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Exploration of Timber Dry and Wet Rot Defects in Buildings: Types, Causes, Effects and Mitigation Methods

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ABSTRACT

The present study is an appraisal of dry and wet rot defects and their effects on structural and non-structural elements. There were three main objectives to be achieved which were to determine the main causes that lead to wet and dry rot defects in structural and non-structural elements of the building, to establish the effects of wet and dry rot defects on the structural and non-structural elements of the building and lastly to recommend approaches and techniques for repairing wet and dry rot flaws on building structural and non-structural elements. Various study methodologies were utilised, including thorough literature review, case study analysis, and interviews with subject matter experts. The study revealed that timber houses can possess notable flaws in both their structural and non-structural components, which can have adverse effects on its materials and environment. These problems can result in diminished comfort levels, health concerns, and potential risks to the occupants' lives. Dry rot mostly impacts timber components, resulting in significant harm and compromising the structural integrity. Wet rot is a type of decay that happens in moist environments and can impact a broader variety of materials. Moreover, it is essential to implement proactive maintenance and repair methods to mitigate the risks connected with rot. Some recommendations include implementing effective moisture management systems, conducting frequent inspections to detect deterioration early, and promptly responding to any evidence of decay by completing targeted repairs or replacements.

1. Introduction

Timber is still commonly used as the popular construction material in structures in Malaysia [1]. In Penang state, there is still a significant number of buildings constructed with timber materials, particularly in the rural areas where the majority of residences are over two decades old [2]. The presence of the dwellings has resulted in a distinctive configuration in terms of their architecture and the diverse designs of each individual house [3]. This project aims to enhance understanding of

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maintenance techniques for addressing flaws and preserving the aesthetic appeal of buildings during extended periods of use. Preventing timber defects is crucial due to the high value and frequent utilization of timber as a natural resource in buildings [4,5]. Given that the majority of traditional timber houses are constructed using locally sourced hardwood and need specialized carpentry skills that are now uncommon, the preservation of timber houses is equally important as the preservation of other historical buildings [6].

Timber exhibits distinct characteristics that set it apart from other commonly used building supplies. Metal, concrete, and brickwork exhibit greater resistance to moisture and humidity, however none of them is impervious to these influences. Timber has anisotropy, meaning that the effects of forces applied along different axes vary [7]. Although it is accurate to say that the majority of constructions are unable to withstand random stresses from every angle, timber exhibits strengths that vary along various axes. Timber is mainly joined to other timber parts by metal fasteners. Timber can be readily modified in the natural environment using traditional equipment, allowing for uncomplicated execution of engineered alterations. One possible reason for the low relationship among end-users and forestry professionals, producers, and dealers is the easy availability of timber to homeowners [8]. Timber is an exceptionally ecological substance. Timber needs lower energy inputs for harvesting, milling, and transportation compared to commodities like steel, concrete, brickwork, and others [9]. Timber based materials effectively store a substantial quantity of carbon in relation to the carbon emissions generated throughout the process of harvesting, manufacturing, and transportation. Timber-framed buildings have demonstrated overall strong performance in winds and seismic disasters when built in compliance with building regulations and sound construction practices [10]. Timber constructions frequently offer a financial benefit compared to alternative types of structures. It is commonly believed that timber constructions are less durable than those made of steel, concrete, or masonry [11]. However, research has indicated that timber structures often have a longer lifespan when used. Failure studies can frequently be regarded as essential for educating the design community about issues and improving design and construction practices. However, these studies tend to focus mainly on large structures or structures made of concrete and steel [12]. A multitude of research has been conducted on the failures and faults in wood or timber framed buildings. These articles have been authored by both professionals and scholars. The multitude of failure kinds has hindered the establishment of a cohesive database that might be utilized to enhance timber construction [13].

In each building, there are several areas where dry wet rots are seen many occur in structural materials such as walls, beams, columns, and non-structural materials [14]. Furthermore, it is important to know what the effects of dry and wet rot defects are in the structural and non-structural of timber buildings. Decay, rotten and deformation of timber structures are recorded as the most frequent types of defects that occur [15]. It is very difficult to do any maintenance using certain materials but forced to change the material to a new one. It is not only because of the quality or material used, but the material itself can be one of the causes of damage if there’s no maintenance taken. Next, Not using the right techniques when doing maintenance is also one of the reasons maintenances is less effective for the defect [16]. Hence, this research will outline the specific questions of this research which are What are the causes and implications of structural and non-structural wet and dry rot defects? What is the effect of wet and dry rot problems on both structural and non-structural elements at once? What are the most appropriate methods for addressing dry and wet rot issues in building materials? From these questions, the research will outline a specific objective which is to examine the main causes and effects of wet and dry rot defects in structural and non-structural materials, to identify the effects at which dry and wet rot defects appear in structural and non-structural elements in building and to determine approaches to mitigate the issues of dry and wet rot that frequently arise in building materials.

2. Literature Review

Building faults can manifest in both new and old buildings, as stated by Bakri and Mydin [4]. A defect can be described as something that diminishes the visual appeal of a building material or piece and causes it to not work properly. Structural defects can arise from deficiencies in design, poor workmanship, failure to meet requirements, or other contributing factors [15]. According to Soh [17], both structural and non-structural problems might arise from poor workmanship, defective materials, faulty design, or a combination of these factors. Building defects can arise due to the use of substandard materials, inadequate supervision, and frequent ecological catastrophes in Malaysia. These factors often lead to accidents and compromise the integrity of construction materials [6]. As stated by Isa *et al.,* [1], defects refer to the inadequacy or malfunction of both the structural and non-structural components in a building, resulting in a failure to meet the necessary construction standards, performance expectations, or user needs. These flaws can have an impact on the building's services, structure, and other given facilities.

The prevalent defects typically include corrosion, blemishes, exterior surface damage, moisture, peeling paint, roof faults, cracking, and similar issues. Yacob *et al.,* [18] revealed in previous research that the most commonly identified flaws were peeling paint, moisture, discoloration, timber degradation, and others. Alauddin *et al.,* [19] have identified various prevalent structural flaws, such as humidity, termite attacks, cracks, loose plasterwork, efflorescence, and paintwork blistering.

2.1 Issues of Dry and Wet Rots in Timber Buildings

Timber is a good option for constructing buildings and structures. In the early 1980s, timber materials were commonly used in the construction of houses due to their enduring nature, pleasing appearance, and other notable qualities. However, as a result of seasonal fluctuations in environmental circumstances, these woody materials may experience continuous hydrostatic pressure throughout a wet day [1]. According to prior study, the Malaysian climate is characterized by consistent high temperatures, abundant humidity, and substantial rainfall. It is exceptionally uncommon to have an entire day with fully clear skies. Consequently, numerous structures in Malaysia are prone to faults such as dampness and water leakages, requiring extensive maintenance. Timber structures may face several risks that can affect their durability, including the natural process of deterioration, damage caused by insects, and attacks from fungi [20].

2.2 Types of Dry and Wet Rot Defects

Timber undergoes degradation when it comes into contact with water infiltration. The four categories of flaws that can cause dry and wet rot are biological, chemical, physical, and mechanical degeneration. Dry rot is a term used to refer to a type of decay in timber, scientifically known as Serpula larryman's [21]. Dry rot is a prevalent issue in timber structures, which is more destructive than wet rot. It mostly affects dry areas of the building and can spread to both timber and non-timber things. Dry rot has the potential to propagate rapidly in comparison to wet rot flaws, although this is contingent upon the presence of optimal circumstances. Dry rot flaws possess the capacity to cause significant structural damage. Moisture is an intermediate stage between wet and dry conditions. It facilitates the proliferation of many types of bacteria that are linked to numerous diseases and insects, posing a threat to the health of residents and items in the house [22].

2.2.1 Timber decay

Timber decay refers to the degradation or disintegration of construction timber caused by several reasons. Timber decay is an inherent phenomenon that is impacted by ambient conditions, biological agents, and various other factors. Timber is a prevalent building material that is susceptible to deterioration if not adequately protected and maintained to ensure the longevity of the structure [15]. Figure 1 depicts an instance of timber deterioration occurring in the staircase area of the house. Timber degradation poses significant risks to the structural integrity and safety of your property. It is essential to recognise the signs, understand the causes, and implement effective solutions to prevent further damage and preserve the longevity of the timber structures.

Fig. 1. Timber decay occurs at the staircase

2.2.2 Deterioration of structure

The deterioration of timber structures refers to the gradual damage and weakening of the timber components over time. Several factors contribute to the deterioration of timber, which can lead to structural problems. Timber deterioration caused by biological decay mostly occurs because of timber-boring insects or rotting fungi [23]. Figure 2 demonstrates a serious deterioration of structural timber at beams and columns section. While it is difficult to determine the exact rate at which brown-rot decay occurs in timber framed buildings with a high level of theoretical assurance, investigation conducted in the area of timber sciences has given enough information to establish the range within which the decay curve can be defined, with an upper limit and a lower limit. Degradation enclosures for timber structures might be accurately established by utilizing evidence obtained via testing and field experiments. Such investigations involve employing identical kinds of timber found in buildings, the identical rot fungi (brown-rot), and comparable humidity and temperature conditions.

Fig. 2. Serious deterioration of structural timber

2.2.3 Cracking

Cracks are the most common defects in buildings, especially in concrete and timber materials. Besides, most of the cracks in the timber structure can be clearly seen in dry conditions. Cracks are frequently observed in the large span timber elements which are more visible in weather. In addition, moisture diffuses across the timber section, large cross-sections develop severe moisture gradients and, as a result, severe moisture-related stresses [24]. Figure 3 shows the visible cracks on a timber structure. Timber checks, referred to as splits and cracks in the lumber trade, are the result of the shrinkage of timber during the drying process. Timber experiences approximately twice as much shrinkage radially, along the growth rings, compared to tangential shrinkage across the rings. The development of checks is caused by the unequal shrinking.

Fig. 3. Visible cracks on timber structure

2.2.4 Spordust

Spores can be found outside of the structural buildings, but it can spread inside of the structural members. Fungi can produce multiple spores, each capable of reproducing a single full entity; thus, fungal infestations are frequently characterized by a rapid and extensive diffusion that is difficult to eradicate [25]. Figure 4 shows the sign of spordust on timber structures. When spores come into contact with damp timber, they will begin to develop and form hyphae. The delicate white tendrils permeate the timber, causing its decomposition. The cobweb strands function as conduits that extract and convey moisture, similar to roots, from the timber.

Fig. 4. Visible cracks on timber structure

2.2.5 Dampness

According to Halim *et al.,* [26], many buildings experience dampness due to the high moisture content in the building. Based on previous research, dampness contributes to 50% of all known building failures. On the other hand, it has been said that most building deterioration is inextricably linked to dampness. Dampness is widely seen as detrimental to buildings. Moisture can indeed lead to issues, whether it infiltrates a structure from above or seeps into its walls or floor from below. Effective management of moisture levels in buildings is crucial, as failure to address deficiencies promptly can result in significant damage to the building structure. Figure 5 visualizes the dampness problem occurring on structural timber part.

Fig. 5. Dampness problem on structural timber

2.2.6 Mould growth

Mould growth in timber occurs when there are fungi find favorable conditions to thrive. Mold usually reproduces by spores which can spread into all structural and structural materials in the building such as walls, ceilings, floors, and other materials. Interior mold growth can be possibly the biggest threat to the building's structural and non-structural elements on timber and most of it is caused by flooding, leaking roofs, building maintenance, or indoor plumbing issues [27]. Figure 6 displays evidence of mould growth taking place at the portion of the timber structural beam.

Fig. 6. Mould growth at timber structural beam

2.2.7 Timber wood

Brittle timber refers to the loss of the flexibility of wood which easily breaks its physical and it is a sign of deterioration of the building that can compromise the structural integrity of a building. Brittle timber may lead to a reduction in the durability and strength of buildings which may cause collapse shortly [28]. Figure 7 illustrates evidence of timber brittleness in the floor joists part of the building.

Fig. 7. Timber brittleness in the floor joist’s section

2.2.8 Termites

Termites are a vital part of the soil ecosystem that can be found all over the world. Their species is alive currently in tropical and subtropical regions, which contribute to a significant portion of 10% of the animal biomass [4]. Typically, insect attacks mostly happen in tropical countries, where most of the insect attacks are caused by termites, biological attacks, beetles, and borers. Figure 8 displays evidence of terminate attack on the timber flooring of a structure. Frequently, termites can be seen inside timber structures, where they create a thin protective layer to shield themselves from the external surroundings. The implementation of chemical and mechanical barriers will effectively deter soil termites from infiltrating the building. However, it should be noted that these measures will not provide protection against dry termites, as they can fly and are not hindered by such barriers.

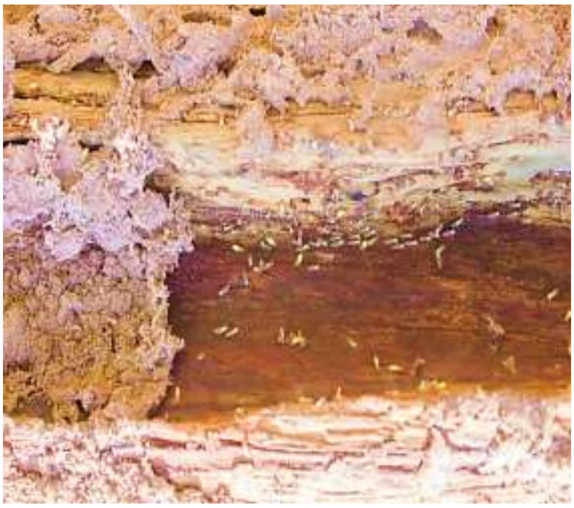

Fig. 8. Terminate attack on the timber flooring of a structure

2.3 Causes of Dry and Wet Rot Defects

Both dry and wet rot are the types of fungi that affect timber in buildings. While they share similarities, they have similar causes and characteristics. A dry rot defect can be defined as a transformation into a dry powder that is brown in color and will weaken the durability of timber structural materials. On the other hand, wet rot defects are caused by the growth of the fungus and the chemical decomposition of timber [28]. Humidity is one of the most common factors that cause building defects both in claddings and structural [29]. According to Isa *et al.,* [1], defects of the timber element can be divided into four categories which are caused by biological agents, physical agents, chemical agents, and mechanical agents. Next, according to Johar *et al.,* [30], biological agents and moisture problems are the most common causes of deterioration. Based on previous research by Isa *et al.,* [1], there are many types of causes of timber defects which are fungi, termite attacks, soil settlement, biological factors, human factors, aging, leakage, dampness, insect attacks, lack of maintenance.

3. Methodology

This section will provide a detailed explanation of the methodologies employed to carry out the investigation. The technique employed will serve as the primary means for gathering data or carrying out processes to gain information in order to accomplish the aims or objectives established in the first phases of the study. The purpose of preparing the technique is to establish a connection between the research question or objective. The researcher will utilize both primary and secondary data sources for data collection during the study. The main data will be gathered using methods such as case studies and interviews, while the secondary data will be obtained from internet resources, websites, and libraries. This strategy is employed because of its ability to gather information that is precise, straightforward, and directly related to the predetermined objectives [31]. The research commenced by providing an examination of the timber building or case study in Penang and its problem that is relevant to the objectives. Mixed methods research facilitates a more profound comprehension of a subject by integrating qualitative and quantitative methodologies. Primary data refers to the data that researchers directly obtain through physical means. The resources are often gathered by means of observations, site inspections, interviews, and questionnaires that will be delivered to the respondents. Thus, the researcher will utilize primary data to facilitate precise data acquisition from the respondent. Secondary data refers to information that is collected from other sources, including newspapers, periodicals, journals, articles, books, the internet, theses, seminar papers, and similar sources. This evidence is crucial for substantiating a statement and bolstering a conclusion. Secondary data refers to pre-existing data that is obtained from multiple sources and used as a point of reference. The researchers in this study relied predominantly on secondary data rather than original data. The reason for this is because secondary data is readily accessible, and the available sources are also dependable.

3.1 Case Studies

Case studies provide a comprehensive method for analyzing and examining particular cases. The efficacy of the study methodology can be shown by generating outcomes under similar circumstances. Case records contain sufficient data to enable the comparison of results from diverse yet comparable scenarios, allowing for the separate investigation of individual variables that may have contributed to variances in outcomes [32]. The researcher will do a thorough visual examination of the site in order to identify five case studies that align with the stated purpose for data collecting. Once all the necessary data is gathered, we will proceed to analyze all the issues presented in the case studies. The researcher will conduct inspections of both the external and internal areas of buildings in Penang. The purpose of these inspections is to identify any faults linked to dry and wet rots, as well as their impact on both structural and non-structural elements. The case studies are situated in Georgetown, Penang, where there is a heritage building and old houses. The remaining three case studies are in Batu Uban, Penang, and consist of three old houses. Table 1 summarizes the list of houses that were opted as case studies

Table 1
List of houses that were chosen as case studies

Case Study	Descriptions
Case study 1	• Location: Jalan Air Itam, Pekan Ayer Itam, 11500 Ayer Itam, Pulau Pinang • Ages of Houses: 50 years • Condition of houses: Good
Case Study 2	• Location: Jalan Air Itam, Pekan Ayer Itam, 11500 Ayer Itam, Pulau Pinang • Ages of Houses: 40 years • Condition of houses: Fair
Case Study 3	• Location: Kampung Batu Uban, 11700 Gelugor, Pulau Pinang, Malaysia. • Ages of Houses: 35 Years • Condition of houses:
Case Study 4	• Location: Simpang Tiga, Nibong Tebal, Pulau Pinang, 14310 • Ages of Houses: 25 years • Condition of houses: Fair
Case Study 5	• Location: Jalan Air Itam, Pekan Ayer Itam, 11500 Ayer Itam, Pulau Pinang • Ages of Houses: 48 • Condition of houses: Good

3.2 Interview Session

The researcher conducted an interview session with the homeowners to gather information regarding the occurrence and timing of the issues. The researcher also managed an interview session with professional actors who possess knowledge of timber faults. Additionally, the researcher performed a face-to-face interview session to facilitate a productive exchange of ideas and secure a favourable response from the interviewee. For instance, the interviewer inquired about the causes of faults in both the structural and non-structural components of the building, addressing either the occupant or professional actors. In this instance, the researcher performed an interview with at least one tenant. In order to gather further information, the interview session will be conducted with a minimum of five experienced actors who possess knowledge regarding timber flaws [33]. Table 2 shows the demography of respondent.

Table 2
Demography of Respondent

Demographic	Mr. X	Mr. Y	Mr. Z
Position	Building Surveyor	Contactor	Civil Engineer
Year of service	15	7	16

3.3 Observations

The observation technique is an essential method employed by the researcher. The observation technique involves visually examining the appearance of a structure and is a critical step in determining the impact of dry and wet rot problems on both the structural and non-structural components of a building. An extensive analysis of the structure should be conducted to identify any apparent signs of corrosion and deterioration. Most of the flaws were identified by eye inspection in order to ascertain the underlying causes of the defects. The visual inspection done will not cause any damage or alteration to the structural or non-structural components of the building [22].

3.3.1 Protimeter testing

In addition, the observation was facilitated by the use of protimeter equipment, which is designed to measure the moisture content in the timber [34]. The Mini C perimeter was utilized to measure the moisture content in the timber. The moisture meter is a pin-type device that provides immediate moisture content readings on an LED scale ranging from 6% to 30%. The magnitude of the three-color coded LED facilitates rapid interpretation of "Dry", "At Risk", and "Wet" circumstances, as presented in Table 3. During the measurement, the researcher saw that the scale consistently displayed moisture readings below 20, indicating a dry condition. The reading was low due to the prevailing meteorological conditions at that specific time. The measurement occurred on a sunny day with a temperature of roughly 35-37°C. All the structural and non-structural parts were devoid of moisture during the measurement, and none of the readings above a value of 20 or higher.

Table 3
Moisture content scale

Scale (%)	Measurement	Colour
6 - 17	Dry	(green)
18 - 20	At Risk	(yellow)
21 >	Wet	(red)

3.3.2 Building condition assessment

The researcher identified the specific dry and wet flaws that have occurred in both the structural and non-structural components of the building. The researcher will conduct data gathering using an observational technique focused on buildings. According to prior studies, observation is the most effective method for identifying and evaluating the flaws present in a building. Subsequently, a Building Condition Assessment (BCA) will be conducted to assess the structural deficiencies of the timber building [34].

3.3.3 Prioritize ranking systems

The priority ranking systems will be covered, which will show the overall satisfaction of the user comfortability and risk assessment of the houses. With this, the higher the total value, the lower it needs to be prioritized, which means the lower the marks, the more the owner of the house needs to be concerned and needs to take immediate action [34].

4. Results and Discussion

4.1 Causes of Dry and Wet Rot Defects

Table 4 shows the total causes of timber defects of 5 case studies considered in this study. According to the inspection, the majority of attacks target the non-structural components of timber buildings, specifically the walls of the building. The primary cause for termites targeting walls in most locations is the susceptibility of the timber, which makes it more vulnerable to their destructive activities. According to the interviews with the homeowners, it was found that four out of five residences did not utilise a termite extermination spray. This suggests that there is a possibility of a high concentration of termites nesting in that particular location. According to the examination, the majority of the leaks are caused by the incorrect location of the roof, which allows rainwater to enter. In addition, the researcher was unable to get access to the rooftop for further examination. Nevertheless, the inference of water seepage is mostly attributed to the inadequate positioning of the roof. In addition to termite attacks, there is another biological factor that leads to the deterioration of timber material on both structural and non-structural aspects. The inspection reveals the presence of biological factors in the rotted and damaged timbers. Bacteria and fungus degrade the timber structure, resulting in a loss in the strength of the timber. Table 5 shows the types of defects found in the case study.

Table 4
Total causes of timber defects of 5 case studies

No.	Causes of Defects	Frequency	Percentage (%)	Rank
1	Termites Attacks	20	21.05	1
2	Biological Factor	14	14.74	2
3	Aging	13	13.68	3
4	Leakage	12	12.63	4
5	Fungus	12	11.58	5
6	Moisture Content	11	10.53	6
7	High Humidity	6	8.42	7
8	Human Factors	8	7.39	8
Total		98	100	-

Table 5
Types of Defects in Case Study

No.	Types of Defects	Photos	Explanations (Possible causes)
1	Timber Decay		Timber decay is an inherent phenomenon that is impacted by ambient conditions, biological agents, and various other factors. Timber degradation typically occurs due to the presence of leaks and condensation, which creates the necessary moisture for bacterial and fungal agents to thrive.
2	Deterioration		Biological decay of timber primarily arises from the activities of timber-boring insects or rot fungus. Insect infestations are primarily responsible for the degradation of both the structural and non-structural components of a building, hence impacting the materials and the long-term functionality of the structure.
3	Cracking		The low tensile strength of timber can potentially lead to the formation of cracks in the timber. Cracks are exclusively observed on the structural timber element known as the column.
4	Spore Dust		The occurrence of spore dust on the timber structure is due to the presence of fungi. Fungi have the ability to generate numerous spores, each capable of reproducing an entire organism. As a result, fungal infestations often spread quickly and extensively, making them challenging to eliminate.
5	Dampness		According to the inspection, all five case studies encountered moisture in their building, particularly on the ceiling and wall surfaces. The occurrence of these faults can be attributed to the roofing system's susceptibility to water infiltration, which permeates the timber components.
6	Mould Growth		Mould often reproduces through spores, which have the ability to disperse and infiltrate many components of the building, including walls, ceilings, floors, and other structural materials. The mould proliferation in the case study was attributed to roof leaks and plumbing problems.
7	Brittle Woods		Biological causes can lead to the development of brittle timber in lumber, particularly in non-structural components such as walls. Bacterial insects and fungi infest the timber, causing internal weakening and rendering it susceptible to more harm.
8	Termites		The majority of insect attacks are attributed to termites, biological pests, beetles, and borers. The primary cause of these problems is the exposure of the timber to environmental conditions during its use. Timber is often consumed by insects, particularly termites, as part of the natural cycle of life.
9	Peeling Paint		Peeling paint primarily occurs on both the structural and non-structural components of the building, particularly on the columns, plastered walls, flooring, ceilings and beams. The exposure of these elements to sunshine and weather led to the paint flaking.

Table 6, Table 7, Table 8, Table 9 and Table 10 summarize the causes of defects on structural and non-structural elements of case study 1, case study 2, case study 3, case study 4 and case study 5, respectively.

Table 6
Causes of defects on structural and non-structural elements of case study 1

No.	Causes of defects on structural and non-structural elements	Frequency	Percentage (%)
1	Termites Attacks	4	19.0
2	Biological Factor	2	10.0
3	Aging	3	14.0
4	Leakage	4	19.0
5	High Humidity	1	5.0
6	Human Factors	1	5.0
7	Moisture Content	3	14.0
8	Fungus	3	14.0
Total		21	100

Table 7
Causes of defects on structural and non-structural elements of case study 2

No.	Causes of defects on structural and non-structural elements	Frequency	Percentage (%)
1	Termites Attacks	3	22.0
2	Biological Factor	2	14.0
3	Aging	3	22.0
4	Leakage	1	7.0
5	High Humidity	1	7.0
6	Human Factors	1	7.0
7	Moisture Content	1	7.0
8	Fungus	2	14.0
Total		14	100

Table 8
Causes of defects on structural and non-structural elements of case study 3

No.	Causes of Defects on Structural and Non-Structural Elements	Frequency	Percentage (%)
1	Termites Attacks	4	30.8
2	Biological Factor	3	23.1
3	Aging	1	7.7
4	Leakage	1	7.7
5	High Humidity	1	7.7
6	Human Factors	1	0.0
7	Moisture Content	2	15.4
8	Fungus	1	7.7
Total		14	100

Table 9
Causes of defects on structural and non-structural elements of case study 4

No.	Causes of defects on structural and non-structural elements	Frequency	Percentage (%)
1	Termites Attacks	6	21.0
2	Biological Factor	4	14.0
3	Aging	3	10.0
4	Leakage	4	14.0
5	High Humidity	2	7.0
6	Human Factors	4	14.0
7	Moisture Content	3	10.0
8	Fungus	3	10.0
Total		29	100.0

Table 10
Causes of defects on structural and non-structural elements of case study 5

No.	Causes of Defects on Structural and Non-Structural Elements	Frequency	Percentage (%)
1	Termites Attacks	3	17.0
2	Biological Factor	3	17.0
3	Aging	3	17.0
4	Leakage	2	11.0
5	High Humidity	1	5.0
6	Human Factors	1	5.0
7	Moisture Content	2	11.0
8	Fungus	3	17.0
Total		18	100.0

4.1.1 Summary of causes of dry and wet rot defects for 5 case studies

Based on the observations, it can be concluded that all five case studies attribute the main causes of dry and wet rot faults to termite infestations. This is a common issue found in older constructions, as materials gradually degrade with time, requiring frequent repairs and very expensive restorations. Based on visual inspection and observations, it is evident that Case Study 4 has had the greatest impact on both the structural and non-structural components of timber, affecting a total of six areas. Moisture content and fungus are the second most significant factors that contribute to flaws and degradation in both the structural and non-structural components of timber. In addition to that, these significant conditions can lead to the degradation of timber elements, which can impact their longevity and structural stability. Biological factors, excluding termites and fungi. These could encompass supplementary pests or insects that cause harm to the structural components. Elevated humidity is a significant worry as it can exacerbate issues such as moisture levels and the growth of fungi. Human considerations highlight the significance of human error or neglect in the degradation of architectural structures.

4.2 Effects of Dry and Wet Rot Defects to the Timber Elements

Table 11, Table 12, Table 13, Table 14 and Table 15 summarize the effects of dry and wet rot defects on case study 1, case study 2, case study 3, case study 4 and case study 5, respectively.

Table 11
Effects of dry and wet rot defects on case study 1

No.	Effects of Rot Defects on Elements	Frequency
1	Damaged	0
2	Decayed	3
3	Cracks	2
4	Aesthetic Failure	4
5	Loss of Strength	1
6	Loss of Functionality	1
Total		11

Table 12
Effects of dry and wet rot defects on case study 2

No.	Effects of Rot Defects on Elements	Frequency
1	Damaged	3
2	Decayed	1
3	Cracks	1
4	Aesthetic Failure	4
5	Loss of Strength	1
6	Loss of Functionality	3
Total		13

Table 13
Effects of dry and wet rot defects on case study 3

No.	Effects of Rot Defects on Elements	Frequency
1	Damaged	2
2	Decayed	1
3	Cracks	1
4	Aesthetic Failure	7
5	Loss of Strength	1
6	Loss of Functionality	1
Total		13

Table 14
Effects of dry and wet rot defects on case study 4

No.	Effects of Rot Defects on Elements	Frequency
1	Damaged	2
2	Decayed	2
3	Cracks	3
4	Aesthetic Failure	10
5	Loss of Strength	2
6	Loss of Functionality	3
Total		22

Table 15
Effects of dry and wet rot defects on case study 5

No.	Effects of Rot Defects on Elements	Frequency
1	Damaged	1
2	Decayed	3
3	Cracks	1
4	Aesthetic Failure	6
5	Loss of Strength	2
6	Loss of Functionality	1
Total		14

4.2.1 Summary of effects of dry and wet rot defects on structural and non-structural elements

Based on observation from 5 case studies, the most affected areas are from the non-structural elements which is there's a particular area affected from aesthetic failures. It includes peeling paint on walls, columns, ceiling, etc. Aesthetic failure is the most impact failure that could happen by the causes of these defects. All case studies have similar effects to these defects and aesthetic failure is the most influential to affect the timber elements. Next, based on the observations, these defects not only impact the aesthetic value of the houses, but it also can damage a certain area of timber elements, which could loss of the strength of the timber itself.

Most of the case study have a similar significant impact to the timber elements unlike case study 1 is the only timber elements that didn't experience any decayed elements to their timber houses. Based on observations, the researcher finds that some of the timber elements face a decrease in their stability due to the deterioration, decay, and deformation of their elements. Some of these defects are caused by termites, moisture content, high humidity, and biological factors.

Due to these defects, the elements face losses of their material's strength, and if this happens with no prevention taken, the building may lead to more dangerous hazards which can probably cause a building collapse. Luckily, these defects commonly appear in the non-structural area which did not cause a collapse of the timber houses.

4.2.2 Potential risk and user effects

Table 16 presents the rankings of priority systems, with the highest total value of 14 marks assigned to case study 1. Following that is case study 3 with a total value of 12 marks, then case study 5 with a total value of 11 marks. Lastly, case study 2 and case study 4 both have a total of 10 marks. The exemplary performance of the case study demonstrates the owner's profound commitment to timber housing. According to the interview, they want to use chemical measures to combat insect infestations and other biological factors that could potentially damage their buildings. This demonstrates the reason why the majority of the components of the timber remain in excellent condition, despite the occurrence of small flaws in the home. Both case study 3 and case study 5 still get a combined score over 11, indicating that they remain in good condition. Although Case Study 2 and Case Study 4 have a lower total value of only 10 (lower than 11), this indicates that these timber houses are still in a satisfactory state. This suggests that there are no significant problems that could result in structural damage, such as failure or collapse.

Table 16
Priorities ranking system

Types of Data	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5
Physical Condition	3	3	3	3	3
Fabric Affects	2	1	2	2	1
User Effects	2	2	2	1	2
Potential Risk	3	2	2	2	3
Risk Effects	4	2	3	2	2
Total Marks	14	10	12	10	11

4.3 Mitigation Methods of Dry and Wet Rot Defects

The majority of data regarding the mitigation of dry and wet rot problems was obtained through interviews with three specialists who had specialised knowledge in timber structures. Interviewer 1 is a building surveyor, interviewer 2 is a contractor, and interviewer 3 is a civil engineer. Most of them provide a comparable solution for addressing dry and wet rot issues. A somewhat analogous response will be provided for a certain aspect.

4.3.1 Use of chemical agent treatment

The interviewer concurred that the utilisation of chemical sources can effectively impede the degradation of timber products. There are numerous chemical sources available for usage in buildings, including fumigants (Figure 9). The individuals in case study 1 have reported employing chemical treatment within their residences to inhibit the proliferation of pests. They applied it to the timber materials once, and this application lasted for a duration of two years. Based on a comparison of five case studies, it can be concluded that case study 1 exhibits less faults than the other four. This technique can be utilised on both the load-bearing and non-load-bearing components of timber and can be implemented by several means such as spraying or coating the timber. This chemical compound is extensively utilised as a timber surface treatment to deter and exterminate various pests, such as termites, beetles, and carpenter ants. Handheld sprayers are efficient and uncomplicated tools for targeted treatments and indoor applications, making them ideal for pest control operations on a small scale.

Fig. 9. Chemical agent treatment on timber surfaces

4.3.2 Removal of deteriorated timber elements

The optimal solution for severely deteriorated timber elements is to remove the existing material and replace it with new timber parts (Figure 10). This method can be utilised for the restoration of any degraded timber components, following the specified procedure. Commence the process by eliminating any deteriorating or putrefying sections of timber, progressively uncovering sound and robust timber. Exercise caution to avoid causing harm to any adjacent structural components or surface treatments when removing them. Once the decaying timber has been eliminated, assess the structural integrity of the remaining elements.

Fig. 10. Remove deteriorated timber part and replace with new timber

4.3.3 Choose a high-quality timber

The new timber materials require improved quality in order to boost their ability to avoid the spread of damages and ensure better long-term durability. Interviewer 1 stated that there is a range of timber quality available, with the highest grade being SG1. According to their statement, this lumber is inherently durable and does not require any treatment or coating. Additionally, it was stated that termites are unable to consume the nutrients present in this timber due to its inherent thickness and quality. Timber of superior quality, free from imperfections such as knots, distortions, and fractures, offers structural integrity and durability against environmental factors such as wind, moisture, and pests.

4.3.4 Regular inspection and maintenance

Consistent maintenance and thorough examination are essential for reducing timber flaws and guaranteeing the long-term quality of timber goods. By adopting a proactive maintenance strategy, potential issues can be promptly detected and addressed, hence minimising the likelihood of faults and enhancing the longevity of timber structures. Homeowners have the ability to regularly or semi-annually observe or examine their own residences. Utilising this approach can aid in promptly identifying any possible flaws in timber structures. By assessing the size of the house, they can employ a simple method of using fungicidal or chemical agents to spray and eradicate the nest of the pests.

4.3.5 Follow proper installation procedures

The presence of excessive moisture and fungi in the ceiling and wall areas is primarily attributed to the inadequate installation of new materials in the buildings. Improper installation methods can result in faults and serve as a cause for other frequent issues, including moisture content and humidity. According to the findings from the case studies, the ceiling surface and walls are the areas that are most severely impacted by high moisture levels and the growth of fungus. During the interview session, the experts provided instructions on how to improve installation procedures. They advised to install timber items in a manner that prevents the accumulation of moisture and ensures sufficient ventilation. Figure 11 depicts the timber laying technique employed to achieve a superior finished item.

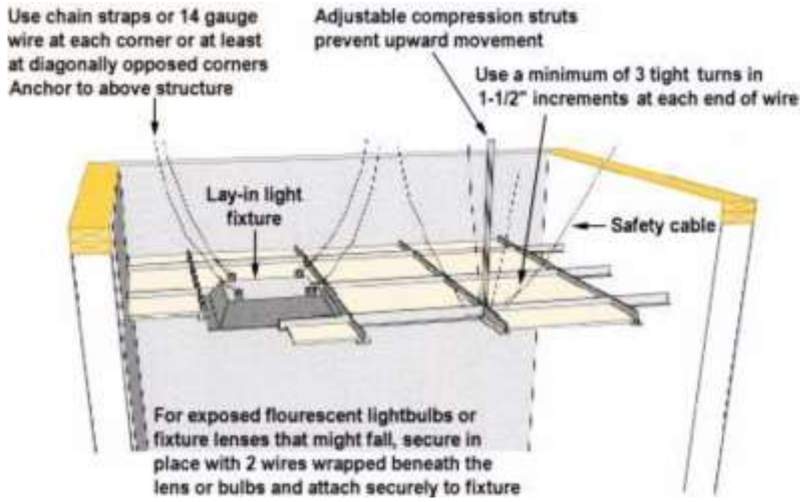

Fig. 11. Timber laying method

4.3.6 Repainting and coating

It is recommended to repaint and add a coating to the timber structure to improve the stability and integrity of the timber components. Repainting and adding coatings create a protective barrier that prevents moisture from penetrating the timber surface as shown in Figure 12. Paints and varnishes are formulated with preservatives and fungicides to inhibit the growth of mould, mildew, and organisms that cause degradation. Applying a fresh coat of paint to timber surfaces provides an additional level of defence against deterioration, so prolonging the longevity of the timber. Furthermore, the act of repainting and coating timber surfaces enhances their longevity by creating a defensive barrier that prevents scratches, abrasion, and mechanical harm. Coatings like varnish, polyurethane, and lacquer offer a robust and enduring coating that strengthens the surface of timber and enhances its resistance to deterioration.

Fig. 12. Repainting decayed timber surfaces

5. Conclusions

According to the findings of this study, structural and non-structural parts on timber houses might have substantial flaws that influence their materials or the environment, such as reduced comfort levels, health issues, potential threat to their own lives, and so on. The researcher's findings show that dry rot mostly affects timber elements, causing significant damage and weakening the structural parts. damp rot happens in damp settings and can harm a variety of materials. Furthermore, the study's findings emphasise the necessity of proactive maintenance and repair methods in mitigating the risks connected with rot. The recommendations include implementing effective moisture management systems, undertaking regular inspections for early detection, and responding rapidly to any evidence of degradation via targeted repair or replacement. Furthermore, using rot-resistant materials and design elements in building construction can assist lessen the possibility of future faults. Considering these findings, the researcher recommends a variety of techniques to lessen the risks connected with rot through interviews, which are supported by a thorough literature analysis. Proactive maintenance methods, such as regular inspections, are crucial for timely detection and response. Based on the observations, it is determined that most of the problems are caused by termite assaults or any biological source. Five case studies have demonstrated the same possible causes of wet and dry rot faults in lumber. These insect attacks became the most common source of faults, with the majority focusing on attacks on non-structural materials. Corresponding to the observations and interviews with the house owners, the most impacted location is on the wall, which includes damage, decay, and aesthetic failure to the design itself. The majority of it is caused by water leakage, insect infestations, and natural ageing of the timber. According to the interview, some of the owners have experienced discomfort due to mould growth, loss of wall functionality, and health dangers. Based on the interview session with three experts from timber elements, they have mentioned that the best way to ensure the structural and non-structural elements' integrity is by using any remedial work, which includes a proper coating, repainting, reinstallation, using chemical agents, etc. using chemical sources as their main method of prevention from the spread of any pest that may damage the timber materials.

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