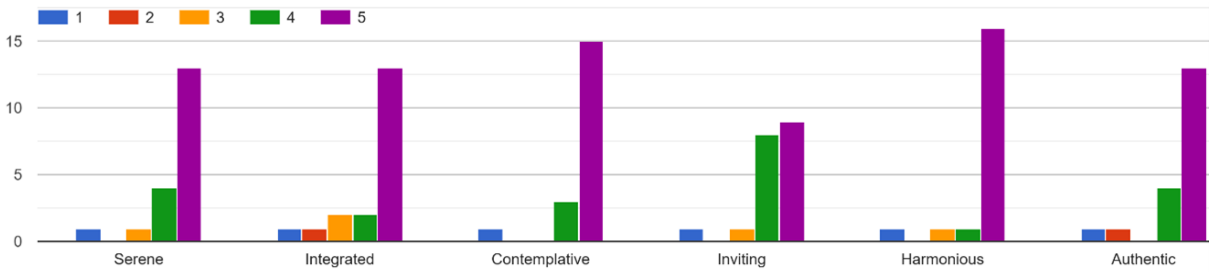

Fig. 12:*(1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree): Validation of Design Intent and Balance (Source: Author)*

4.5. Appropriateness of Multifunctional Elements

The data is directly relevant to the project's hybrid nature. The traditional meditative attributes (viewpoints and reading places) were very well rated, and modern facilities that encourage independent work and a small coffee facility were rated as appropriate.

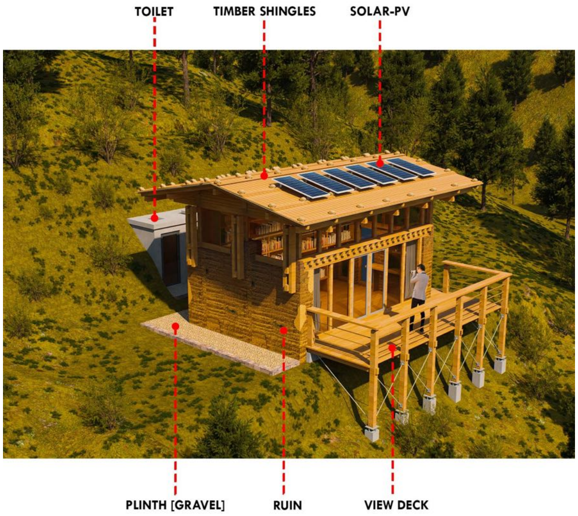

Fig. 13: *Aerial View (Source: Author)*

This shows that these functions are viewed as compatible with the site's spiritual context, serving as integrated and welcomed enhancements that improve usability and prolong visitor engagement.

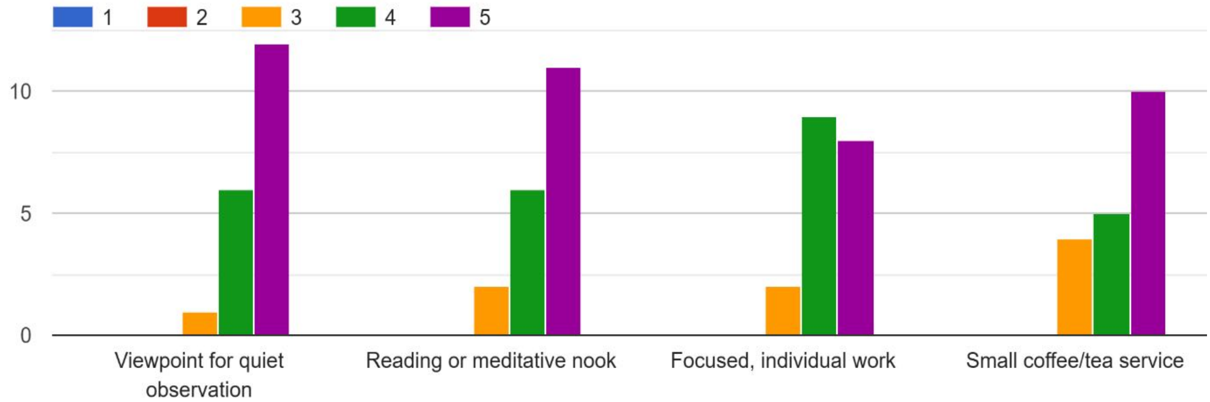

Fig. 14*: (1=Very Inappropriate, 2=Inappropriate, 3=Neutral, 4=Appropriate, 5=Very Appropriate): Appropriateness of the Integrated Services (Source: Author)*

4.6. Core Value: Well-being and Spiritual Continuity

Upon inquiry regarding the project's key values, participants predominantly recognized "Modern Well-being" (a mindful escape) and "Spiritual Continuity." This alignment accurately reflects Bhutan's GNH concept, indicating that the project is viewed as enhancing individual psychological well-being, with a focus on Spiritual Continuity and the conservation of national cultural legacy.

5. CONCLUSION

This study shows small-scale adaptive reuse can be used to rehabilitate abandoned vernacular ruins to modern use while maintaining their cultural, spiritual and environmental value. The combined retrofit strategy has resulted in a reduction of 32.6% in annual energy use intensity from 72.0 to 48.5 kWh/m²·yr using dynamic energy simulation with no change in the material character of the rammed earth envelope. The thermal mass of 600 mm earthen walls brings the temperatures to within ±3°C of the average for the season for 70 to 80% of occupied hours.

The results of the sensitivity analysis confirm that reduction of infiltration and roof insulation are the most important retrofit priorities for the sample buildings and have transferable implications for the inventory of vernacular buildings in rural Bhutan and throughout the Himalayas.

The design proposals for the contemplative retreat are based on a minimalist approach, using locally available materials and passive design elements that reflect the spiritual significance of Tandin Ney while also catering to the modern-day demands for a tranquil and contemplative space for reflection and creative expression. Stakeholder surveys validate that the intervention is culturally resonant and encourages contemplative use by both monastic and non-monastic users, supporting the idea that a heritage objective and the modern objective are

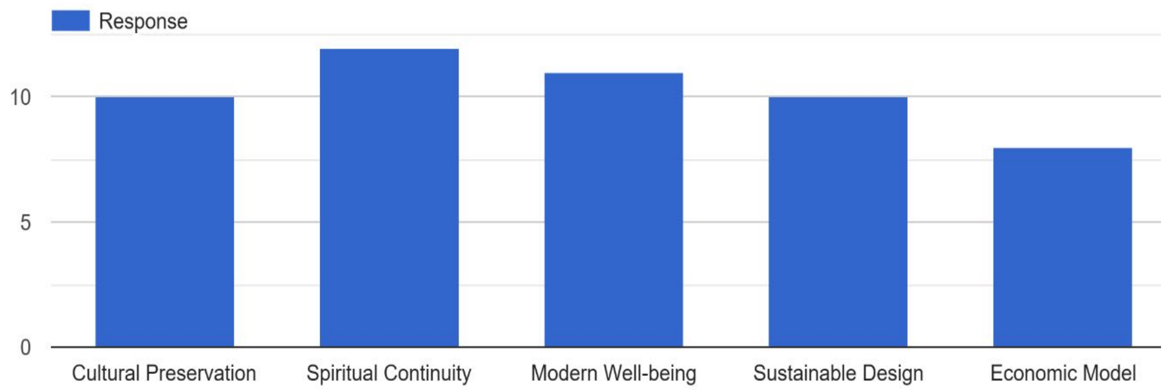

***Fig. 15**: Stakeholder Prioritization of Core Project Values*

not conflicting but at least as possible through a sensitive adaptive reuse strategy.

All these findings suggest a replicable scenario for rural Bhutan and suggest that solutions can be found within the existing systems, rather than in the landscape, and can reconnect people to nature and to memory. It eventually provides a concrete architectural embodiment of the Gross National Happiness principles and is a clear statement that caring for what already exists can be as rigorous a technical statement, culturally significant and environmentally productive as building anew.

***Fig 16**: Realistic View (Source: Author)*

6. ACKNOWLEDGEMENT

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