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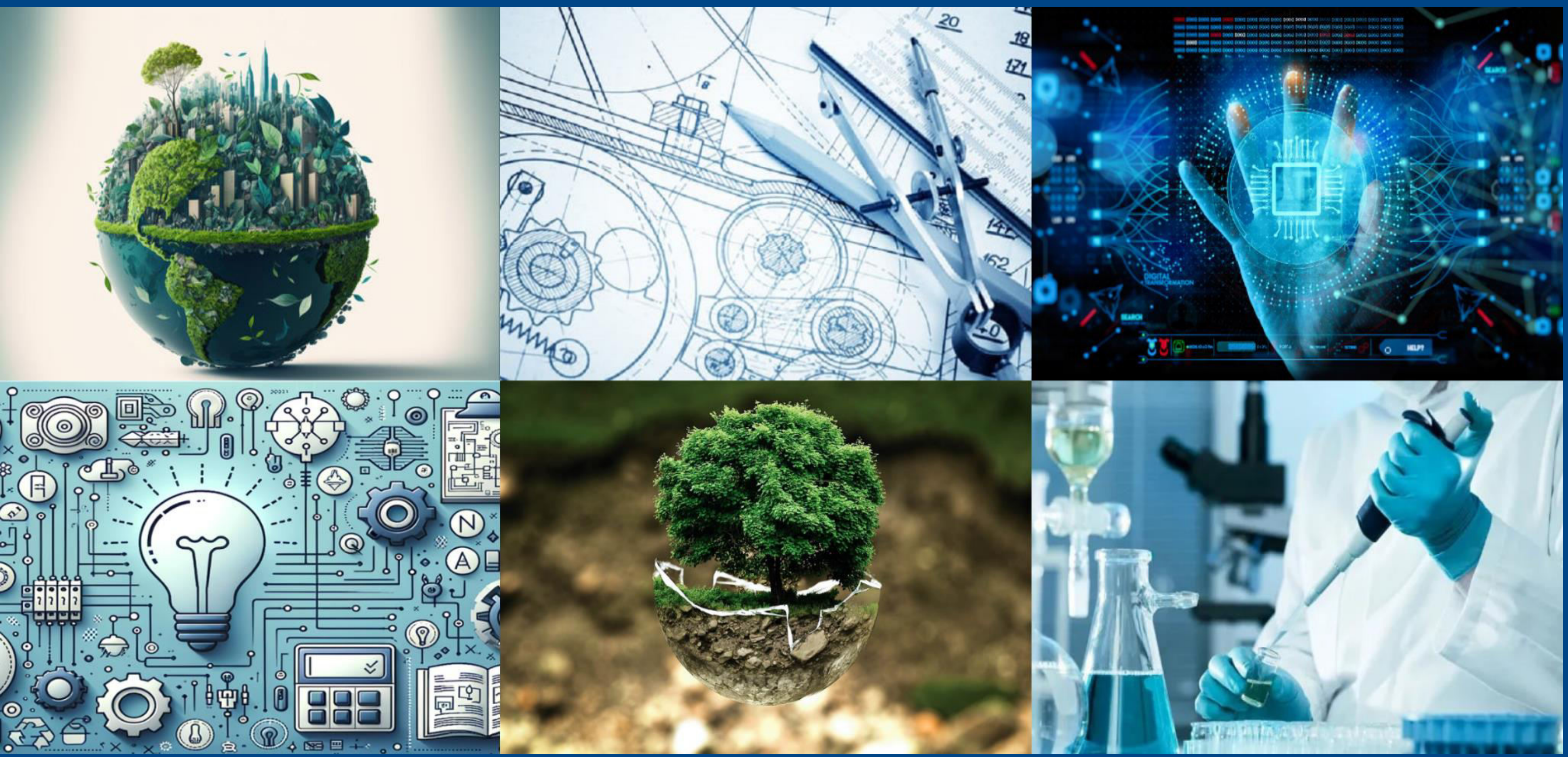

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Comparative Analysis of Economical Waterproofing option for Residential Buildings

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ABSTRACT: Waterproofing is an essential component of residential construction that has a direct effect on a building's longevity, security, and upkeep expenses. In order to find solutions that strike a compromise between affordability, performance, and sustainability, this study compares many low-cost waterproofing techniques used in residential buildings. The study looks into popular methods such bituminous membranes, liquid-applied membranes, polyurethane systems, crystalline waterproofing, and cementitious coatings. Important factors such initial cost, simplicity of application, durability, impact on the environment, and long-term maintenance are taken into account. A review of the literature, field trips, expert interviews, and on-site observations from residential structures in various climate zones are all part of the technique. Keywords—Prosumer, Renewable Energy Sources (RES), Load Forecasting, Gaussian Process Regression (GPR), Energy Hub (EH), Hub Energy Surplus (HSE). The most economical options for short-term use are cementitious and bituminous technologies, but crystalline and polyurethane systems perform better in terms of longevity and low maintenance. Practical suggestions for choosing suitable waterproofing techniques based on building location, financial constraints, and functional requirements are provided in the study's conclusion. Through this research, homeowners, architects, and civil engineers will be able to make well-informed and financially sound waterproofing decisions.

I. INTRODUCTION

Water infiltration is a recurrent and destructive problem in residential building construction. Water leakage, dampness, and moisture buildup can cause major structural component degradation, shorten a building's lifespan, and result in expensive maintenance and health problems like mold and mildew. Effective waterproofing measures are crucial for reducing these dangers both before and after construction. The term waterproofing describes the use of materials and methods to keep water out of a building's walls, roofs, balconies, basements, and moist areas like bathrooms and kitchens. The demand for long-lasting and reasonably priced waterproofing solutions has increased more than ever due to the quick expansion of urban development and shifting weather patterns, particularly in areas that are vulnerable to severe rainfall or groundwater seepage. In the construction industry, there are many different waterproofing processes, each with its own set of pricing, application methods, lifespans, and environmental effects. Long-term protection is provided by sophisticated systems, although their installation and material costs are frequently higher. Traditional approaches, on the other hand, could be less expensive at first but might need more frequent replacements or repairs. Consequently, it is crucial for homeowners, contractors, and legislators to carefully assess how cost-effective these approaches are.

The objective of this study is to compare the most popular waterproofing techniques for residential structures, taking performance and cost factors into account. Finding solutions that provide the optimal balance between cost and long-term efficacy is the goal in order to make well-informed decisions on home construction techniques.

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II. LITERATURE SURVEY

Michal Nývlt , Jiˇrí Pazderka and Pavel Reiterman [1] The study compares different types of waterproofing screeds based on their adhesion to various building materials after undergoing freeze-thaw cycles. It highlights that the cohesion strength between screeds and substrates like concrete, brick, and metal significantly varies depending on the type of waterproofing material used. Polyurethane-based and polymer-modified screeds generally showed better performance and durability under freeze-thaw stress compared to traditional cement-based screeds. The findings suggest that material compatibility and environmental resistance are crucial in selecting an effective waterproofing system. This research aids in optimizing waterproofing choices for structures exposed to harsh weather conditions.

1Dhruvil N Bhatt, 2Dr D.M Patel, 3Rahul S Shah [2] The study compares different waterproofing methods including Brick Bat Coba, Membrane Waterproofing, Injection Grouting, and Damproof Coating, focusing on their application, effectiveness, and cost. Among these, Brick Bat Coba is found to be the most feasible and commonly used method due to its cost-effectiveness and durability. The research highlights that poor workmanship and low-quality materials are the primary causes of waterproofing failures. Chemical products like Dr. Fixit are preferred for their reliability and longer durability. Ultimately, the choice of waterproofing system should depend on site-specific conditions, budget, and performance needs.

Sangyong Kim , Gwang-Hee Kim , and Young-Do Lee [3] The paper "Sustainability Life Cycle Cost Analysis of Roof Waterproofing Methods Considering LCCO2" evaluates four types of roof waterproofing methods using a life cycle cost (LCC) analysis that incorporates both economic costs and life cycle CO_2 emissions ($LCCO_2$). It compares polyurethane coating, asphalt waterproofing, synthetic polymer sheets, and composite materials, analyzing not only initial and maintenance costs but also their environmental impacts. The study concludes that polyurethane coating offers the most favorable balance between cost and sustainability, with the lowest combined LCC and $LCCO_2$. The findings aim to support decision-making for sustainable construction by integrating environmental criteria into cost analysis.

Ahmed Hadj Sadok , Luc Courard . [4] Key Findings:Chloride Diffusion: Mortars with increased BFS content (30%, 50%, 70%) show a significant reduction in chloride diffusion.This reduction is due to the refinement of the pore structure and reduction in connectivity of capillary pores.Even though the slag used had low hydraulic reactivity, its filler effect and pozzolanic reaction (with $Ca(OH)_2$) contributed to improving the microstructure.Oxygen Permeability:Similar to chloride diffusion, oxygen permeability decreased with increasing BFS content.Lower permeability is linked to better compactness and finer pore size distribution, reducing the ease with which oxygen can penetrate. Microstructural Observations: SEM and mercury intrusion porosimetry showed denser microstructures with increasing BFS.Pozzolanic reaction was confirmed, although the BFS had relatively low reactivity.

Jurga Šeputyte -Jucike , Modestas Kligys , Marijonas Sinica. [5] This paper investigates the effectiveness of various waterproofing chemicals used in concrete to enhance its resistance to water ingress. The study includes both laboratory and field evaluations of different chemical additives, aiming to identify the most efficient products in terms of water absorption reduction, compressive strength, and durability.Objective:To evaluate and compare the performance of different waterproofing compounds when mixed with concrete.To assess improvements in compressive strength and reduction in water permeability.Materials & Methodology:Several concrete cubes and cylinders were prepared with various waterproofing chemicals.Tests were conducted including:Water absorption test Compressive strength test Visual inspection for surface cracks Waterproofing Chemicals Tested:

Multiple commercial brands and compounds were tested, each labeled with a code (e.g., WPC-A, WPC-B, etc.).These included integral waterproofing compounds, polymer-based coatings, and silicate-based products.Results:Some waterproofing chemicals significantly reduced water absorption by over 40%.A few compounds improved compressive strength marginally (5–10%).Visual inspections revealed that treated surfaces resisted hairline cracks better than untreated concrete.Conclusion:Not all chemicals performed equally. Some showed exceptional performance in water resistance but not necessarily in strength enhancement.The study recommends selecting waterproofing chemicals based on specific needs (e.g., water exposure level, structural load).Recommendations:Further long-term studies are needed for durability assessment in real-world conditions.Application methods (mixing, curing) play a crucial role in performance outcomes.

III. METHODOLOGY

The methodology for this study is designed to systematically evaluate and compare various waterproofing options for residential buildings, focusing on their cost-effectiveness and performance across different application areas. Drawing inspiration from the experimental and evaluative approach of An and Kim (2023), who assessed waterproofing methods for underground slabs, this study broadens the scope to include multiple parts of residential buildings—such as basements, roofs, and interior wet areas—while emphasizing economic considerations alongside technical performance. The methodology comprises six key steps, detailed below, to ensure a robust and replicable analysis.Understanding Energy Hub:

1. Categorization of Waterproofing Applications
Residential buildings require waterproofing in diverse areas, each presenting unique environmental and structural challenges. To provide a comprehensive analysis, waterproofing applications are categorized into three primary domains:
- Below-Grade Applications (Basements): These include basement walls and floors, which are exposed to soil moisture, hydrostatic pressure, and potential chemical interactions from groundwater.
- Above-Grade Exterior Applications (Roofs, Balconies, Exterior Walls): These areas face weather-related stresses, such as rainfall, ultraviolet (UV) radiation, temperature fluctuations, and wind exposure.
- Interior Wet Areas (Bathrooms, Kitchens): These zones experience frequent water exposure but are less affected by external environmental factors, requiring solutions compatible with finishes like tiles.

This categorization allows for tailored evaluation criteria and method selection, reflecting the specific demands of each building component.

2. Selection of Waterproofing Methods
A representative set of waterproofing methods is selected for each category, based on their common use in residential construction, availability, and potential for economic viability. The selection draws from industry practices and includes methods assessed in the reference study, supplemented by additional options relevant to broader residential applications. The chosen methods are:
Below-Grade Applications: Bituminous Torch-On Membranes: Widely used for their durability and water resistance. - Cementitious Crystalline Waterproofing: Known for its affordability and ability to integrate with concrete. - Polyurethane Liquid Membranes: Flexible and effective against hydrostatic pressure. - PVC Sheet Membranes: Durable and resistant to soil chemicals.- Above-Grade Exterior Applications:- Acrylic Coatings: Cost-effective and UV-resistant, suitable for roofs and walls. - Polyurethane Liquid Membranes: Versatile with strong weather resistance. Thermoplastic Polyolefin (TPO) Membranes: Energy-efficient and durable for flat roofs. - Ethylene Propylene Diene Monomer (EPDM) Membranes: Flexible and long-lasting, ideal for balconies and roofs.- Interior Wet Areas: - Cementitious Waterproofing Slurry: Economical and easy to apply under tiles. - Acrylic-Based Liquid Membranes: Flexible and mold-resistant.- Polyurethane Liquid Membranes: High-performance option for wet areas.- Waterproof Tile Adhesives: Combined waterproofing and adhesion for tiled surfaces.These methods are chosen to balance performance and cost, with some overlap (e.g., polyurethane liquid membranes) to assess versatility across categories.

3. Definition of Evaluation Criteria
The evaluation framework integrates performance and economic criteria, adapting the rigorous testing approach of An and Kim (2023) to include cost factors critical to your study's focus on economical options. Criteria are tailored to each category's specific needs.Performance Criteria

Below-Grade Applications:
Water Tightness Under Hydrostatic Pressure: Resistance to water penetration under pressure (e.g., 0.3 N/mm² for 3 hours, per KS F 4919).
-Durability in Soil Contact: Resistance to degradation from soil moisture and chemicals.
- Chemical Resistance: Stability against groundwater contaminants.
- Adhesion to Concrete: Strength of bonding to basement substrates.
- Above-Grade Exterior Applications:
- Water Tightness: Prevention of water ingress during rainfall.
- UV Resistance: Stability under prolonged sunlight exposure.
- Temperature Fluctuation Resistance: Ability to withstand thermal expansion and contraction.

- Ease of Maintenance: Simplicity and frequency of upkeep.
- Interior Wet Areas:
- Water Tightness: Resistance to standing water and splashes.
- Mold Resistance: Prevention of fungal growth in humid conditions.
- Ease of Application: Practicality in confined, tiled spaces.
- Compatibility with Tile Adhesives: Integration with common finishes.

Economic Criteria (Common Across Categories)

- Initial Material Cost: Cost per square meter of the waterproofing material.
- Labor Cost for Installation: Expenses related to application, based on complexity and time.
- Expected Lifespan: Duration of effective performance before replacement, estimated from industry data.
- Maintenance and Repair Costs: Long-term expenses for upkeep and fixes over the lifespan.

4. Data Collection

Data is gathered from multiple credible sources to ensure accuracy and relevance:

-Performance Data: Derived from standardized tests (e.g., ASTM, ISO, or Korean Industrial Standards like KS F 4919), manufacturer technical sheets, and peer-reviewed literature. Where direct test data is unavailable, performance is inferred from similar studies or specifications.

- Economic Data: Collected from market surveys, contractor quotes, and industry reports specific to the United States (as a reference region). Costs are expressed in USD per square meter and averaged to account for regional variations.

- Lifespan Estimates: Based on manufacturer claims, case studies, and industry standards (e.g., bituminous membranes: 10-15 years; EPDM membranes: 20-30 years). Assumptions are clearly noted to address variability.

This approach avoids the need for primary experimental testing, leveraging existing data to focus on comparative analysis, while acknowledging limitations in data consistency.

5. Scoring and Ranking

A quantitative scoring system is employed to evaluate and rank the waterproofing methods, integrating performance and cost-effectiveness.

Performance Scoring

- Each performance criterion is scored from 0 to 10, based on relative performance compared to other methods in the same category. For example, the method with the best water tightness receives a 10, the worst a 0, and others are scaled proportionally.
- Scores are aggregated into a total performance score (out of 40 for four criteria per category), weighted equally unless specified otherwise by expert input.

Economic Analysis

- Annual Cost Calculation: The annual cost per square meter is computed as:

  (Initial Cost (Material + Labor) + Estimated Maintenance Cost Over Lifespan) / Expected Lifespan
- Maintenance costs are estimated as a percentage of initial costs (e.g., 5-10% annually) unless specific data is available.

Combined Evaluation

- A cost-effectiveness metric, termed the "Value Score," is calculated as:

  Value Score = Performance Score / Annual Cost
- Higher Value Scores indicate better cost-effectiveness. Methods are ranked within each category, and sensitivity analysis is conducted by varying lifespan estimates (e.g., optimistic vs. pessimistic scenarios) to test robustness.

6. Case Studies and Field Validation

To ground the analysis in real-world contexts, case studies of residential buildings using the selected methods are reviewed. These cases, sourced from industry reports or contractor interviews, provide qualitative insights into performance and cost over time, validating the quantitative rankings. At least one case per category is included, focusing on typical U.S. residential projects.

This methodology ensures a balanced assessment of technical efficacy and economic feasibility, tailored to the diverse needs of residential waterproofing.

IV. PERFORMANCE COMPARISON

To determine the most suitable and economical waterproofing solution for residential buildings, a comparative analysis of four commonly used waterproofing systems was conducted: **Cementitious Waterproofing**, **Liquid Membrane Waterproofing**, **Bituminous Membrane Waterproofing**, and **Polyurethane Waterproofing**. The performance of each system was evaluated using key metrics: initial cost, durability, ease of application, maintenance requirements, and environmental impact.

Key Observations:

- **Cementitious Waterproofing** is the most affordable and easy to apply but lacks long-term durability and flexibility, making it suitable for low-risk or interior applications.
- **Liquid Membrane** systems offer a balanced option, with good performance across most parameters, ideal for moderate-budget residential buildings.
- **Bituminous Membranes** provide excellent water resistance and durability but have higher environmental impacts and installation complexity.
- **Polyurethane Waterproofing** excels in durability, flexibility, and performance under harsh conditions but is the most expensive and requires skilled labor.

Criteria	Cementitious	Liquid Membrane	Bituminous Membrane	Polyurethane
Initial Cost	Low	Moderate	Moderate	High
Durability	Moderate	High	High	Very High
Ease of Application	Easy	Moderate	Moderate	Requires expertise
Maintenance Requirements	Low	Moderate	Moderate	Low
Environmental Impact	Low	Moderate	High (due to bitumen)	Moderate
Water Resistance	Moderate	High	Very High	Very High
Crack Bridging Ability	Low	Moderate	High	Very High
Life Span (Years)	5–10	10–15	10–15	15–25

V. PROPOSED SYSTEM ARCHITECTURE

Proposed System Architecture

The proposed system architecture for analyzing and comparing economical waterproofing options in residential buildings is structured as a multi-phase evaluation framework. It integrates data collection, criteria definition, performance evaluation, and recommendation generation. The architecture ensures objective assessment and applicability across various building types and climatic zones.

1. Data Collection Module

Sources: Manufacturer datasheets, construction standards, field surveys, and expert interviews.

Inputs: Material properties, cost estimates, installation procedures, climatic suitability, and lifecycle data.

2. Criteria Definition Module

Identifies key performance indicators (KPIs):

- Initial Cost
- Durability/Lifespan
- Application Complexity

- Maintenance Frequency
- Environmental Impact
- Waterproofing Efficiency
- Crack-bridging Ability

3. Evaluation Engine

Methodologies:

- Weighted Scoring Model (WSM)
- Analytic Hierarchy Process (AHP) for multi-criteria decision making

Functions:

- Normalizes data across metrics
- Assigns weights based on priority or project constraints
- Computes composite performance scores for each method

4. Comparative Analysis Dashboard

Visualization:

- Radar charts
- Bar graphs
- Heat maps

Output:

- Ranked list of waterproofing options
- Cost-performance trade-off analysis
- Sensitivity analysis for changing conditions

5. Recommendation Module

Provides:

- Best option based on user-defined priorities (e.g., cost-sensitive or durability-focused)
- Risk analysis for selected system
- Suggested application scenarios (e.g., rooftop, basement, wet areas)

VI. CONCLUSION

In conclusion, the use of prosumer energy systems within Energy Hubs offers a promising path to energy independence and sustainability. The study shows how advanced forecasting methods like Gaussian Process Regression (GPR) combined with distributed energy generation and renewable resources can greatly improve energy management. While forecasting Renewable Energy Sources (RES) has traditionally been done using techniques like Artificial Neural Networks (ANN) and ARIMA, GPR has shown to be more accurate and error- free. The paper also highlights how Energy Hubs can be used to optimize demand-response systems, estimate maintenance needs, evaluate environmental implications, and trade energy autonomously. The study emphasizes how crucial it is to balance energy production and consumption for effective resource usage by examining energy demand, supply, and costs as well as applying machine learning and smart grid technology. Overall, this study demonstrates how prosumer energy models can minimize environmental effects, increase energy security and sustainability, and lessen reliance on outside electricity sources.

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