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Appraisal of Flat Roof Defects in Commercial Buildings and the Remediation Techniques

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ABSTRACT

Recently, there has been a trend in Malaysia where many buildings have been built with a concrete flat roof instead of the usual pitch roof. Some buildings have a combination of sloped roofs and flat roofs, where the flat roof surface is used to house facility equipment. Roof constructions in equatorial climates often suffer from surface-related problems, damage to the waterproofing membrane, and fractures in the roof parapet wall. These issues are caused by the hot and humid conditions that persist throughout the year. As a result, periodic maintenance is necessary to address these typical faults. This study aims to examine the different types of flat roof defects, as well as recommendation of remediation techniques. The methods employed for data collection include case studies and formal interview sessions with the professionals in the built environment. Based on the findings, there were few types of flat roof defects such as water pounding, membrane damage, blistering, cracking, vegetation growth, sagging and material degradation. Several rectification procedures were suggested, including implementing an efficient drainage system, adhering to a regular maintenance plan, applying waterproofing coating or membrane, regularly removing debris, and utilizing epoxy injection. The identification of various varieties of flat roof defects and the proposed modifications will be of interest to designers and those responsible for the maintenance of flat-roofed buildings in Malaysia.

1. Introduction

Given the tremendous progress in technology, the building construction sector continues to be burdened by problems related to faults [1]. These issues arise due to various factors, including substandard craftsmanship and flawed design and construction, thereby diminishing the overall worth of the structure [2]. The prevalence of these structural flaws has emerged as a significant concern in recent years, resulting in substantial expenses and delays incurred to address them. If the structure experiences a malfunction, prompt intervention is necessary to rectify the issue [3-5]. This

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is a common problem encountered in construction projects in Malaysia. A significant proportion of project flaws are inadequately documented and tracked, leading to the client's lack of awareness regarding the defects and prolonged neglect [6-8].

A building functions as a refuge from the elements and offers protection and seclusion to its inhabitants. However, the purpose of a structure may change with time. Certain buildings adapt their functions to align with the surrounding development, while others maintain their original planned function for an extended period. In the contemporary day, a structure fulfills a multitude of purposes to enable and support human endeavors. As individuals' lifestyles evolve, their societal roles also undergo transformation. Essentially, the role of a building in facilitating our daily activities undergoes changes [9,10]. Nevertheless, due to both external and internal influences, the performance of the structure may be compromised, not only in terms of design functionality but also in actual construction. External elements are predominantly influenced by meteorological conditions, whilst inside factors are influenced by the age of the building and the necessity for adequate care [11-13]. In essence, the primary objective of a building is to offer individuals a delightful and conducive living and working atmosphere.

The roof of any building is essential, as it protects the structure from the weather and enhances the building's energy efficiency and structural integrity. Prognosis, repair, planning, and routine maintenance are all necessary components of a comprehensive strategy to ensure the roof's lifespan and functionality [14-16]. Effectively addressing these factors can save expensive damage, improve safety, and increase the roof's lifespan. The prognosis of a roof entails evaluating its present state and forecasting its future functionality. Regular inspections are usually part of this procedure to find possible problems like leaks, material deterioration, and structural weaknesses [17].

Flat roofs were widely used in commercial building design. This is to reduce the high construction cost and save construction time. In recent years, many Malaysian buildings have also made use of flat roofs for commercial buildings. However, this design can lead to a lot of defects due to the slope of its shape. A building condition survey is one of the alternatives to detecting problems in the whole building [18]. Generally, the condition survey is carried out to assess the structure and materials used on the flat roofs. To make it clear, this research is about the common defects in the flat roofs of commercial buildings. It will be focusing on Malaysian buildings, especially in the Pulau Pinang area. This is because many defects are always found on the flat roof, and some parties did not pay attention to them as they were at the top of the building. They will only realise this if any leaking happens and affects some of the other structures in the building. This issue needs to be focused on as it is one of the most important elements in building structures as it provides protection from hot weather and rain.

Commercial buildings often use flexible roof coverings on flat roof structures because they are durable and require little maintenance. On the other hand, costly building problems or damage may be caused by mistakes in the design or installation of flat roofs [19] Many defects can be found on the flat roof, as the shape of the roof is flat, and it can make stagnant water when it rains heavily. Other than that, the materials of the structure also make the flat roof easily exposed to various defects. Thus, this research paper will gather many causes of defects that happen on the structure and at once provide some remedies to treat them and prevent them from occurring again. Hence, the flat roof structure quality can be improved from time to time.

To maintain the roof in good condition over time, proactive planning is necessary. Creating a maintenance programme comprising routine cleanings, inspections, and minor repairs is required for this. A roof's unique requirements, depending on its age, design, materials, and climate in the area, should be taken into account during planning. Maintenance planning helps prevent unanticipated and expensive repairs by identifying and treating potential problems early on, ensuring the roof stays

in good condition for as long as possible [20]. Therefore, the objective of this investigation is to evaluate the various types of flat roof defects and to suggest remediation methods.

2. Literature Review

2.1 Definition of Building Defects

A building can be defined as a structure with a roof and walls that can be used for human activity. While defects mean something, or none, that leaves something inadequate, defective, or lacking, Defects are defined, according to Mydin *et al.,* [4], as any feature of the design, construction work, or materials that does not meet the terms of the contract under which they were acquired and are divided into two categories: latent and patent. Normal wear and tear is the source of the patent faults, whereas construction craftsmanship errors are known as latent defects. However, these defects can appear in a variety of ways and impact the integrity, safety, use, and aesthetics of the building, among other elements. Building defects can be caused by several things, including shoddy construction, subpar materials, flawed designs, and deterioration over time. Leaks, wall fractures, and structural instability are typical instances.

2.2 Types of Roofs

2.2.1 Flat roof

Almost level compared to sloping roofs, a flat roof can have a pitch of up to around 10° [20]. It's an old style of roofing that's common in dry areas and allows contractors to use the space above as a living room, or "living roof." It is known by another name as "low-slope" roofing, this kind is frequently found on commercial buildings all around the world. Most flat roofs are designed with a little slope to help with water drainage. Flat roofs are coated in a waterproof membrane and have a horizontal base that is integrated into the ceiling joints.

Nevertheless, according E Andenæs *et al.,* [19], flat roofs or compact roofs are commonly found on large buildings with a flat roof structure. These roofs consist of a sandwich structure of vapour protection, insulation, and the roofing itself, built on top of a supporting structure. However, there are some advantages of using a flat roof as a roof which is it is cost effective. This is because, flat roof can be cost effective since they are so inexpensive, flat roofs are becoming more and more common to be used as a roof [21]. Compared to pitched roofs, they drastically reduce the cost of extending an upper-floor area or adding additional rooms, like a conservatory.

Other than that, the flat roof also durability. High- performance, environmentally friendly materials like EPDM, which is made of rubber, are used in modern flat roof construction. When combined with modified bitumen, which was first used in the 1960s, EPDM provides outstanding resistance to inclement weather. These roofs have a 50-year lifespan. Flat roofs hold up year after year and unlike brittle materials like clay or tiles that easily chip. In contrast, they also have some disadvantages such as leak of drainage system and shorter life span. According to the Robyn [21], although flat roofs offer certain benefits, drainage is by far their biggest disadvantage. While they have a little incline to help with water drainage, it's not as efficient as pitched roofs. Rainwater gathering on the roof due to this inefficiency may result in leaks or other damage. Furthermore, older flat roofs, which are frequently made of traditional felt, have a lifespan of just ten to fifteen years, making them less resilient than pitched roofs.

2.3 Impact of Flat Roof Defects

2.3.1 Decreased the property value

Defects in a flat roof can have a major impact on a property's worth and considerably lower its market value. Problems like standing water in the pools, obvious leaks, and structural issues spooked prospective renters or purchasers and eventually drove down the property's total market value. This is due to the fact that structural flaws in a flat roof can also reduce the structure's strength. As a result, the renter or buyer will demand a cheap price that is in line with the building's quality. This result emphasizes how crucial it is to identify and mitigate flat roof faults right once in order to preserve property value and competitiveness in the market.

2.3.2 Structural integrity

Building structural integrity can be seriously threatened by flaws in a flat roof. Over time, the support elements such as beams and columns are weakened when there is a breakdown in waterproofing, material degradation, and inadequate drainage at the rooftop. Water exposure over extended periods of time, particularly with standing water on the roof, accelerates material deterioration and defects the structure further [10].

2.3.3 Water damage

According to the Wai [22] The building may experience increased water intrusion (water seeping into the property) when there is damage and one of the most important effects of flaws in a flat roof is that they will immediately cause water damage to the structure. The reason behind leaks is inadequate drainage andinadequate waterproofing on the roof, which allow water to seep through and cause damage to interior areas like walls, ceilings, and expensive furniture or valuables. Significant water damage will have an impact on the building's structure.

2.3.4 Increased maintenance cost

The impact of flat roof defects can increase the maintenance cost. This is because Flat roof defects frequently need ongoing care and repair, which adds to the expense of upkeep maintenance. The total cost of maintenance will significantly rise day by day based on the types of defects. When a defects problem is ignored for an extended period of time without any early action, the financial cost burden will grow. This demonstrates the financial consequences that are inherently linked to flat roof defects and highlights how crucial it is to take preventative action to lower and control maintenance-related costs [23].

2.3.5 Occupant discomfort

For occupants, structural issues and water damage from flat roof flaws result in an uncomfortable living or working environment. The total discomfort of occupants is influenced by the combined impacts of leaks, mold development, and impaired structural stability. Acknowledging these negative consequences highlights how important it is for owners to put occupant safety first by inspecting flat roofs and doing maintenance promptly. This will guarantee a comfortable and secure atmosphere

within the building, promote preventative actions to address flat roof issues, and preserve a suitable living or working area for building occupants.

3. Methodology

This section will discuss case studies to achieve the aim and objective of this research. This chapter has outlined many strategies to accomplish the objectives. Furthermore, this chapter will elucidate the study approach implemented by the researcher. Other than that, these chapter also will discuss about the case study building and tools that helps to measures the strenght of flat roof structure and moisture content in it. In addition, an iformal interview session also carried out in order to get a right information from the expert person.

3.1 Case Studies

The case study buildings that have been found and collected are from Georgetown, Gelugor, Bayan Lepas, Pulau Pinang. The total of case studies are five buildings. The reason that all of these building was chosen as a case study is because it meets the criteria of research, which is that all of them used flat roofs as roof types, and the building is a commercial building. Hence, at the rooftop of this building, researchers can find several defects that occur on the structure that can be dangerous if ignored. Table 1 summarizes the case studies location.

Table 1
Case studies location

Name	Location
Building A	Georgetown, Pulau Pinang
Building B	Gelugor, Pulau Pinang
Building C	Georgetown, Pulau Pinang
Building D	Georgetown, Pulau Pinang
Building E	Bayan Lepas, Pulau Pinang

3.2 Non-Destructive Test

The concrete encounter and rebound hammer are two measures of non-destructive testing (NDT) techniques that are vital for evaluating the state of concrete buildings without inflicting harm. The surface hardness of concrete is measured by the rebound hammer and it is a good indicator of the material's compressive strength. This approach is perfect for on-site inspections since it is quick and simple to implement. Conversely, the concrete encounter is employed to ascertain the concrete's moisture content. This instrument measures electrical impedance, which gives useful information about the interior moisture levels and may be used to identify any problems with water intrusion and durability. In these research, both of the measures of non-destructive testing (NDT) are used in order to collect the data at a case studies choosen. These following is more details about the NDT tools :

3.2.1 Rebound hammer

The rebound hammer test is a quick and easy non-destructive way to determine the strength of concrete. Alternatively called the Schmidt hammer, it consists of a mass that is controlled by springs and slides on a plunger housed in a tube casing. A mass strikes the concrete surface when the plunger is forced against it, and the rebound is gauged using a graduated scale. Surface hardness is indicated

by this rebound value, often known as the rebound index or rebound number. Reduced strength and stiffness in concrete causes it to absorb more energy, which lowers the rebound value. In essence, the test uses the hammer's rebound to quickly assess the compressive strength of the concrete [24]. Figure 1 shows the setup for rebound hammer test.

Fig. 1. Rebound hammer test

3.2.2 Concrete encounter

The survey was conducted using concrete encounter equipment (Figure 2). The reason for this is because concrete encounter devices are capable of measuring the moisture present on the surface structure and accurately determining the moisture level. Furthermore, it has the capability to provide an immediate measurement of moisture content [25].

Fig. 2. Concrete encounter meter

3.3 Informal Interview

Interviews are one of the methods used to achieve the aim and objectives. In the informal interview session, a lot of information can be gathered as the person is a professional in this field. The interview sessions are carried out face-to-face at different locations and times. This session can help researchers collect information that may have been left out during the observation. An interview session is conducted with at least one of the persons in charge of the case study building. Other than that, researchers also interviewed the lecturer in the School of Housing, Building, and Planning at

Universiti Sains Malaysia (USM)and professional expert in this field in order to complete the research and collect the data from the professionals. Some of the names that have been interviewed are as follows:

i. Lecturer
ii. Facilities manager
iii. Building Surveyor

4. Results and Discussion

4.1 Types of Defects

There are several defects that has been identify and analyse at the case study building. Most of the defects at case study building is water-pounding. The causes of each defects occur are different as it is based on the location and age of the building. Other than that, design of the structure also a main reason towards the possible defects occur. Table 2 shows the overall building rating table and Figure 3 demonstrates the analysis of building defects in several case studies.

Table 2
Overall building rating

Case study	Total marks	Number of defects	Total score	Overall Building Rating
Building A	82	9	9	Fair
Building B	46	7	6.6	Fair
Building C	20	5	4	Good
Building D	27	5	5.4	Fair
Building E	14	5	3	Good

Table 2 shows the overall building rating for five case study buildings. The highest total marks of building rating is Building A at 82 and follow by Building B at 46. Both case studies also have the same code for overall building rating, which is “fair” (yellow colour code), while Building C and Building E are in good condition (green colour code) at 20 and 14, respectively. Hence, it also shows that the lowest of total marks for building rating is Building E. However, Building D shares the same colour code for the overall building rating as Buildings A and B, which is yellow (fair). Figure 3 shows the overall building rating of five case study buildings. The highest overall building rating is Building A, total score at 9 and the colour code is fair which is in a condition monitoring categorized while the lowest is Building E at 3 which is under categorized good (green colour). Building B is higher than Building D at 6.6 and 5.4, respectively. These show that both buildings are in a condition monitoring category. Nevertheless, Building C total score is 4 and in a plan maintenance categorized same with the building E.

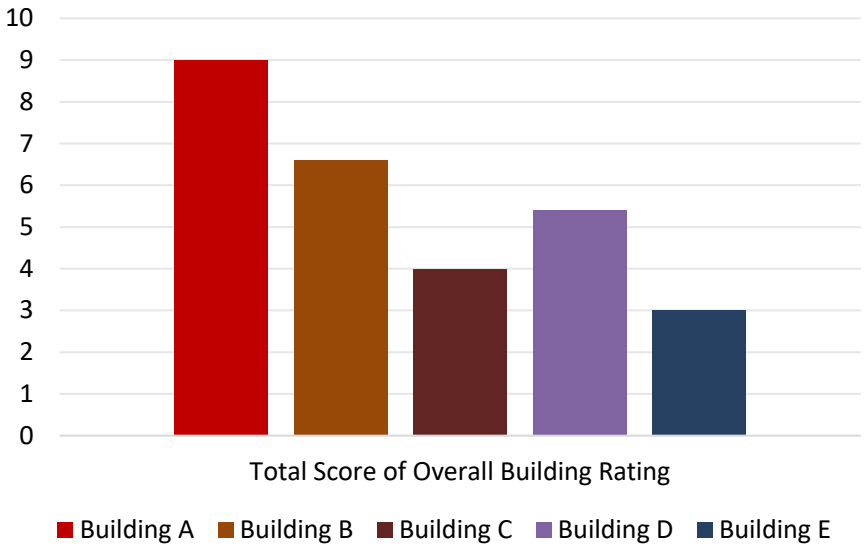

Fig. 3. Overall building rating of five case study buildings

4.1.1 Water pounding

Ponding is the term for the (usually) unwelcome accumulation of water, usually on a flat roof. When water accumulates and remains still on a roof's surface for more than 48 hours, it is known as water pounding. Large puddles may occur on the roof surfacebecause of various problems with the building infrastructure or roof design, or because the drainage The system is insufficient for the structure. The amount of liquidis so great that it cannot evaporate off the roof, leaving the stagnant water with nowhere to drain. After a rainstorm, standing water on a flat roof for 12 to 36 hours is typical; however, the National Roofing Contractors Association advises that anywater that is left pounding on a flat roof for more than two full days must be checkedout by a qalified commercial roofing contractor [26].

4.1.2 Membrane damage

The quality of the roof covered by the membrane is also not durable. Over time, the surface of the membrane will be damaged, which may cause other defects to occur. This is because the surface of the membrane has been damaged and is no longer of good quality, so rainwater or water around the surface of the rooftop can absorb to the base of the original concrete surface before being covered with a membrane layer.

4.1.3 Blistering

Blistering on flat roofs occurs when moisture becomes trapped beneath the roofing membrane, either because of a water infiltration or during installation. The contained moisture turns into vapour in the presence of sunshine, which raises the pressure and causes the roof's surface to form visible defects. The pressure leads to the debonding of the membrane, which might fracture the cracks and increase the intrusion of water and can lead to the leaking [27].

4.1.4 Cracking

There are several reasons why a flat roof structure might develop cracks. Temperature variations induce thermal expansion and contraction in roofing materials, which can result in fractures. Materials that are getting older, particularly those on roofs made of asphalt, can crack and become brittle. Cracks may also arise from settling or structural movement within the structure building.

4.1.5 Vegetation growth

Mould, moss, fungi, and other types of vegetation growing on a roof's surface are frequently signs of extended water retention and might be a sign of deeper problems with the roof's structure. This growth is not only an aesthetic problem; it may be a symptom of poor waterproofing or drainage, which, if ignored, might result in more serious structural difficulties. Furthermore, if the vegetation is given unregulated growth, it may worsen the damage to the roofing surface

4.1.6 Sagging

Roof sagging is not a phenomenon that is limited to new or ancient buildings; it may occur in constructions of all ages and is visible from the outside of the roof. The drooping phenomenon is frequently caused by fundamental design defects, namely in the strutting beams and roof struts. Unbalanced pressures can cause drooping when the roof tries to transmit weights within this damaged structure, resulting in an evident deformity in the roofline [28].

4.1.7 Material degradation

The use of substandard roofing materials or the ageing process itself can cause material degradation, which might jeopardize the roof's structural integrity. The term "material degradation" describes how roofing materials gradually weaken and deteriorate over time because of ageing, different environmental variables, or subpar quality [29].

4.2 Methods of Rectification

4.2.1 Proper drainage system

For flat roofs, a well-designed drainage system is necessary to avoid excess moisture and the damage that follows. To enable water runoff, this involves making sure the roof has a sufficient slope, usually around 1/4 inch for every foot. Maintaining gutters, down pipes, and drains regularly is essential to avoiding debris-related clogs [30]. Moreover, improving the roof's capacity to manage water effectively and lowering the risk of leaks and structural damage is possible by installing additional drainage solutions like inner drains which carry water through the building and out at ground level and scuppers, which are holes that allow water to drain off the roof edge. Figure 4 shows the proper drainage system on the flat roof.

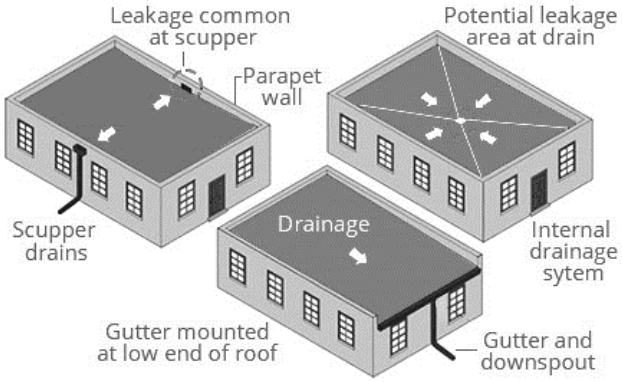

Fig. 4. Proper drainage system on the flat roof

4.2.2 Schedule regular maintenance

Scheduling regular maintenance on the flat roof structure to ensure there are no defects occurs. For example, carry out an inspection and minor repair for each defect to prevent future defects. Other than that, examining the roof deck's underside is the first step. This might require getting into the attic or lifting ceiling tiles. Once it's found, measure from the leak in the attic to the two exterior walls of the building; these measures are vital while getting on the roof. Take note of these dimensions and take pictures of the leak beneath the decking. Pipes can occasionally be seen going through the roof, which helps identify rooftops defects [31]. Figure 5 shows the flowchart of routine maintenance work.

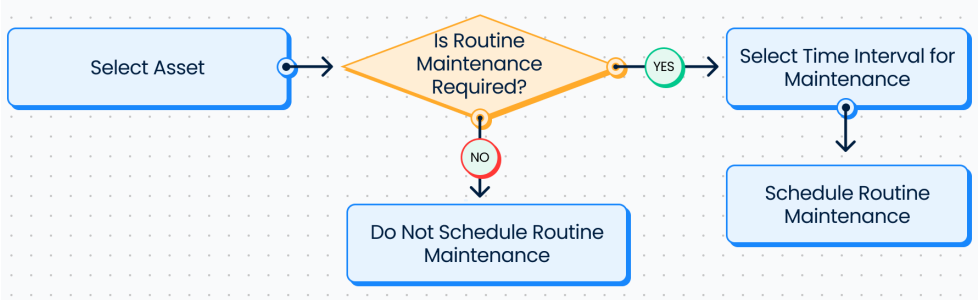

Fig. 5. Routine maintenance work

4.2.3 Waterproofing coating/membrane

Flat roof defects can be solved by using a waterproof coating or membrane on the surface of the rooftop structure. These methods can be used for the leaking and water- ponding defects. A responsible person needed to clean the surface and fill the space using the waterproofing elements. These are some types of waterproofing membrane for commercial buildings [32] :

i. TPO (Thermoplastic Olefin) is a durable single-ply membrane widely used in roofing for its longevity, energy efficiency, and reflective surface. Easily recognizable by its smooth and typically white appearance, TPO roofing is known for its resilience. The life expectancy ranges from 20 to 30 years, contingent on factors such as thickness and proper installation.
ii. Synthetic rubber roofing membranes, known as EPDM (Ethylene Propylene Diene Monomer), are prized for their durability, flexibility, and resistance to weather. Easily identified by its dark rubber look, EPDM (Figure 6) is renowned for its resilience. Its

lifetime, which spans 20 to 30 years, is impacted by variables like application technique and thickness.

iii. Strong single-ply membranes made of PVC (polyvinyl chloride) are well-known for their resilience to chemicals, longevity, and energy-saving qualities. With their white rubber look and 20- to 30-year lifetime, PVC roofs are similar to TPO in that they offer long-lasting performance.

Fig. 6. EPDM (Ethylene Propylene Diene Monomer)

4.2.4 Clean the debris

The building owner is required to designate a cleaner to perform cleaning duties on the rooftop no less than three times per week (Figure 7). The purpose of this task is to remove any debris present on the surface of the flat roof, as it has the ability to obstruct the flow of drain water down the gutter. Hence, it is imperative to regularly remove debris in order to prevent the issue of obstructed drains, which can result in water accumulation and subsequent leakage in the ceiling of the building, among other complications.

Fig. 7. Cleaning of debris

4.2.5 Use of epoxy injection

A defect crack that measures greater than 0.3 mm is identified as a thorough crack. The rectify approach, which involves injecting epoxy straight into the fracture, is typically used for repairs. Prior to surface sealing the fractures, groove cutting is done for epoxy injection crack repair (Figure 8). The next step is to drill holes at a 45-degree angle to intersect the crack, and then put mechanical injection packers into the holes that have already been drilled. Then, using an eoxy injection machine, low-viscosity epoxy—which often comes in two parts—is injected into the cracks via the pre-drilled holes

in accordance with the manufacturer's recommended ratio. The depth of the fissures determines how much epoxy is needed.

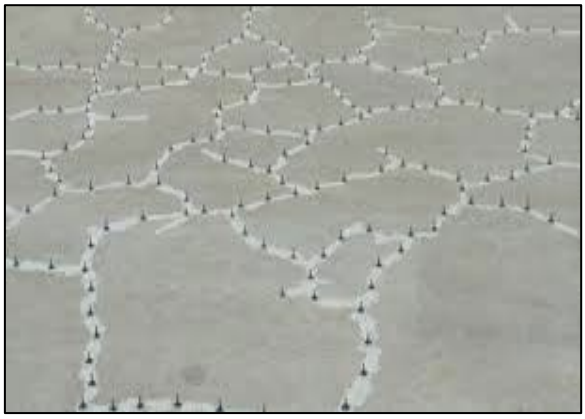

Fig. 8. Epoxy injection

4.3 Non-Destructive Test
4.3.1 Rebound hammer test

According to Table 3, Building C has the highest quality concrete at a good and very good level, with average values of 40 and 48, respectively. Building A has a high-quality concrete layer, with average data points of 39 and 37 at different locations. In contrast, Buildings D and E have a moderate quality of concrete. Both case study buildings need meticulous monitoring from their respective supervisors, as the structural integrity may deteriorate over time.

Table 3
Average rebound hammer test

No.	Structure	Location	Average	Quality of concrete
1.	Flat roof	Building A - Point 1	39	Good
2.	Flat roof	Building A - Point 2	37	Good
3.	Flat roof	Building B - Point 1	25	Fair
4.	Flat roof	Building B - Point 2	35	Good
5.	Flat roof	Building C - Point 1	40	Good
6.	Flat roof	Building C - Point 2	48	Very good
7.	Flat roof	Building D - Point 1	23	Fair
8.	Flat roof	Building D - Point 2	29	Fair
9.	Flat roof	Building E - Point 1	28	Fair
10.	Flat roof	Building E - Point 2	25	Fair

Figure 9 shows the average result for the rebound hammer test at 2 points. There are five case study buildings that will be tested: Building A, Building B, Building C, Building D, and Building E. The highest average result for the rebound hammer test is Building C at 40 and 48 for both points, while the lowest is Building D for point 1 at 23 and Building E for point 2 at 28. Nevertheless, Building A's average rebound hammer is higher than Building B's average result for both points. These show that the flat roof structure of Building A is better than Building B.

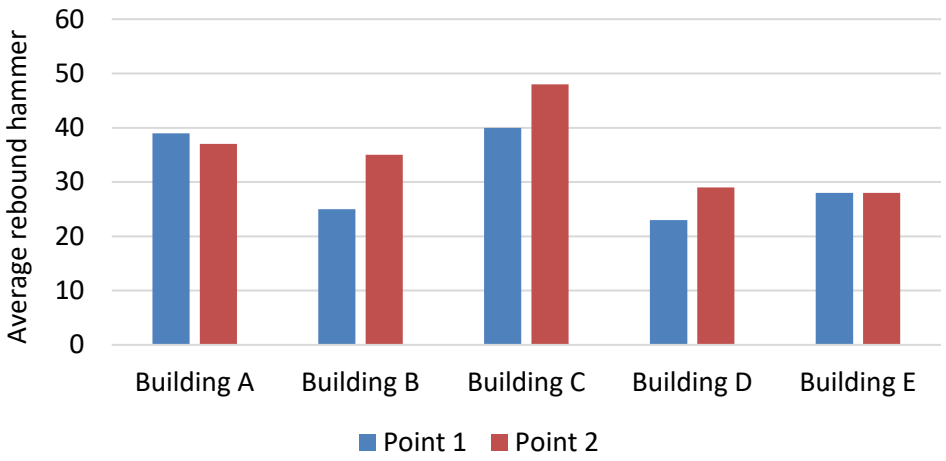

Fig. 9. Average result rebound hammer

4.3.2 Concrete encounter meter test

Table 4 shows the average moisture content of five case study buildings. The highest moisture content on the flat roof structure is Building E at 4.6%, as most of the defects on the rooftop of these buildings are water-pounding, which contributes to the moisture content, while the lowest moisture content on the flat roof structure is Building B at 3.7%. These show that building B has the fewest moisture defect problems. Building A and Building C also have the highest moisture content on the structure at 4.4% and 4.0%, respectively, while Building D has a slightly different number than Building B at 3.8%. Figure 10 shows the percentages of moisture content in a flat roof structure for five case study buildings. There are three-point tests for each case study in three different areas of defects. The highest percentages of moisture content for point 1 are in Building A at 5.8%, while for point 2, it is in Building C at 5.8%, and for point 3, it is in Building D at 4.5%. However, the lowest percentages of moisture content for point 1 are in Buildings B, C, and D, as these 3 case study buildings share the same percentages at 3.8%. For point 2, the lowest percentage is Building D at 3.2%, and Building C for point 3 is also at 3.2%.

Table 4
Concrete encounter meter test results

No.	Structure	Location	Moisture Content (%)	Average Moisture Content
1.	Flat Roof	Building A - Point 1	5.8	4.4
2.	Flat Roof	Building A - Point 2	3.8	
3.	Flat Roof	Building A - Point 3	3.6	
4.	Flat Roof	Building B - Point 1	3.8	3.7
5.	Flat Roof	Building B - Point 2	3.6	
6.	Flat Roof	Building B - Point 3	3.8	
7.	Flat Roof	Building C - Point 1	3.8	4.0
8.	Flat Roof	Building C - Point 2	5.8	
9.	Flat Roof	Building C - Point 3	3.2	
10.	Flat Roof	Building D - Point 1	3.8	3.8
11.	Flat Roof	Building D - Point 2	3.2	
12.	Flat Roof	Building D - Point 3	4.5	
13.	Flat Roof	Building E - Point 1	4.7	4.6
14.	Flat Roof	Building E - Point 2	5.0	
15.	Flat Roof	Building E - Point 3	4.0	

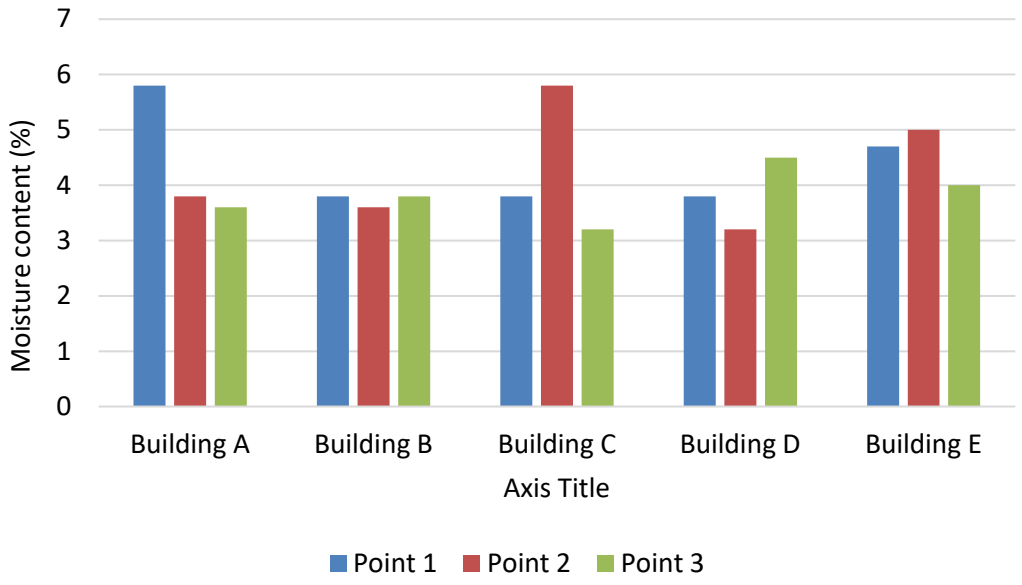

Fig. 10. Moisture content results

5. Conclusions

A study conducted on flat roof flaws in commercial buildings in Pulau Pinang has identified several prevalent issues, including water ponding, material degradation, blistering, cracking, plant growth, and sagging. Varying levels of concrete quality and moisture content were identified during the investigation of the case study building, emphasizing the need for targeted corrective methods. Implementing the recommended measures can enhance the quality and longevity of flat roof systems, resulting in reduced maintenance expenses and improved safety and value of commercial buildings. Implementing proactive planning and regular maintenance is crucial for guaranteeing the long-term sustainability and optimal performance of flat roofs.

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