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An Innovative Approach to Modeling and Sustainable Conservation of Architectural Heritage in Historic Buildings

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Abstract
Sustainable growth has emerged a goal for all countires striving to achieve equilibrium among ecological, social, and financial needs. The primary aim of a sustainable built environment is to generate innovative models that optimize power and material usage. This concept must contemplate old buildings made years ago. Despite the structural stability of many of these structures, they are outdated, and their potential is not entirely realized. To revitalize and create sustainable value from this structure, adaptive recycling is used to renovate, adapt, and repurpose outmoded buildings to prolong their life cycle while serving a new function. The adaptive redevelopment of a historic structure must exert minimum influence on the heritage value of the structure and its surroundings. A plan of inquiry is formulated to achieve four goals. Initially, literature about sustainable growth, ethical principles, adaptive recycling, and emerging countries is examined; two scenarios are provided and assessed to explore the contribution of adaptive recycling to enhancing the long-term value of heritage structures; thirdly, an approach accompanied by an action model is formulated to promote the adaptable recycle of antique structures in emerging nations; ultimately, study findings are delineated, and suggestions beneficial to professionals engaged in the flexible reuse of significant structures are suggested.

Keywords – Sustainability, Architectural Heritage, Historic Buildings, Sustainable Development

1. Introduction

Attaining sustainable development goals necessitates balancing the community's ecological, social, and financial requirements and the resources at its disposal [1]. The main objective of a built environment is to create creative structures that employ energy and intelligent elements. This concept must be considered old architecture constructed years ago. Global acceptance is increasing, and preserving historic structures yields substantial financial, cultural, and social advantages [21]. Historic edifices should be preserved for posterity as they connect societies to their heritage. Several landmark buildings of cultural and historical importance are being altered and repurposed instead of destroyed to revitalize and create long-term value from these structures [26]. The adaptive redevelopment of historic buildings is a chance to develop sustainable social, ecological, and financial benefits. Owing to their attributes, developing nations face numerous problems that impede the adaptive recycling of ancient structures and block long-term value creation for these edifices [23].

This research examines the efficacy of adaptive recycling as an innovative strategy for creating long-term value in historic structures within emerging nations. A qualitative study method is employed to fulfill these four goals.[4]. The literature review examines the notions of sustainable growth, ethical values, reuse and adaptation, and the attributes of developing nations.

Secondly, two instances are provided and analyzed to elucidate the function of adaptive recycling in enhancing the environmental principles of historic structures. An approach accompanied by a plan of action is formulated to promote the adaptive reuse of old structures in emerging economies. The research findings are summarized, and suggestions for practitioners involved in the adaptive reusing of historic structures are presented.

2. Background

Numerous initiatives have been undertaken in the scientific domain to safeguard Cultural Heritage (CH) [5]. The implementation of Structural Health Monitoring (SHM) methodologies to evaluate safety and architectural integrity is outlined to advance SHM information processing to quantify ambiguity and minimize static and dynamic surveillance variables [6]. The primary aim is to comprehend the building dynamics of edifices.[3]. The significance of tracking the condition of historical edifices to anticipate and mitigate deterioration through detectors and cutting-edge technology is underscored by utilizing a forecasting methodology grounded in statistical methods such as data mining, forecasting, and artificial intelligence to forecast future occurrences [7]. A museum surveillance is developed to enhance visitor administration inside the museum environment. Utilizing Bluetooth signals, statistical evaluation, and multiple-tier perceptron neural networks facilitates the accurate reconstruction of guest itineraries, which is crucial for stochastic estimation and optimizing museum activities [8].

The authors detail implementing a room tracking system designed to conserve artworks on wooden substrates, wherein the interior microclimate variables such as humidity, heat, and vibrations are assessed. Intelligent Internet of Things (IoT) devices known as Smart Tags are designed for deployment around landmarks and interconnected via middleware [9]; the architecture aims to utilize low-energy detectors, enhancing overall efficiency.[10].

Among the methodologies for detecting faults or deterioration in artifacts, Acoustic Emissions (AEs) are extensively utilized in art conservation [22]. Utilizes a convolutional autoencoder derived from images captured by thermal cameras to assess potential damage to modern artworks, conducting the testing stage. The AE is used to discern keywords that enhance the accessibility of historical writings by streamlining access to repositories.[2].

This study proposes a system that integrates an automated encoder for extraction of hidden characteristics from database meta-features and a k-nearest neighbor (kNN) for selecting effective learning pathways according to the separation among characteristic vectors, enabling it to surpass traditional model and other conventional meta-approaches [11]. AEs safeguard structures via processing images and crowdfunding [12]. These literary works validate the efficacy of AE in detecting deviations, ensuring the capacity for timely intervention to preserve cultural treasures.

3. Method

In contrast to conventional preservation design for historic regions, the sustainability building features assessment approach suggested in this research includes a phase of dynamic review and ongoing modification (Figure 1). By distilling the structure's characteristics pre- and post-renovation into spatially qualitative indicators, the procedure for renovation, the extent of feature value augmentation, and the category of building preservation are graphically encapsulated [13]. By consistently juxtaposing the building characteristic components with a sustainable value introduction, the spatial particle positions can be modified by changing the appropriate components of the building characteristics size to approximate the region of the most excellent overall value as much as possible. The preservation approach in the historic areas will evolve from a singular, static approach to a feasible, evolving procedure that allows for continual comparison and reflection [25].

The suggested methodological approach was mainly applied to the southwestern external façade of the castle, using a workflow designed to implement an innovative approach that fulfills the study's originality (Figure 2):

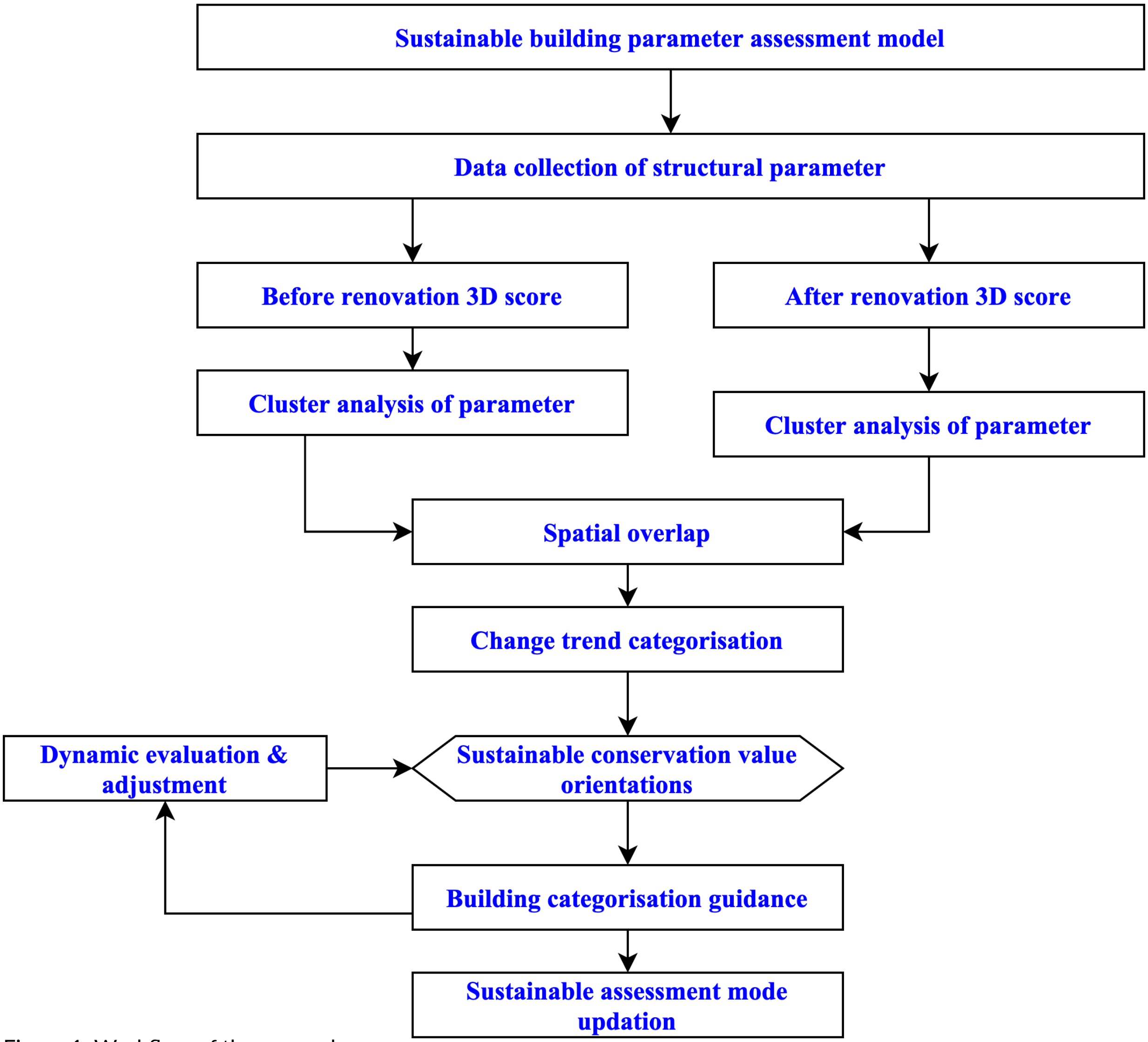

Figure 1. Workflow of the research

The photogrammetric collection facilitates the stratigraphic analysis of ancient masonry and evaluates the efficacy of alternative survey data and exceptionally High-Definition (HD) laser scanning data [15]. This stage was crucial for acquiring the most precise foundation for geological mapping (currently, photography is the most effective method) and evaluating its accuracy against laser scanning.

Planning and data enhancement to facilitate the shift from conventional 2D geological representations linked to a rehabilitation operation to 3D stratigraphy imaging to support preservation initiatives [16].

Semi-automated generation of the Harris vector to explore the feasibility of displaying and upgrading architectural alterations in a semi-automated manner as the structure evolves in response to fresh insights about the past and prospective alterations.

Improvement of laser scanner information inside the Building Information Model (BIM) framework to examine the primary role of HD collection in facilitating stratigraphic research [17].

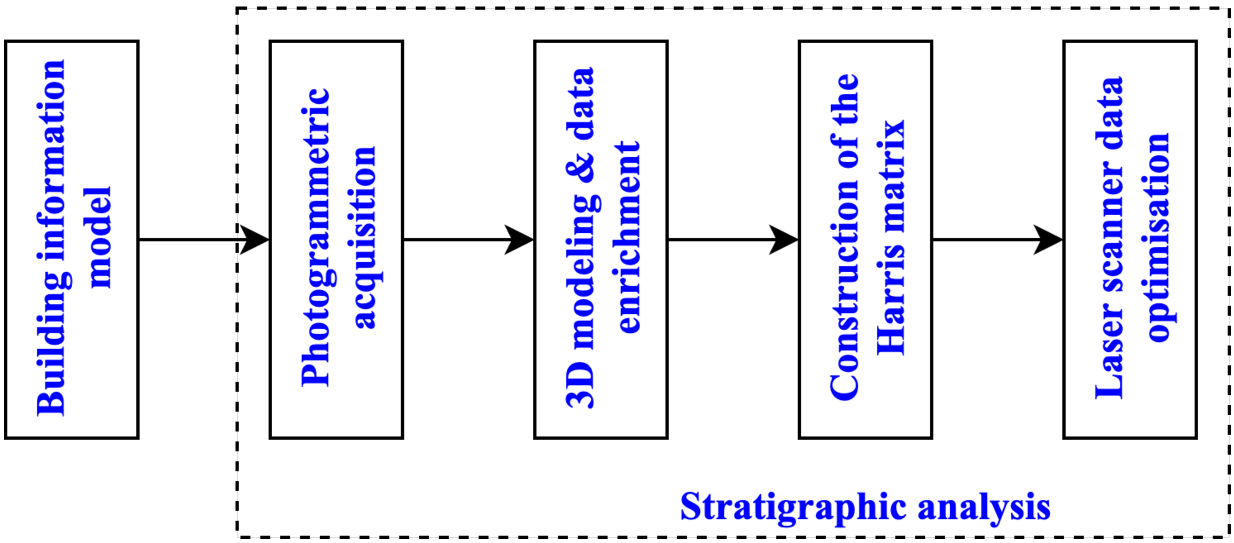

Figure 2. Stratigraphic analysis of the BIM model

The primary changes in the suggested workflow are found in the subsequent steps, which provide a novel method of participation, enhancing the administration of data and its retrieval and filtration [18]. The whole workflow serves as a convergence point for subdomains from other disciplines. This trial serves as a chance to apply teamwork and reinforce the necessity for interdependence in historical endeavors.

3.1 Architectural design

As previously observed, existing literature on protecting cultural heritage sites lacks broad strategies encompassing all significant components. This section presents a design that integrates the three essential aspects of maintaining buildings in the CH group: tracking, preventive preservation, and making choices for the interventions to be carried out. The procedure illustrated in Figure 3 comprises four operational tiers: the Sensing Tier, the Knowledge-Base Tier, the Interpretation Engine Tier, and the Application Tier.

The Sensor Tier aggregates all IoT gadgets to convey ecological variables pertinent to the item under investigation. This tier comprises various devices, including detectors that facilitate gathering data on environmental and micro-environmental illnesses, material modifications, structural deficiencies, and motors that modify these external circumstances [19]. This data enables the acquisition of supplementary details that enhance the system, including degradation processes and associated treatments aligned with existing services that delineate the situations of the Cultural Property [20].

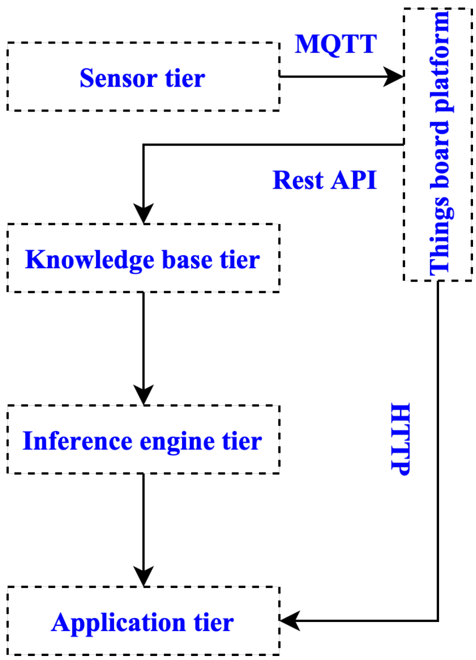

Figure 3. The layered architecture of the suggested model

Data collected via sensors utilizes the Message Queuing Telemetry Transport (MQTT) communication standard. The MQTT procedure, using a publish-subscribe model, comprises three entities: the author, who disseminates information on a specific topic; the member, who accesses the details released on the subscribing subjects; and the facilitator, who oversees message management across the numerous issues. The proposed design facilitates data collecting via the IoT ThingsBoard system, which offers multiple features, such as handling acquired information from transferrable sensors using Rest Application Programming Interface (API)-based services. These APIs enable the gathering of organized and unorganized information about applicable sensors.

The fundamental component of the suggested layout is the knowledge-based tier. This tier obtains data via the Representational State Transfer (REST) APIs provided by the IoT Thingboards panel, facilitating the preservation of information in preparation for analysis within the Interpretation Engine Tier. This tier involves preparing and verifying the information gathered, ensuring its homogeneity before storage for future use. The preparation stage is essential for collecting pertinent information in CH conservation, hence augmenting the historical data. The obtained data are subsequently utilized to supply the inference blocks.

The Interpretation Engine Tier employs algorithms for learning to characterize actual circumstances and ascertain various factors depending on the gathered data. This section is essential to the overall effectiveness of the process since it comprises all the data streams for the inferences upon which the decisions for tracking, forecasting, and treatment will rely. The Inference Engine Tier shall consist of two sub-classes: The Forecasting Maintenance Component and the Decision Assistance Component. As demonstrated in the research review, the previous study utilizes specific Artificial Neural Networks (ANNs) known as AEs. Each monitoring the framework uses has a corresponding trained AE model. The second tier uses the anomalies detected by the Forecasting Maintenance Component to suggest appropriate treatments for the building.

The Application Tier facilitates the dissemination of acquired knowledge and data to a subsequent component that conducts surveillance and essential analyses for project management and optimal decision-making. The gathered data is accessible for viewing via ThingsBoard, an open-source IoT system that facilitates control, manufacturing, and visualization of the information gathered. The proactive upkeep and decision-making module relies on algorithmic reasoning that analyzes patterns within the inferential engines. This application is designed for proficient users. This approach offers insights into the surroundings for monitoring, enabling self-governing actions to enhance the system, including humidification and temperature oversight, air quality evaluation, and utilization of energy reduction. Professionals can leverage current information for managing assets or autonomous tasks the algorithm performs through customized panel visualizations. Another feasible application posits that data acquired from surveillance can be utilized to extract data related to the timing and method of maintaining assets, optimizing the operational phase of potential intervention strategies.

4. Trend Categorization Analysis

The building characteristics were geographically superimposed to identify the clusters of structures before and after refurbishment in a single spatial area. The dataset of historic buildings and associated qualities was loaded into the Statistical Package for the Social Sciences (SPSS), utilizing the two categories of clustering type data pre- and post-renovation variables for methodical clustering. The number of groups for the change tendency for previous building characteristics was 10, while the tendency for other architectural characteristics was 16.

In summarising the ten distinct ways in which features of historical buildings have evolved, three overarching tendencies emerge.

Pattern I: Enhancing both form and structural scores and augmenting the outward functional advantages of the establishing while preserving its conventional shape and construction, encompassing 84 structures;

Pattern II: Numerous edifices featuring traditional architectures and designs sustained significant damage. Fifty-five of these edifices have been transformed into modern buildings owing to challenges in preserving their conventional characteristics or considerations. This behavior compromised the obligation of historical structures to communicate genuine historical knowledge.

Pattern III: Certain edifices featuring traditional architecture and design have not received adequate protection. Their architectural and procedural qualities have deteriorated over time, encompassing 20 buildings. These structures require immediate additional conservation efforts.

In summarising the 15 distinct alterations in various structures' attributes, there are six patterns, omitting demolition practices.

Pattern I: The contemporary architectural design was enhanced with forms exhibiting greater cultural diversity, encompassing 105 structures.

Pattern II: the conventional architectural design was fortified, with forms aligning more closely to the intended historical style, comprising 20 structures.

Pattern III: The conventional building framework was converted into a modern edifice with enhanced durability while maintaining the original architectural form, consisting of nine structures;

Pattern IV: conventional structures have been transformed into edifices with enhanced structural integrity and historical attributes, encompassing 25 structures.

Pattern V: The structural integrity of the contemporary edifice was augmented, and the facade was reconfigured to resemble an antiquated building comprising seven structures.

Pattern VI: Contemporary structures have been transformed into ancient edifices, preserving three structures' ancient architectural forms.

4.1 Orientation towards Sustainable Preservation

The evaluation model included the aforementioned patterns in building feature alterations onto the rebuilt building map using spatial positioning to evaluate various conservation methods.

The three evolving tendencies of historical buildings indicate that the assets are nearing the first sector. The restoration process reveals that, despite numerous trends in attribute modifications of historical structures, the singular objective of conservation efforts is to preserve authentic conventional structures, forms, and external characteristics. This pertains to the obligation of historical edifices to convey the authenticity of cultural heritage.[24].

Building construction, shape, and benefit dimensions must intersect at the locations (5, 5, 5). The building must enhance its structural integrity while preserving its conventional design; its design should reflect the true nature of the designated traditional design, and the practical advantages should be as externally visible as feasible. Due to the statutory obligatory preservation standards for historic properties, there is limited adaptability in counseling regarding ecological preservation; thus, the focus of counseling and regulation is directed toward other structures and specific instances of structures in the vicinity.

I and IV suggest that the 3D characteristics are nearing the third region of the six characteristic modified developments of other structures. At the same time, VI is disregarded due to errors in the modification. In alignment with sustainable conservation principles, additional nearby structures should integrate building organization, form, and utility at designated coordinate locations. They denote that:

The structure's structural integrity has been enhanced by preserving its original design, which reflects its genuineness of the "target period style," while the spatial arrangement offers practical advantages.

The edifice has been upgraded and reinforced structurally. The structure has a contemporary design while conveying extensive cultural and archaeological content. The constructed space serves a practical function that yields advantages; it features a sleek building with a facade that conveys historical or cultural significance, or it is designed in an older antique style while exhibiting a contemporary form, all while providing efficient functional advantages.

By analyzing the evolving characteristics of buildings in various methods of preservation and their leaning towards sustainable preservation values, three main groups and five subcategories of structures were identified:

1. Group A - Authenticity-oriented Group, focused on enhancing genuineness: This kind of construction is a genuine historical structure in its original position, possessing a three-dimensional alignment rating of (5, 5, 5). The control components encompass the enlargement of the conventional architectural framework, the preservation of the building's size and floor count, the alignment of the structure's shape with the "targeted archaeological model," the comprehensive enhancement of the facade's aesthetic, and the integration of suitable functional uses for preservation.

2. Group B - Image-display Group, focused on enhancing façade aesthetics: This indicates a disparity in the structural and dimensional characteristics of the construction, reflecting a juxtaposition of conventional and contemporary introductions, with a three-dimensional alignment rating of (5, -5, 0) or (-5, 5, 0). The guiding components encompass structural encouragement, minor variations in dimension and the number of floors, and a focus on showcasing historical knowledge of the facade's imagery. Restore and enhance the cultural data presented by the "targeted history style" to the greatest extent possible while incorporating suitable functional applications.

3. Group C - Cultural-based category, with the primary objective of enhancing diversity:

Sub-class C-1: Restoration Structure. It pertains to structures reconstructed in their place, with the 3D alignment value (-5, -5, #0). The primary criteria are that the dimensions and configuration of the structure must closely resemble the original edifice, and the outer facade and inside design should preserve the intended characteristics to the greatest extent feasible.

Subclass C-2: Reproduction Structure. It pertains to replicating unreserved structures utilizing past information or relocated historical edifices, with a three-dimensional alignment score of (-5, -5, 0). The governing factors, encompassing the structure's shape and design, must align with the temporal or practical data corroborated by evidence; the dimension and amount of stories are not mandated, and the construction style should not be jarring.

Sub-class C-3: Deductive Construction. It pertains to contemporary structures or historical edifices possessing a 3D orienting rating of (-5, -5, 0). The guiding principles must encompass the outward shape and distinctive characteristics that reflect regional past and present richness, using a variable scale and varying levels. The architectural design should not adhere rigidly to the intended historical fashion but instead, reinterpret old cultural components via a modern lens. The shape should incorporate distinctive elements and characteristics that effectively showcase the cultural and historical significance of the region, highlighting the area's unique culture.

Conclusion

- Upon examining the principles of sustainable growth, the sustainable attributes of developing nations, and reuse and adaptation while considering insights gained from instances, the study arrived at the following findings and suggestions:
- Governments globally are focused on providing facilities and infrastructure projects that fulfill sustainable growth's social, financial, and ecological objectives.
- This necessitates balancing society's boundless demands and accessible, constrained resources. Although the focus is on new initiatives, this vision must include old structures.
- The adaptive recycling of old structures in developing nations is an innovative strategy for revitalizing and enhancing their ecological worth. Emerging nations face numerous constraints that impact historic structures' usage and adaptive reuse.
- Consequently, the study presents the following suggestions.
- The adaptable recycling of historic structures ought to be a fundamental strategy for rejuvenating old edifices and fostering sustained social, financial, and ecological benefits in emerging nations.
- The obstacles faced by developing nations regarding adaptable reuse must be addressed.
- The strategy produced by this study and its implementation plan established a foundation and an initial framework for promoting the adaptive recycling of heritage structures across the domains of community, economy, surroundings, laws, and technologies.

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