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Preservation Strategies for Historic Timber Mosques: Structural Integrity Assessment on Masjid Jamek An Nur, Batu Pahat, Johor

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Abstract: This study addresses the critical need for preservation strategies to protect the Masjid Jamek An Nur in Kampung Patah Pedang, Batu Pahat, Johor and similar timber mosques from decay and neglect. Utilising building checklist assessment (BCA) methodology, this study thoroughly documented the condition of the mosque and identified a significant array of timber defects, including cracks, insect attacks and rot. The findings revealed that 30 structural elements (17 columns and 13 roof beams) were compromised, underlining the vulnerability of the mosque to structural failures. Severe weathering contributed to the most critical defects, with cracks alone constituting 38.27% of the defects. Through ultrasonic pulse velocity (UPV) testing, an analysis of the modulus of elasticity (MoE) revealed further structural vulnerabilities. Specifically, decay-induced compromise was detected in 43.63% of the columns tested, whereas the other columns displayed robust MoE values, representing 21.35% of the total tested. Notably, all roof beams met or exceeded the minimum MoE standards, boasting an average index of 16,721 MPa, indicating a satisfactory condition. Despite this, the study emphasises the urgent need for maintenance and repair interventions to prevent ongoing deterioration. It advocates the implementation of strategic repair strategies, including preservative treatments and innovative techniques, to ensure the structural longevity and continued cultural relevance of timber mosques. By adopting these recommendations, stakeholders can preserve invaluable cultural artifacts for future generations, thereby, continuing the historical legacy.

Keywords: Preservation, Timber mosques, Building checklist assessment (BCA), Ultrasonic pulse velocity (UPV), Modulus of elasticity (MoE)

INTRODUCTION

Structural failures in buildings pose a serious risk to public safety. In Malaysia, there have been incidents of building collapses, either during construction or after being occupied, due to a combination of factors such as excessive loading, poor structural design and the use of low-quality materials (Tchamba and Bikoko, 2016; Klasson et al., 2018). This is especially concerning for historic timber structures such as mosques, which have been exposed to environmental conditions and changes over many years. Timber is a popular construction

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material owing to its advantages such as fire resistance, structural properties and insulation (Asdrubali et al., 2017; Żmijewki and Wojtowicz-Jankowska, 2017). However, timber structures are also susceptible to termite damage and decay over time. The aesthetic, comfort and safety of building occupants can be affected by structural defects (Harte, 2009). It is crucial to regularly assess the condition of timber buildings, especially historically and culturally significant structures such as mosques, to identify any signs of damage or deterioration.

Many historic timber mosques in Malaysia are at risk of structural issues and deterioration owing to their age, exposure to environmental factors and lack of proper maintenance (Tchamba and Bikoko, 2016; Klasson et al., 2018). Several traditional historic wooden mosques in Malaysia further strengthen the case study for Old Mosques. For example, the Kampung Laut Mosque (Kelantan; one of the oldest wooden mosques [18th century]) and the Kampung Bukit Tinggi Mosque (Pahang; an early 20th century wooden mosque), where these mosques have good conservation documentation for reference. Furthermore, the conservation needs of the Old Mosque of Mulong, compared to more contemporary wooden mosques such as the Kampung Baru Mosque (Negeri Sembilan) built in the 1960s, highlights the differences in damage profiles and intervention approaches that can be referenced. However, non-destructive testing on the case study of these wooden mosques was not conducted and only physical test checklists were used as a guide for the study.

The Patah Pedang Mosque, located at Minyak Beku under Batu Pahat district, Johor and built with timber in 1930, is one such example that requires a thorough assessment of its condition. Timber structures are susceptible to problems like termite damage, rot and weathering over time, which can compromise their structural integrity and pose safety hazards (Asdrubali et al., 2017; Żmijewki and Wojtowicz-Jankowska, 2017). Without timely intervention, structural defects in timber mosques could potentially lead to building collapses, endangering the lives of worshippers and the surrounding community. There is a critical need to evaluate the state of historic timber mosques and develop appropriate preservation and maintenance strategies to safeguard this important cultural heritage.

The study on the timber mosque at Patah Pedang is of significant importance in conversations surrounding heritage preservation and structural safety. By evaluating the modulus of elasticity (MoE) and strength of the timber components in a mosque, this study aims to contribute to the preservation and maintenance of this traditional structure, which is an essential part of Malaysia's cultural heritage. Understanding the structural integrity of a mosque is crucial for ensuring its longevity and safety for future generations.

Furthermore, the findings of this study can inform discussions on the importance of maintaining historical timber buildings, especially mosques, which have cultural and religious significance. By identifying potential issues and areas for improvement in the timber construction of mosques, this research can help develop better-quality standards and practices for timber construction in Malaysia's construction industry. This not only ensures the safety of the structure but also helps preserve the heritage and cultural identity associated with traditional mosques like the one at Patah Pedang.

TIMBER STRUCTURE CONDITION

Common Issues on Mosque Timber Structure

Timber mosque structures, including the Patah Pedang Mosque, face various problems that impact their structural integrity and longevity. The impact of defects and deterioration on timber structures, which encompasses damages and failures affecting building quality, functionality, usability and aesthetics, is influenced by environmental conditions and the passage of time (Richardson, 2002). Various issues can arise in timber mosque structures and it is crucial to address these issues through preventive measures to ensure their durability and structural integrity. Some common issues include:

1. Cracking: Cracks can develop in timber components due to factors such as age, environmental conditions, or improper maintenance. These cracks weaken the structure and compromise its stability (Shahrir and Rahman, 2021).
2. Termites and fungal infestations: Timber structures are vulnerable to infestations by termites and fungi, especially in humid environments. This biological deterioration can lead to decay and structural damage (Johar et al., 2013).
3. Physical decay: Non-biological deterioration, such as physical decay, high moisture content and dimensional instability, can affect the timber components over time. Exposure to environmental elements can cause the physical deterioration of the structure (Shahrir and Rahman, 2021).
4. Moisture damage: Moisture-related issues, such as the rotting of timber beams and columns, can occur if water ingress or dampness are not properly addressed. This could weaken the structure of the mosque (Shahrir and Rahman, 2021).
5. Insect attacks: Insect attacks, including dry and wet rot, significantly affect the structural integrity of timber mosque structures. Such attacks can lead to structural weaknesses and compromise the overall stability of a building (Johar et al., 2013).

It is essential to address these issues through preventive measures to ensure the longevity and safety of timber mosques. By implementing proper maintenance practices, controlling moisture levels, conducting regular inspections and employing appropriate pest control, these challenges can be mitigated and the structural integrity of sacred spaces can be preserved (Mustafa et al., 2011; Johar et al., 2013; Ahmed, 2019; Shahrir and Rahman, 2021).

Timber Mosque Assessment

The essence of heritage preservation, as Harun (2011) notes, transcends merely safeguarding historical artifacts; it is foundational to the ongoing health and enrichment of both present and future societies. This principle acutely manifests in the preservation of historic mosques, which are more than just places of worship; they are custodians of deep cultural and historical legacies, serving as conduits between the bygone eras and today and hold immense value for subsequent generations. Through their unique architectural designs, these structures echo the cultural identity and heritage of their communities. Given their pivotal role not only in the religious landscape, owing to Islam's historical proliferation, but also as epicentres of education and cultural dissemination, maintaining the integrity of these mosques is critical. This underscores the importance of employing ultrasonic pulse velocity (UPV) testing and building checklist assessment (BCA) to evaluate their condition. By facilitating a thorough and non-invasive examination, these methodologies ensure that conservation efforts respect the mosques' structural and historical integrity while addressing the specific preservation needs without compromising their role in the cultural tapestry of Islamic societies. Thus, in alignment with the broader aim of fostering the cultural and spiritual welfare of communities, as Harun (2011) suggested, the meticulous evaluation and preservation of these timeless edifices with UPV testing and BCA emerge as fundamental actions, as discussed in the following sections.

Ultrasonic pulse velocity

This study leverages non-destructive testing (NDT) techniques, notably UPV testing, to rigorously evaluate the structural integrity and resilience of timber in mosque constructions, identifying a spectrum of damages including voids, cracks and deterioration (Nowak and Nowak 2025), along with similar endorsements from Ettelaei et al. (2019) and Pranata and Tobing (2016), highlighted UPV's utility in determining timber strength and the extent of decay without inflicting damage, aligning with Australian Standard Specifications (ASTM) C597 standards (ASTM International, 2023). By measuring ultrasonic pulse velocities, UPV offers insights into timber's density, MoE and moisture content—crucial parameters for assessing structural health. Low-velocity readings may indicate a decline, signalling the need for potential repairs or reinforcement. Furthermore, UPV's capacity to detect internal defects and assess timber homogeneity underpins ongoing structural monitoring, facilitating early warning of deterioration. This proactive, precise and non-invasive approach ensures the preservation of mosques' architectural and cultural heritage for future generations, underscoring UPV testing's role in maintaining the structural integrity and longevity of these significant edifices.

$MoE_{dyn} = \rho V^2 10^{-6}$

$MoE = 0.899\ MoEdyn$

MoEdyn = Dynamic elastic moduli (MPa)

ρ = Specific gravity (kg/m³)

For Chengal wood, $\rho = 915$ kg/m^{-3} (Forestry Department of Peninsular Malaysia, 2024)

For Ponak wood, $\rho = 560$ kg/m^{-3} (Richter and Dallwitz, 2000)

V = Ultrasonic wave velocity (m/s)

Building condition assessment

The BCA checklists play a critical role in appraising the state and quality of timber mosque structures prior to the initiation of NDT methods that include UPV testing. By conducting a thorough BCA, professionals can conduct a detailed visual inspection to identify visible defects, decay and other areas requiring attention, thereby, pinpointing specific sections for deeper investigation through NDT. This preparatory step is essential in documenting the nature, locations and likely origins of structural defects—ranging from cracks and rot to discoloration and insect damage, facilitating the meticulous selection of NDT techniques aimed at quantifying and evaluating the severity of impairments. Additionally, the preliminary building rating provided by the BCA furnishes a basic impression of the mosque's overall condition, influencing the depth and urgency of subsequent NDT scrutiny. The BCA's consideration of environmental aspects such as ventilation and moisture control further refines the interpretation of NDT outcomes and supports the formulation of effective repair or maintenance plans. Compliance checks against building codes and safety standards ensure adherence to regulatory demands, while the BCA checklist serves as a vital reference, aligning NDT findings with previously noted defects for a well-rounded assessment. Thus, a comprehensive BCA before employing NDT allows for strategic planning, efficient resource utilisation and a holistic approach to the assessment, restoration and conservation of historic timber mosque structures, ensuring their longevity and structural integrity.

METHODOLOGY

The study at Masjid An Nur involved detailed site visits, observations and UPV tests on compromised structural elements. Its aim was to deeply understand the mosque's architecture and history, preparing for further investigation. Data collection was two-pronged: primary data through direct engagement with the site, assessing structural integrity and fault lines and secondary data via literature review for contextual insights. This balanced methodology, supported by a comprehensive checklist, enabled precise identification of defects in the timber structure, including cause and specific location analysis.

During the inspection, a visual inspection or condition survey methodology was utilised to pinpoint the defects in the timber mosque; a strategy that started with the roof and methodically progressed to the exterior facade, ensuring no corner was overlooked. This comprehensive element-by-element evaluation covered critical structural parts such as columns, beams, walls, floors, windows, doors, plinths and stairs. Additionally, valuable historical insights regarding the mosque, like ownership records, construction and completion dates, types of wood utilised and past maintenance activities, were collected. Instruments like the crack metre, equipped with a magnifying lens and a lamp, played a crucial role in these inspections, particularly in measuring crack widths across the timber structures, with 10 divisions of the tool representing a mere 0.2 mm. Timber is prone to cracking due to drying stresses, significantly affecting its structural and aesthetic qualities (Hoadley, 2000). External factors can also influence crack formation. It is essential to manage these cracks to maintain timber's integrity. According to the Australian Standard Specification for Timber by the Standards Australia (2010), heavy structural visually graded cracks should not exceed a width of 3 mm to ensure the material's functionality and appearance are preserved.

Regarding the timber used in the construction of Masjid An Nur in Kampung Patah Pedang, Ponak wood falls under the SG4 category while Chengal wood is categorised under SG1 based on the standard specification by Jabatan Kerja Raya Malaysia (2014). The UPV test, utilising both direct and indirect methods for columns and roof beams, respectively (as shown in Figure 1), involved taking five readings per structure to achieve an average result. To assess the structural health, the MoE was calculated and compared against the MS 544-2:2017 Standards (Department of Standards Malaysia, 2017), which stipulate a minimum MoE of 14,000 Mpa for Chengal wood and 7,600 Mpa for Ponak wood. Structures surpassing these MoE benchmarks are in good condition, thereby, offering a scientific basis for evaluating the structural integrity of the mosque's timber components. This layout is utilised to determine the positions of beams and columns in the mosque. The structural layout plan (as shown in Figure 2) provided the necessary directional indicators, using "C" for columns and "RB" for roof beams, to determine the exact testing positions.

Figure 1. Timber columns at main prayer hall in Masjid An Nur

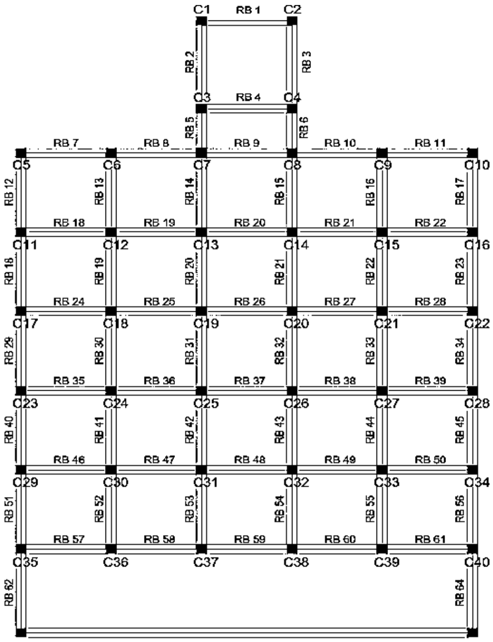

Figure 2. The column and roof beams position for UPV test at Masjid An Nur

This provides the numerical data needed to assess structural performance against the MS 544-2:2017 safety benchmarks (as shown in Table 1), which stipulate a minimum MoE of 14,000 MPa for Chengal and 7,600 MPa for Ponak.

Table 1. Strength group of timbers based on MS 544-2:2017

Strength Group	Condition	Minimum MoE
SG1	Wet	13,300
	Dry	14,000
SG2	Wet	11,700
	Dry	12,600
SG3	Wet	9,800
	Dry	10,300
SG4	Wet	7,400
	Dry	7,600
SG5	Wet	6,100
	Dry	6,300
SG6	Wet	4,900
	Dry	5,200
SG7	Wet	3,000
	Dry	3,400

Data Collection Method

Tables 2 and 3 outline the BCA for data gathering during evaluations, detailing construction elements and defects. These tables break down into sections for identifying defect locations, diagnosing defects (e.g., cracks) and describing specifics like crack width. They also include a priority ranking system from A to E and a summary of these priorities. Table 4 assesses the building's overall condition—ranging from dilapidated to fair or poor—based on average scores. Tables 5 and 6 detail the severity index through multiplier values and analysis, while Table 6 presents the sizes of columns in Masjid An Nur.

Table 2. BCA

No.	Construction Element	Building Survey		Priorities Ranking					
		Defect Diagnosis	Description of Defect	A	B	C	D	E	Total
1									
2									

Table 3. Reference terms for timber defects, priority ranking system

No.	Type of Data	Scale Value	Chronology Value	Linguistic Value
1	Physical condition	0	Repair or replacement is needed in the period of 1 month	Element/structure not functional at all = 2
		1	Repair or replacement is needed for the period of 1 month to 6 months	Serious defect, cannot be functional to an acceptable standard = 3
		2	Repair or replacement is needed for the period of 6 months to 12 months	Functional sound, but need an urgent repair or replacement = 4
		3	Repair or replacement is needed for the period of 1 year to 2 years	Structurally functional, only minor defects = 5
		4	No need for repair or replacement	Free from any visible defects = 6
2	Fabric effects	1	Significant effect	If one element/structure is malfunction, what is the possible effect to the other element/ structure member?
		2	Have effect	
		3	Minor or no effect at all	

(*Continued on next page*)

Table 3. *Continued*

No.	Type of Data	Scale Value	Chronology Value	Linguistic Value
3	User effect	1	Significant effect	If one element/structure is malfunction, what is the possible effect to the other element/ structure member?
		2	Have effect	
		3	Minor or no effect at all	
4	Potential risk	1	Most possible	Risk for structural damage, which in turn can lead to death or injury (If the scale value is "3", the "risk effect" should have the score value of "4")
		2	Possible	
		3	Not possible	
5	Risk effects	1	Death or serious injury	Risk for structural damage or injury
		2	Injury	
		3	Minor injury	
		4	No risk associated	

Source: Che-Ani et al. (2008)

Table 4. Condition assessment of the building

Condition	Linguistic Value	Average Marks
Condition 1: Dilapidated	Not safe for occupancy	4 to 9
Condition 2: Fair	• Sign of defect in structural member (no effect on building stability) • Needs repair or replacement	10 to 13
Condition 3: Poor	• Main structural member is strong and stable • Defects that influence aesthetic value only	14 to 17

Table 5. Multiplier value

Score	Multiplier	Accumulate Multiplier
1	0.25	1.00
2	0.25	0.75
3	0.25	0.50
4	0.25	0.25

Table 6. Sizes of columns in Masjid An Nur

Size (m)	Code
0.16 × 0.17 × 5.00	C10 and C16
0.18 × 0.17 × 5.00	C28, C34, C23, C29, C16, C22 and C36
0.21 × 0.25 × 5.00	C11, C17 and C35
0.15 × 0.15 × 5.00	C40, C45, C1, C2, C7, C8, C38, C44 and C50
0.15 × 0.15 × 7.00	C12, C13, C14, C15, C18, C24, C30, C31, C32, C33, C27, C21 and C15
0.15 × 0.15 × 10.00	C19, C20, C25 and C26
0.14 × 0.14 × 5.00	C37, C41, C6, C3, C4 and C1
0.14 × 0.16 × 5.00	C46, C47 and C48
0.15 × 0.14 × 5.00	C42, C43, C49, C5 and C39

RESULTS AND DISCUSSION

The structural evaluation of Masjid Jamek An Nur, as detailed in Table 7, reveals a facility categorised in Condition 2 (Fair). While primary members remain stable, the BCA identified 26 distinct defects yielding a cumulative priority score of 362. Numerical analysis identifies five specific columns as the primary safety risks to the mosque's integrity. First, critical safety violations regarding crack widths were recorded in columns C10 (4.30 mm) and C21 (7.00 mm). As illustrated in Table 8, both columns significantly exceed the 3 mm safety threshold mandated by ASTM. Second, severe structural failures were identified through non-destructive testing in columns C2, C23 and C42. These elements failed to meet the minimum MoE requirement of 7,600 MPa stipulated by MS 544-2:2017. These findings underscore an urgent requirement for targeted preservative treatments to prevent localised collapse of this cultural artifact.

Table 7. Analysis of building survey and priority timber defects

No.	Construction Element:	Building Survey		Prioritise Ranking (Refer Terms of Reference)					
	Column (C); Roof Beam (RB)	Defect Diagnoses Causes	Description of Defect	A	B	C	D	E	TOTAL
1	C2	Beetles (woodworm)		3	3	2	3	4	15
2	C10	Crack (average = 1.60 mm)	2.45 mm 0.75 mm	3	2	2	3	4	14
3	C11	Knot		4	3	3	3	4	17
4	C15	Crack (average = 0.50 mm)	Length = 0.90 m 0.60 mm 0.40 mm	4	3	3	3	4	17
5	C18	Beetles		4	3	3	3	4	17
6	C19	Termites/crack	Length = 6.10 m 5.00 mm 1.00 mm 0.80 mm	4	3	3	3	4	17
7	C20	Crack	2.65mm	4	3	3	3	4	17
8	C21	Decay/crack	Length = 7.62 m 10.00 mm 5.00 mm 6.00 mm	2	2	2	2	3	11
9	C23	Dry rot	45.00 mm × 70.00 mm	2	2	2	2	3	11
10	C25	Crack	Length = 9.0 m 0.20 mm 0.45 mm 0.50 mm	3	3	3	3	4	16

(*Continued on next page*)

Table 7. *Continued*

No.	Construction Element:	Building Survey		Prioritise Ranking (Refer Terms of Reference)					
	Column (C); Roof Beam (RB)	Defect Diagnoses Causes	Description of Defect	A	B	C	D	E	TOTAL
11	C26	Cracks/beetles	1.40 mm	4	3	3	3	4	17
12	C27	Cracks (Average = 0.33mm)	0.20 mm 0.30 mm 0.50 mm	4	3	3	3	4	17
13	C28	Beetles		4	3	3	3	4	17
14	C30	Cracks	0.80 mm	4	3	3	3	4	17
15	C32	Fungi		4	3	3	3	4	17
16	C34	Dry rot	40.00 mm × 4.50 mm × 3.50 mm	3	3	3	3	4	16
17	C42	Dry rot		3	2	2	2	3	12
18	Wall (C1/C3)	Peeling of paint		4	3	3	3	4	17
19	Wall (C3/C7)	Wane		4	3	3	3	4	17
20	Wall (C9/C10)	Knot		4	3	3	3	4	17
21	Wall (C1/C3)	Peeling of paint		4	3	3	3	4	17
22	Frame (C1/C2)	Dry rot		3	3	3	3	4	16
23	Wall and Door (C3)	Fungi		3	3	3	3	4	16
24	Roof (C8)	Termites		3	3	3	3	4	16
25	Roof (C8)	Termites		3	3	3	3	4	16
26	Settlement (at the door)	Settlement		3	2	2	2	3	12
	Total								362

Table 8. Frequency and severity index on Masjid An Nur's structures based on defect types

Types of Defect	Frequency (Raw)	Frequency (%)	Average Score of Risk Effect	Accumulate Multiplier	Severity Index (Raw)	Severity Index (%)
Beetles	4	13.79	4.0	0.25	3.45	8.51
Peeling of paint	2	6.90	4.0	0.25	1.73	4.27
Fungi	2	6.90	4.0	0.25	1.73	4.27
Wane	1	3.45	4.0	0.25	0.86	2.12
Knot	2	6.90	4.0	0.25	1.73	4.27
Check	9	31.03	4.0	0.50	15.52	38.27
Decay	5	17.24	3.4	0.50	8.62	21.26
Termites	3	10.35	3.0	0.50	5.18	12.77
Settlement	1	3.45	3.0	0.50	1.73	4.27
Total	29				40.55	

Figure 3 illustrates the width of cracks at the mosque. The lines on the chart indicate that the highest width of cracks is at the C10 position, measuring 4.3 mm and C21 has a width of 7 mm, exceeding the allowable crack line permitted for timber building, which is 3 mm. The dark blue represents C10, yellow corresponds to C20, blue-black indicates C27, orange represents C15, maroon is for C30, grey corresponds to C19, green is C25 and finally, red represents the allowable crack based on the Australian Standard.

Figure 4 shows the UPV test results for the column structure at Masjid An Nur. The delivery method used in conducting this test is the direct method. The minimum level of MoE based on the Malaysian Standard (MS 544-2:2017) for SG4 is 7,600 MPa. Based on the results obtained, there are three columns that are in a weak condition. It is because these columns did not exceed the minimum level of SG4 which is C23 (5,058 MPa), C2 (5,239 MPa) and C42 (6,692 MPa) and column C23 recorded the lowest among others. Next, column C21 exceeded the MoE minimum level with 7,668 MPa. In contrast, column C18 recorded the highest integrity at 17,754 MPa, followed by C19 (17,456 MPa) and C25 (16,721 MPa). Most remaining columns displayed robust MoE values ranging from 10,000 to 16,000 MPa. Specifically, it identifies that while most elements are "Good", three columns (C2, C23 and C42) are "Weak" because they fell below the 7,600 MPa threshold.

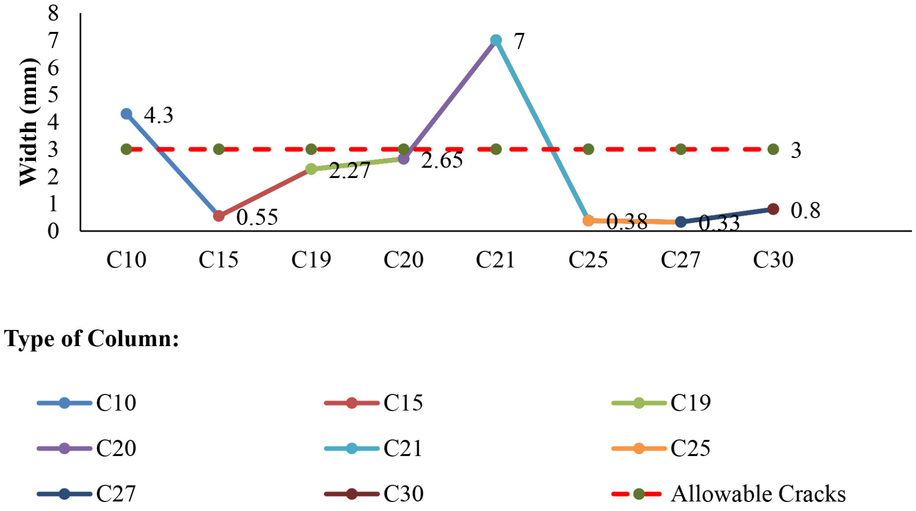

Figure 3. The defect detected in the mosque structure

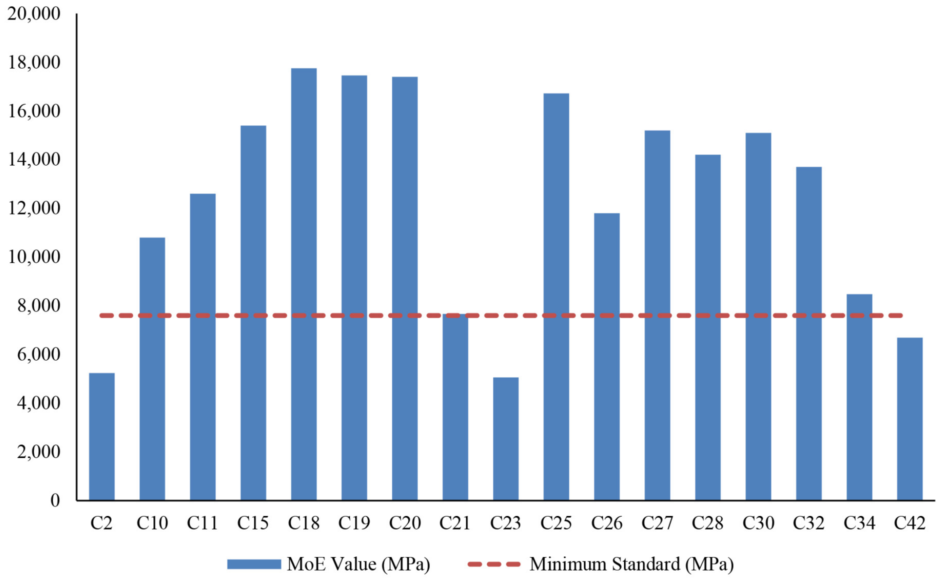

Figure 4. MoE distribution level for Masjid An Nur columns relative to SG4 minimum standard benchmarks

Figure 5 shows the UPV test results for the roof beam structure at Masjid An Nur. For the roof beam, the delivery method for the UPV test is indirect method. Based on Figure 8, it was found that all roof beams passed the minimum MoE which is 7,600 MPa and are in a good condition. The roof beam that has the highest MoE value is RB 17 which is 16,721 MPa followed by RB 40 which is 16,287 MPa. Next, the third highest value is 16,002 Mpa which is RB 58 and followed by RB 23 with a MoE value of 15,021 MPa. The roof beams that obtain MoE values in the range of 10,200 Mpa to 13,600 MPa are RB 1, RB 9, RB 7, RB 11, RB 18 and RB 51. Lastly, RB 56 recorded the lowest MoE value with 10,156 Mpa.

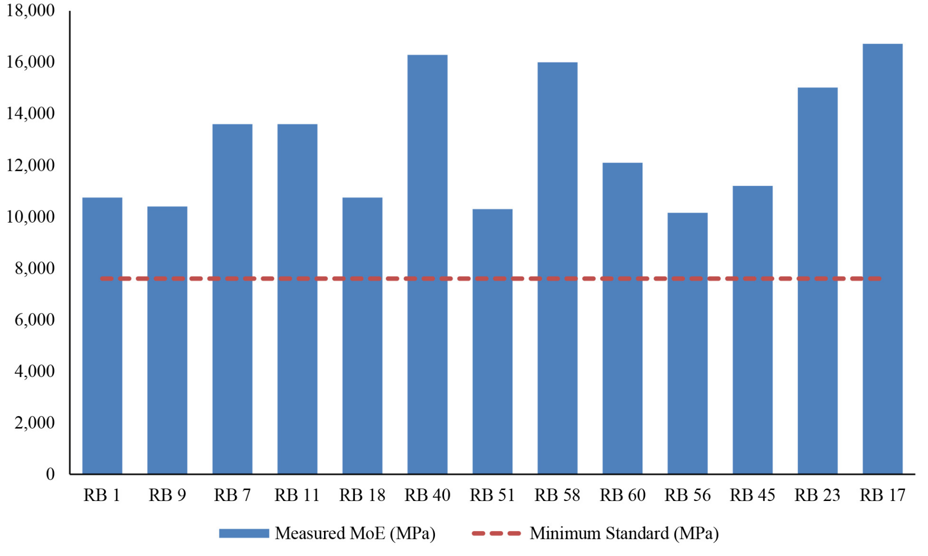

Figure 5. Comparative analysis of roof beam MoE results identifying consistent structural integrity compliance

CONCLUSION

In this investigation, UPV testing was conducted on timber column and beam structures showing damage such as decay, checks, knots and fungi. The primary objective was to ascertain the MoE of the timber, with higher MoE values indicating stronger timber. The results revealed significant variations in MoE values between the two mosques under study, due to differences in wood types, damage levels and structural heights of the beam and column structures.

Table 7. *Continued*

The analysis identified three columns at Masjid An Nuras compromised, failing to meet the minimum MoE threshold of 7,600 MPa stipulated by the Malaysian Standard (MS 544-2:2017). The lowest MoE readings were 5,058 MPa, 5,240 MPa and 6,691 MPa for columns C23, C2 and C42, respectively – all of which exhibited decay. Structural height was also found to affect the timber's strength, with columns at higher elevations being more vulnerable.

At Masjid An Nur, 26 timber defects were identified, with cracks/splits and beetle attacks being the most common, followed by various types of rot and a single instance of termite attack. These defects were most prevalent in the mosque's interior, particularly in columns C21 and C23, which showed significant weather-related damage like cracks and dryness. Despite these issues, the mosque was classified as being in fair condition overall, as determined by a severity index analysis. Cracks were the most critical defect, occurring at a frequency of 38.27%. However, cracks wider than the Australian Standard of 3.0 mm—specifically at 4.3 mm and 7.0 mm on columns C10 and C21, respectively—highlight the need for regular monitoring, maintenance and timely repairs to maintain the structural integrity and safety of the mosque.

To further enhance the generalisability of these findings and recommendations, future research should include additional case studies of similar timber mosques. By expanding the scope of the study to encompass a variety of timber mosque structures, researchers can provide comparative insights that may strengthen the conclusions drawn from the Masjid Jamek An Nur analysis. This broader approach will enrich the understanding of preservation strategies and contribute to the development of more robust guidelines applicable to a wider range of timber mosque constructions.

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REFERENCES

Ahmed, F. (2019). Defects in timber: Defect types and causes. Available at: https://civiltoday.com/civil-engineering-materials/timber/85-defects-in-timber-types-and-reasons [Accessed on 27 October 2024].

Asdrubali, F., Ferracuti, B., Lombardi, L., Guattari, C., Evangelisti, L. and Grazieschi, G. (2017). A review of structural, thermo-physical, acoustical and environmental properties of wooden materials for building applications. *Building and Environment*, 114: 307–332. https://doi.org/10.1016/J.BUILDENV.2016.12.033

ASTM International (2023). *Standard Test Method for Ultrasonic Pulse Velocity Through Concrete (ASTM C597-22)*. West Conshohocken, PA: ASTM International.

Che-Ani, A.I., Ramly, A., Mohd-Zain, M.F.M., Mohd-Tawil, N. and Hashim, A.E. (2008). Assessing the condition of traditional Khmer timber houses in Cambodia: A priority ranking approach. *Journal of Building Appraisal*, 4(2): 87–102.

Department of Standards Malaysia (2017). *MS 544-2:2017: Code of Practice for Structural Use of Timber: Permissible Stress Design of Solid Timber*. Cyberjaya, Malaysia: Department of Standards Malaysia.

Ettelaei, A., Layeghi, M., Hosseinabadi, H.Z. and Ebrahimi, G. (2019). Prediction of modulus of elasticity of poplar wood using ultrasonic technique by applying empirical correction factors. *Measurement*, 135: 392–399. https://doi.org/10.1016/j.measurement.2018.11.076

Forestry Department of Peninsular Malaysia (2024). Density and properties of Chengal wood. Available at: http://www.forestry.gov.my [Accessed 15 October 2024].

Harte, A. (2009). Introduction to timber as an engineering material. In M.C. Forde (ed.), *ICE Manual of Construction Materials*. London: Institution of Civil Engineers, 1–9.

Harun, S.N. (2011). Heritage building conservation in Malaysia: Experience and challenges. *Procedia Engineering*, 20: 41–53. https://doi.org/10.1016/j.proeng.2011.11.137

Hoadley, R.B. (2000). *Understanding Wood: A Craftsman's Guide to Wood Technology*. 2nd Ed. Newtown, CT: Taunton Press.

Jabatan Kerja Raya Malaysia (2014). *Standard Specifications for Building Works: Schedule of Timber Species in Accordance with Strength Grouping (S.G)*. Kuala Lumpur, Malaysia: Government of Malaysia.

Johar, S., Yahiya, H., Che-Ani, A.I., Mohd Tawil, N. and Ahmad, A.G. (2013). Defects investigation in old timber building: Case study of Masjid Lama Mulong, Kelantan. *Research Journal of Applied Sciences, Engineering and Technology*, 12: 3354–3358. https://doi.org/10.19026/rjaset.5.4579

Klasson, A., Björnsson, I., Crocetti, R. and Hansson, E.F. (2018). Slender roof structures: Failure reviews and a qualitative survey of experienced structural engineers. *Structures*, 15: 174–183. https://doi.org/10.1016/j.istruc.2018.06.009

Mustafa, N.K.F., Johar, S., Ahmad, A.G., Zulkarnain, S.H., Rahman, M.Y.A. and Ani, A.I.C. (2011). Conservation and repair works for traditional timber mosque in Malaysia: A review on techniques. *International Journal of Humanities and Social Sciences*, 5(5): 663–668.

Nowak, T. and Nowak, K. (2025). Prevention of failure of heritage buildings through diagnostic testing using the example of testing of roof structure elements from the 15th century. *Engineering Failure Analysis*, 178(3): 109709. https://doi.org/10.1016/j.engfailanal.2025.109709

Pranata, Y.A. and Tobing, H.L. (2016). Non-destructive testing to obtain the dynamic elastic modulus of the existing Minangkabau wooden house. In *International Conference on Technology, Innovation, and Society (ICTIS)*. Padang, Indonesia: ITP Press, 389–393. https://doi.org/10.21063/ictis.2016.1060

Richardson, B. (2002). *Defects and Deterioration in Buildings: A Practical Guide to the Science and Technology of Material Failure*. 2nd Ed. London, England, UK: Spon Press.

Richter, H.G. and Dallwitz, M.J. (2000). Commercial timbers: Descriptions, illustrations, identification, and information retrieval. 4 May. Available at: http://biodiversity.uno.edu/delta/ [Accessed 15 October 2024].

Shahrir, N.A. and Rahman, M.A.A. (2021). A study on common defect of heritage mosque in Kedah, Malaysia. *Progress in Engineering Application and Technology*, 2(1): 464–469.

Standards Australia (2010). *AS 1720.1–2010 Timber Structures: Design Methods*. Sydney, NSW: Standards Australia.

Tchamba, J.C. and Bikoko, T.G.L.J. (2016). Failure and collapse of building structures in the cities of Yaoundé and Douala, Cameroon from 2010 to 2014. *Modern Applied Science*, 10(1): 23–33. https://doi.org/10.5539/mas.v10n1p23

Żmijewki, T. and Wojtowicz-Jankowska, D. (2017). Timber: Material of the future; Examples of small wooden architectural structures. *IOP Conference Series: Materials Science and Engineering*, 245(8): 082019. https://doi.org/10.1088/1757-899X/245/8/082019