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Integrating GIS and Revit for Waterproofing Solutions in Historical Pitched Roof Buildings

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Abstract: ***Historical pitched-roof structures distinguished by their complicated craftsmanship and cultural significance, struggle with a critical issue of water infiltration, a consequence of their unique architectural composition. This study adopts a comprehensive approach to finding a waterproofing solution using Geographic Information System (GIS) technology and Building Information Modeling (BIM) to address this challenging threat. Through careful historical scrutiny, innovative construction methodologies, and precise distress mapping, we seek to thoroughly evaluate and enhance the waterproofing systems. By harnessing contemporary materials and construction techniques, our objective is to support these architectural landmarks against future water-related threats. The integration of GIS technology provides precise insights into various elements affected by water ingression. This research not only rectifies existing vulnerabilities but also lays the groundwork for a sustainable and resilient preservation endeavor. The outcomes of this study is composed to revolutionize the conservation of historical pitched-roof buildings, safeguarding their enduring legacy as living evidence of human Creativity and artistic mastery.***

Keywords: GIS, Revit, Waterproofing, Pitched Roof, Historical Structures.

1. Introduction

Historical structures serve as silent witnesses to the craftsmanship, culture and stories of past eras, ranging from grand palaces, temples to charming cottages. Each building carries the enduring marks of its time, reflecting the architectural styles, societal values, technological advancement of its era.

However, the passage of time, along with natural forces, has left these esteemed establishments vulnerable. Preserving historical buildings presents a significant challenge, requiring a delicate balance between conservation and restoration efforts. Central to this endeavor is the critical element of waterproofing, especially concerning pitched roofs.

Pitched roofs, known for their steep angles, provide a distinctive visual character to historical architecture. Yet, their design exposes them to the constant threat of water infiltration. The interplay of rain, snow and moisture poses an ongoing risk, potentially compromising the very foundations of these cherished structures. If not addressed, water seepage can lead to structural deterioration, endangering the building's integrity and putting its historical significance at risk. The challenge is intensified by the reduced workforce of skilled labour with expertise in traditional pitched-roof construction methods. Modern construction practices often lack the specialized knowledge required to replicate the craftsmanship of past eras. While existing waterproofing solutions, such as underlayment, offer some level of protection, they are frequently constrained by limitations in cost-effectiveness and long-term durability.
In response to this urgent issue, the study adopts a comprehensive approach to finding a waterproofing solution using GIS technology and BIM to address this challenging threat. This forward-thinking approach seeks to comprehensively address the challenges of waterproofing in historical buildings, surpassing conventional methods.

However, this research project has three key objectives. First, it aims to utilize Revit software for visualizing and understanding the specific areas of distress present in pitched roofs. This visual representation will aid in informed decision-making regarding repairs. Second, the project seeks to propose waterproofing strategies that strike a balance between preserving the architectural integrity of these historical structures and incorporating modern waterproofing technologies. This balance is crucial for ensuring the longevity of these buildings without compromising their historical character. Finally, the project will utilize GIS technology to prioritize locations that require immediate repair efforts. This prioritization will optimize resource allocation and address the most critical issues first.

By combining these innovative technologies, this research project strives to develop a comprehensive waterproofing approach that safeguards our irreplaceable historical structures.

2. Methodology

This research followed a multi-stage approach to waterproof a historical structure. First, a detailed literature review explored the historical significance of structures, the typical building materials and construction methods used in its period, maintenance plans adopted for historical structures, different roofing material used. This understanding helped identify effective waterproofing solutions that wouldn't compromise the structure's historical integrity.

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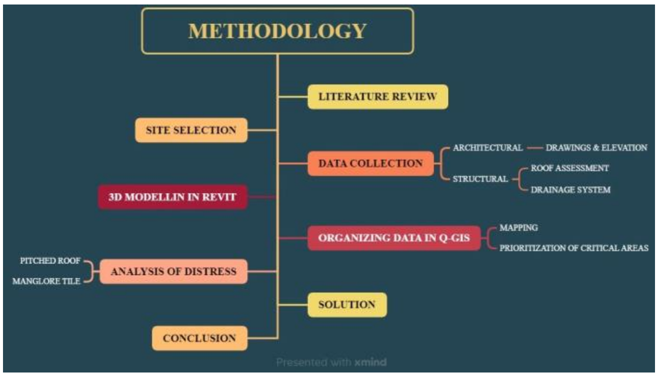

Figure 1: Methodology

Site selection was crucial. Choosing the right historical building set the stage for the entire project, impacting the research process, the depth of findings, and ultimately, the project's success.

Once a suitable site was chosen, data collection began. This included architectural details, structural details (2D drawings), and a structural assessment. The assessment focused on the roof and drainage system to pinpoint any weaknesses that might be causing water leaks.

A 3D model of the structure was then created using Revit software. Any defects identified during the structural assessment were marked on this model to aid communication and collaboration with stakeholders involved in the project's management.

Next, all the collected data was organized within QGIS software. This allowed for the identification of areas with the most significant defects, facilitating targeted resource allocation during the waterproofing process.

With a firm grasp of the pitched roof's condition and the specific type of roofing material (Mangalore tiles), a detailed analysis of potential water leakage points was conducted. Identifying the exact causes of the leaks was essential for formulating the most appropriate waterproofing solution. Finally, with a clear understanding of the structure's vulnerabilities, solutions were developed to stop water ingress and prevent further deterioration of the historical building.

3. Case study- Veermata Jijabai Technological Institute

1) Introduction & History of VJTI

Veermata Jijabai Technological Institute, previously named Victoria Jubilee Technical Institute, was established in 1887. It relocated to its current location in 1923. The area of the campus is about 16 Acres presently the institute currently offers diploma, undergraduate, postgraduate, and doctoral programs across 9 distinct disciplines.

The institute consists of number of buildings for academic and administration works such as: Main Building Constructed in year 1923, Old north wing consisting structural, hydraulics lab. And maintenance cell in year 1923, Old south wings consisting Electrical Engg. Dept. in-1923, Principal and Secretary bungalow and its out houses in -1923, Textile Department-1940, Chemistry Department-1943, Mechanical Engg. Dept. building -(1948-1964), Civil and Electrical Engg. Dept. building-(1951-1964), Extension to old south wing housing Math's, Geology and Humanities department 1974, Rector's bunglow-1957.

It's important to recognize that all the buildings listed here have a long history. Most of them were built 80-100 years ago, and some are around 60-70 years old. Because of their age and significance, all these buildings are considered both heritage sites and historical landmarks.

2) About Study Area

Within the esteemed campus of Veermata Jijabai Technological Institute (VJTI), several historic structures stand as evidence to the institution's rich heritage and architectural significance. Among these, the Mechanical Building stands out for its unique roof design, a combination of pitched and flat roof, reflecting the architectural sensibilities of its period.

3) Details of structure

Table 1: Details of Structure

Name of Structure & address	VJTI, Mechanical Engineering Department Building, R. Mahajani Marg, Matunga Road, Mumbai -19, Maharashtra, India.
Year of construction	1948-1964
Drawings Available	Yes
Current Use	Institutional Building
Type of structure	RCC
No. of floors for building	G+3
No. of Staircase	3
Floor to floor height	5m

Figure 2: Mechanical Engg. Department building, VJTI

4) Data Collection

To fully identify defects in the historical structure's roof system, an intensive data collection process was undertaken. This involved two key steps: first, a detailed review of any existing 2D architectural drawings to gain information on the roof's geometry, framing system, materials, and drainage. Second, a thorough visual inspection was conducted from both the interior and exterior of the roof.

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This inspection precisely documented any signs of deterioration, and subsequently categorizing all observations, a clear picture of the roof's condition was established.

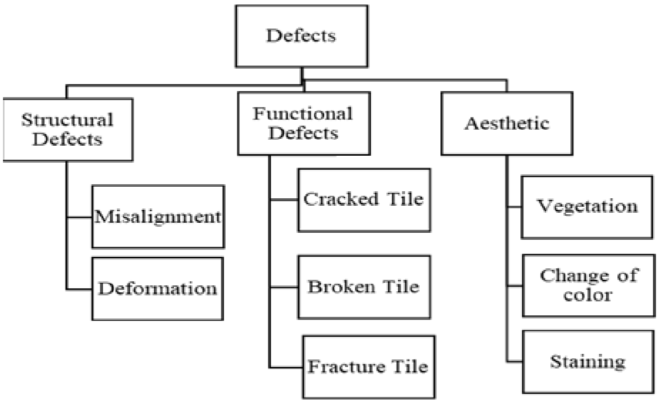


Figure 3: Different defects of pitched roof

5) 3D Modelling

To further enhance the understanding of the roof system's condition and facilitate communication with stakeholders, a 3D model of the historical structure was precisely crafted using Autodesk Revit software. This digital representation provided a detailed and visually intuitive view of the entire building & roofing system. The identified defects and distresses pinpointed during the structural assessment were then precisely mapped onto the 3D model. By employing a color-coding system, the location, extent, and severity of each issue were clearly differentiated. This visual approach offered a significant advantage over traditional 2D documentation. Stakeholders, including architects, engineers, and restoration specialists, could readily grasp the overall condition of the roof system, enabling more informed decision-making regarding the most appropriate and historically-sensitive waterproofing solutions.

Figure 4: 3D model of mechanical building, VJTI

Figure 5: 3D Model of Pitched Roof

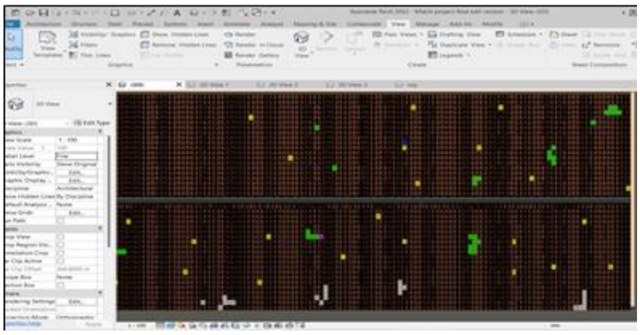


Figure 6: Defects marked on roof (Top view of Pitched roof)

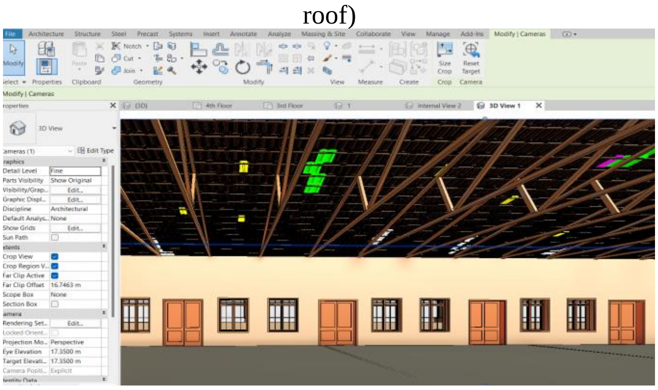
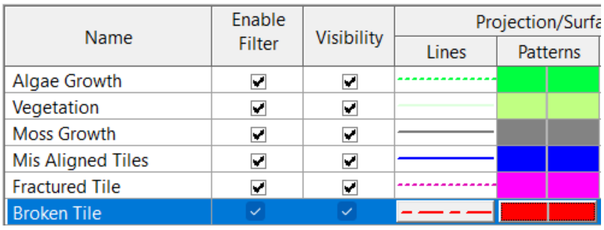


Figure 7: Defects marked on roof (Internal view of roof)



Name	Enable Filter	Visibility	Projection/Surfa	
			Lines	Patterns
Algae Growth	✓	✓		
Vegetation	✓	✓		
Moss Growth	✓	✓		
Mis Aligned Tiles	✓	✓		
Fractured Tile	✓	✓		
Broken Tile	✓	✓		

Figure 8: legend used to mark the defects

6) Organizing Data in Q-GIS

Following the creation of a detailed 3D model incorporating distress markings, the identified defects were meticulously organized within a Geographic Information System (GIS) platform, specifically QGIS. Subsequently, the defects were ranked based on their intensity and potential to compromise the structural integrity of the roof. Employing the Kernel Density tool within QGIS, a heat map was generated This heat map visually represented the concentration of distress, with areas of higher density indicating a greater potential for structural integrity issues. This analysis served two key purposes. Firstly, it helped identify locations where the combined effect of multiple, severe distresses could compromise the integrity of roof. Secondly, the heat map provided insights into potential pathways for water ingress. Areas with a high concentration of distress might be more susceptible to water infiltration, potentially leading to further deterioration.

Proposed degradation levels for defects in roof.

Table 2: Degradation levels for defects in roof

Degradation Level	Percentage Affected area (Aa)
0	Slightly Visible
1	< 10% Aa
2	10%– 30% Aa
3	30% - 50% Aa
4	>50% Aa

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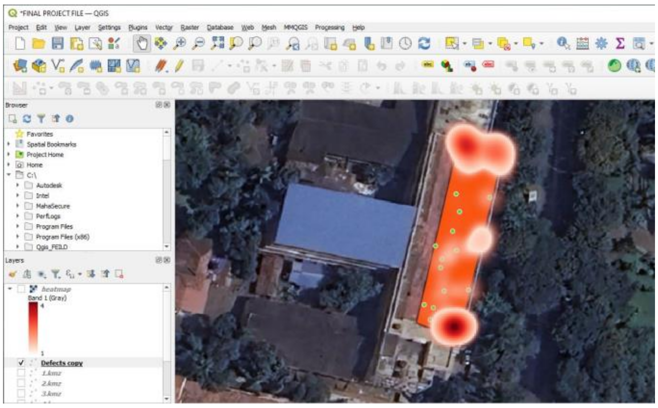

Figure 9: Heat Map of distresses based on level of degradation

7) Detailed Analysis of Distresses

Building upon the analysis conducted within QGIS, the next stage of the research focused on a detailed examination of the distribution of identified distresses across the structure. The heat map generated using the kernel density tool provided valuable insights, particularly regarding areas with a higher concentration of distress. These areas were then prioritized for further investigation to understand the potential causes of water ingression and their impact on the overall structural integrity. The analysis is done in two parts: first for analysis of Mangalore tiles, and then second is the analysis of the pitched roof.

Different types of distress present in **Mangalore tiles** are:

MANGALORE TILE

FUNCTIONAL DEFICIENCY | WATER ABSORPTION

Functional deficiencies in tiles are defects that hinder their ability to protect a structure from sun and water ingress. Examples include cracks, fractures, and broken tiles.

Functional deficiencies such as cracks, fractures, broken tiles, or imperfections in the tile body can create direct pathways for water to seep through, causing damage to the structure.

While **WATER ABSORPTION** itself may NOT DIRECTLY CAUSE LEAKS, it can make tiles more vulnerable when the above-mentioned factors are present. Absorbed water can travel through cracks and contribute to leakage. Lower-quality tiles might have higher water absorption rates and be more prone to cracking.

In areas with freezing temperatures, absorbed water can freeze and expand, potentially causing cracks in the tiles and exacerbating leakage issues.

Figure 10: Distresses Present in Mangalore Tile

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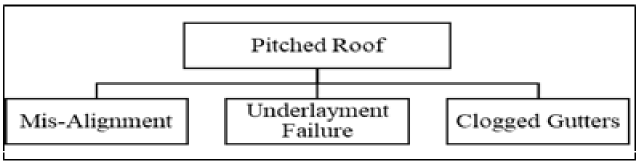
Different types of distress present in **Pitched roof** are:



MISALIGNMENT in pitched roofs can occur due to a variety of factors. Human or animal interventions, (particularly from monkeys), improper installation of roofing tile, strong wind or storm can put pressure on roofing material and can disrupt the alignment of roofing tiles. Additionally, uneven settlement of the supporting truss system and the foundation of the structure can also contribute to misalignment.

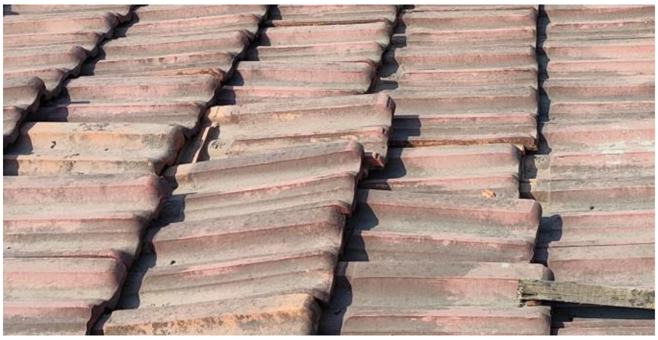


Figure 11: Misalignment of Mangalore Tile

UNDERLAYMENT serve as a protective layer beneath roofing materials, shielding the structure from water ingress. While underlayment offers valuable protection, they also have certain drawbacks. These materials can tear easily and become brittle when exposed to direct sunlight, leading to damage and reduced effectiveness. Additionally, underlayment can be costly. Proper installation is crucial; if not installed correctly, underlayment may fail to provide the desired level of protection.

Figure 12: Failure of underlayment

CLOGGED GUTTERS play a crucial role in channeling rainwater away from a house. When gutters become clogged, water can overflow and seep into the structure, potentially causing water damage. Overflowing water may also damage the eaves board of pitched roofs, compromising the structural integrity of the roof.

Mangalore tiles in pitched roofs are susceptible to cracks, breaks, and misalignment, all of which can compromise their ability to block water and potentially damage the structure beneath.

8) Solution

Following the in-depth analysis of distress distribution and its potential impact on water ingress, the research focused on developing a solution for waterproofing the Mangalore tile roof. The primary objective was to block water ingress and restore the roof's watertight integrity. To achieve this, a hydrophobic material was applied to the surface of the tiles. This treatment aimed to reduce water passage through existing defects in the Mangalore tiles. Additionally, regular maintenance practices can address other potential water ingress points, such as misalignment, broken tiles, clogged gutters, and underlayment failure.

To evaluate the effectiveness of water-repellent material on Mangalore tiles, class A Mangalore tiles with dimensions of 410 mm x 235 mm were used in the testing process.

For a detailed understanding of water repellent's compatibility on roofing tiles, both new and old tiles were tested for water absorption, flexural strength, and breaking load.

This evaluation of the physical properties of uncoated tiles enables a comparison with the results from coated tiles. Additionally, the same tests were conducted on coated tiles to assess the impact of the water-repellent material on their performance.

4. Result & Discussion

To comprehensively assess the effectiveness of the hydrophobic material as a waterproofing solution, a series of standardized tests were conducted to assess the waterproofing solution's efficacy, the results provide insights into the performance of the solution under different conditions.

4.1 Water Absorption

This study can investigate the effectiveness of water repellent treatments on Mangalore tiles by employing a water absorption test. This test is crucial for assessing a tile's capacity to resist water penetration, a key factor influencing durability and performance.

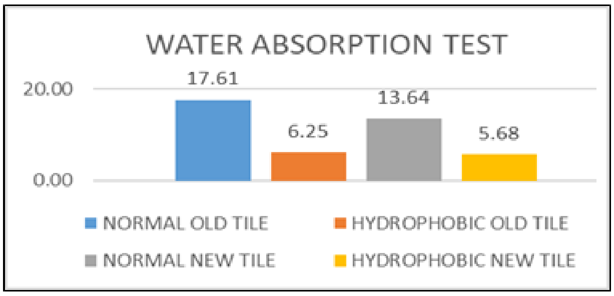


Figure 13: Water Absorption test of tile

The water-repellent coating significantly improves the tile's ability to resist water absorption, reducing absorption to nearly 60% of the normal level. This creates a barrier that prevents water from penetrating the tile's surface as easily, effectively enhancing its water resistance. The substantial decrease in water absorption demonstrates the effectiveness

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of chemical in waterproofing by making the tile more water-resistant.

4.2 Flexural Strength

This study can investigate the effectiveness of water repellent on Mangalore tiles by employing a Flexural strength test to check effect of water repellent on tile. This test is crucial for assessing a tile's capacity to resist bending after application of water repellent a key factor influencing durability.

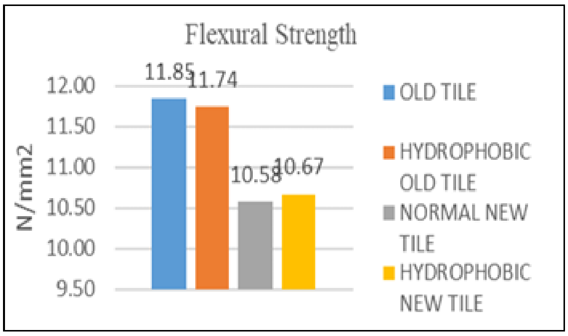

Figure 14: Flexural Strength of Tile

Based on the data, it is clear that the water-repellent chemical does not reduce the flexural strength of Mangalore tiles. This is a significant finding for our research, as it indicates that the chemical can be used for waterproofing pitched roof without compromising the structural integrity of the tiles.

4.3 Breaking Load Test

This study can investigate the effectiveness of water repellent on Mangalore tiles by employing a Breaking Load test to check effect of water repellent material on tiles property, this test is crucial for assessing a tile's ability to withstand the maximum load before breaking after application of water repellent a key factor influencing durability.

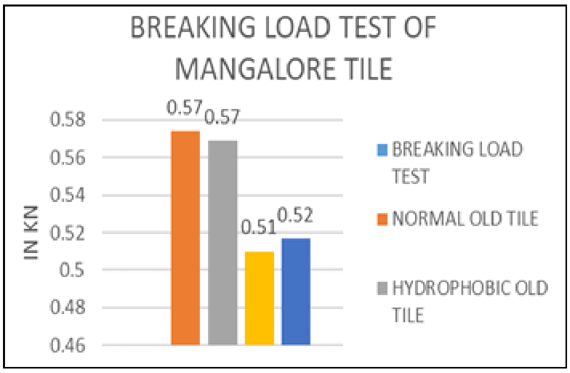

Figure 15: Breaking load of Tile

Based on the data, it is clear that the water-repellent chemical does not reduce the breaking load of Mangalore tiles. This is a significant finding for our research, as it indicates that the chemical can be used for waterproofing pitched roof without compromising the structural integrity of the tiles.

4.4 Contact angle test

This study can assess the effectiveness of water repellents on Mangalore tiles using a contact angle test. This test measures a tile's hydrophobicity, or its ability to repel water. Higher contact angles indicate a more effective treatment.

Table 3: Contact angle of uncoated Tile

Tile	Sample	Left Angle	Right Angle	Average Angle
1	1	52	48	50
	2	70	67	68.5
	3	63	65	64
	4	70	71	70.5
2	5	71	69	70
	6	63	60	61.5
	7	65	68	66.5
	8	73	66	69.5
3	9	73	63	68
	10	73	68	70.5
	11	73	64	68.5
	12	73	74	73.5

Figure 16: Contact angle of uncoated Tile

Table 4: Contact angle of coated Tile

Tile	Sample	Left Angle	Right Angle	Average Angle
1	1	93	92	93
	2	95	95	95
	3	120	103	112
	4	104	108	106
2	5	104	101	103
	6	102	110	106
	7	91	97	94
	8	95	104	99.5
3	9	111	125	118
	10	106	101	103.5
	11	99	113	106
	12	95	110	102.5

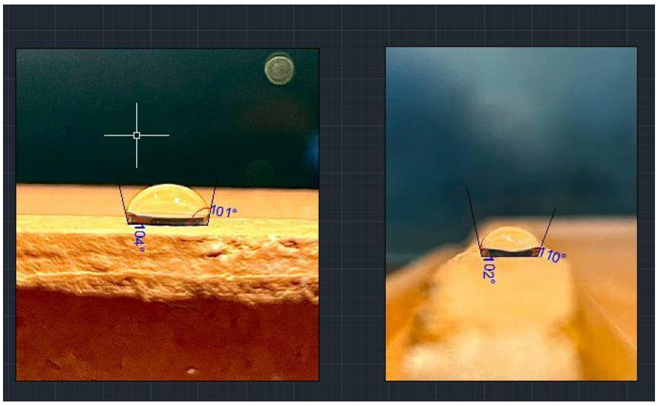

Figure 17: Contact angle of coated Tile

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Interpretation:
1) **Low Contact Angle (<90°):** Indicates high wettability. The liquid spreads out on the surface.
2) **High Contact Angle (>90°):** Indicates low wettability. The liquid forms a more spherical droplet on the surface.

The data from the contact angle test clearly indicates that treated tiles have a contact angle greater than 90 degrees, demonstrating low wettability. This finding suggests that the treatment effectively increases the hydrophobicity of the tiles, which can contribute to improved water resistance and is advantageous for applications such as waterproofing.

5. Conclusion

This research proposes a novel method for preserving historical pitched roofs by combining Revit modelling and GIS analysis. Revit generates data visualizations of roof damage, facilitating communication with stakeholders and streamlining material procurement for targeted repairs. This integrated approach, incorporating 3D modelling with defects analysis through GIS, allows for precise interventions based on the severity of issues. Furthermore, the combined Revit-GIS approach prioritizes critical repairs, ensuring efficient resource allocation. Additionally, water-repellent materials enhance roof water resistance, extending the lifespan of these historical structures.

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