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Abstract
Traditional heritage architecture is an important part of society's heritage that is presently threatened by destruction, extinction, and ambiguity in modern times. However, to this day, areas on the various branches of Malay wisdom in building technology have received little attention and promotion. While previous research has widely demonstrated the different typologies of Malay architecture, the variation or diversity of typologies according to state distribution is often dominated by prominent carpenters or locally referred to as 'tukang' such that each area has its own set of carpenters. For instance, a Malay house system without nails, dubbed 'Joinery' and 'Mortise' is among (100) the innovative technology architecture, which serves as the primary method of wood consolidation employed in the traditional Malay architecture. ‘Mortise’ is generally used to join two basic components of a building to form the building's main structure that includes the floor, walls, and roof. However, only a few studies in Malaysia have explored mortise and tenon as a branch of sustainable design because the discussions are mostly concentrated on the methods and techniques of mortise fabrication in the broader discipline of architecture. Hence, this work aims to overcome this knowledge gap through data documentation initiatives on mortise types and techniques associated with different construction periods. Along with the building's age, mortise categories and techniques are further classified according to their application. This study outlines two primary objectives: i) to identify the types of mortise and tenon joints found in Rembau heritage houses and ii) to assess the placement and function of mortise and tenon. Using a descriptive approach, a qualitative investigation was undertaken on ten residences over 100 years old, located in the Rembau district of Negeri Sembilan. The current

study demonstrates four distinct mortise types that are further grouped into four distinct designs: (i) repeated perforated component mortise; (ii) perforated component mortise, (iii) partially perforated component mortise, and (iv) non-perforated component mortise. Various mortise and tenon types and applications were also discovered in all of the house designs examined in this study; hence, it can be deduced that the main functions of joint in timber construction can be seen in terms of structural strength, component continuity, the flexibility of use in reducing construction costs, and consolidation of various parts of the building. Indeed, the types of mortise and tenon joints are not influenced by the roof type or house typology. Overall, the findings can increase awareness of the unique characteristics of Malay architecture, including the possibility for technological advancement in contemporary wood building construction.

Keywords: Traditional architecture, Mortise and Tenon, Typology.

1 Introduction

1.1 Timber Construction & Structures in Malay Houses

Architecture is a manifestation of a society's worldview. In this region, the traditional Malay architecture is greatly influenced by climate, geography, socio-culture, local tradition, and belief system such that each aspect expresses an in-depth appreciation of the local genius loci. Environmental elements are also meticulously articulated in the traditional Malay architecture, symbolizing the unity of the society with the environment, both physically and spiritually [1]. In general, the designs of traditional Malay architecture are unique in different regions or states. This includes the unique architecture in Malay houses without the nails consolidation system called 'mortise and tenon', which is the main consolidation method of the wood used in traditional buildings. Mortise serves to connect two small components of a building to form the main structure of the building such as the floor, walls, and roof. Amidst the differences, several similar features can also be analyzed and observed from different dimensions. For instance, the physical design of the traditional and vernacular Malay architecture includes the use of a suspended floor supported by pillars, which is best known as stilt houses.

Timber Construction. Branches of trees laid against one another and tied together to form free-standing structures were the earliest building materials used by the first inhabitants in the Malay world, and this includes the use of palm leaves to cover the roof of the house. As time went by, post and beam became the basic structural system of traditional timber houses in Malaysia. The database collection through photographs, illustrations, and measured drawings from KALAM, UTM describes the timber structure development of traditional Malay houses across Malaysia. The indigenous structures using locally available materials have characteristic features in terms of construction by which they are held together through a variety of jointing and mortising techniques, reinforced by pegging or wedging without nails. Hence, these characteristic

features serve as the indigenous characters of the traditional architecture in Malaysia [2].

Timber Structures. The main house (rumah ibu) and the kitchen (rumah dapur) in traditional Malay houses are the larger of the two units, with three or four larger bays lengthwise and three almost equally divided bays in cross section. The basic building units are built with the king post trussed roof system and a rectangular frame. By using wedges or pegged mortise and tenons, the pre-formed timber structural components are assembled together [3].

The construction of these basic units, which reflects the traditions of a particular region and varies in scale, proportion, and form of buildings, can be achieved through different combinations or arrangements. For instance, the planning of timber structures and the grid technique allow for the flexibility of internal structures to be added later according to need. The additions can be attached without interference to the existing structure and can be dismantled without causing damage [4]. Using timber wedges, the building depends on its strength in the complex jointing system.

Timber Structural System (Timber Floor and Roof Framing System). A series of floor joists supported by bearers is constructed at the suspended timber floor and the vertical stress of the weight is exposed to the floor joists. From the floor to the post, the live and dead loads are transferred directly to the plinths, while 25 mm thick timber boards are laid directly across the floor joists. The use of wedges (baji) is also an important feature of the Malay timber architecture to tighten mortise and tenon joints so that they can be reassembled and taken apart easily without damaging the building. Besides, in hot humid climates, the raised platform floor provides sub-floor ventilation and shaded spaces [5]. Within the basic construction system, the roof skeleton framing system is beneficial because all different lengths can be spanned with equal-sized members. While the layout of the floor and roof plane determine the building forms within the primary structural grid, the span and direction of the floor joists take the position and directions of the bearers. Roof structure posts are anchored in the ground and the roof frame is governed by the spacing. In a simple bracing, the centre post is fixed; nonetheless, the only rigid components and transverse are these triangular supports [6].

In this work, discussions on the typology of mortises are based on the types of mortises used in Traditional Malay Houses as evidenced by past studies, while the nature and characteristics of mortises are discussed in reference to the design of a specific mortise and the strengths of its structure.

Roof and Space Designs. Malay house types can be divided according to the typology of the roof and its space. Basically, there are three types of roofs, namely ‘bumbung panjang’ (gable roof), ‘bumbung limas’ (‘rabung lima’ roof), and ‘bumbung meru’ (pyramid-like roof). In addition, there are also several variations of roof designs with a certain style depending on its territory such as ‘bumbung lentik’, ‘bumbung gajah menyusu’, and ‘bumbung limas potong perak’. Although there is a difference in design between all traditional houses in the Malay world, they are generally in harmony with nature and mankind. Almost all architectural styles in the Malay world feature

‘kediaman berlubang’ or ‘cerucuk’, with high and open interiors and openings that allow for excellent cross ventilation [7]. Its high and steep roof design allows for smoother rainwater flow and is one of the main features of the Nusantara architecture style in facing the hot and humid tropical weather. However, the traditional house of Negeri Sembilan has its own uniqueness that is not found in other states.

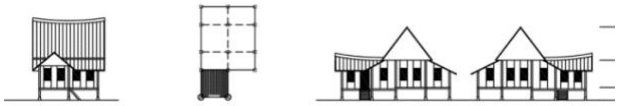
2 Typology of Malay Traditional Houses in Malaysia

Generally, the design of the Malay world architecture differs from one another. The difference is influenced by the history, social, and culture of a place. A clear similarity that exists in the physical design of traditional and vernacular architecture in the Malay world is the construction of stilt houses supported by pillars or better known as ‘rumah panggung’ or ‘rumah bertiang’ [8]. The design of stilt houses with space underneath is called ‘kolong’. In addition to safety factors, the spacious area under the house is often used to store goods or to relax during tropical heat. ‘Kediaman cerucuk’ or ‘rumah panggung’ is the main identity of traditional Malay houses. In traditional Malay architecture, the process of building the main pillar (‘tiang seri’) is a very important event. It represents the strength or wholeness of a house. ‘Tiang seri’ is the first to be constructed in the process of building a house [9].

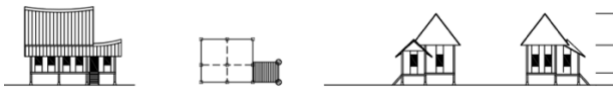
2.1 Typology of Negeri Sembilan Traditional Houses

The uniqueness of Negeri Sembilan traditional houses can be seen through the long roof, which is slightly curved on the left and right. Besides, the traditional houses have several columns called ‘tiang’ 9, 12, 16, 20, and 24 according to the house area. These traditional houses (Figure1), which are passed down from generation to generation, are divided into 8 types according to ‘serambi’ and ‘anjung’ (the Malay verandah):

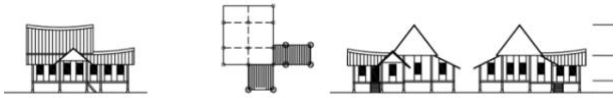
1) Rumah Berserambi Tengah



2) Rumah Berserambi Tengah Beranjung

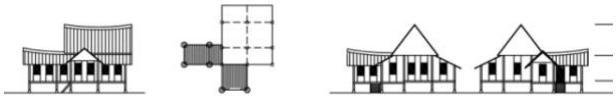


3) Rumah Berserambi Pangkal

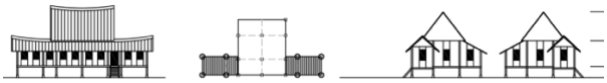


4) Rumah Berserambi Pangkal Beranjung

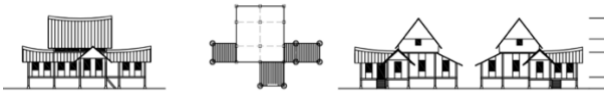
5) Rumah Berserambi Hujung



6) Rumah Berserambi Hujung Beranjung



7) Rumah Berserambi Dua



8) Rumah Berserambi Dua Beranjung

Fig. 1. Eight (8) Typology Negeri Sembilan Traditional Houses [10].

3 Introduction Mortise & Tenon Joints Structural System In Malay Traditional Houses [Literature Review]

Each heritage house from 14 states in Malaysia has its own uniqueness and speciality in reference to the diversity of religious, racial, and cultural backgrounds (Figure 2). Each state also has its own cultural practices and religious rituals and this has produced a variety of architectural styles that are so unique throughout the generations [11]. Cultural elements such as lifestyle, customs, religion, beliefs, and social values of

society have impacted the equivalence and unique design of the architecture of the local community heritage houses in Malaysia (Figure 3).

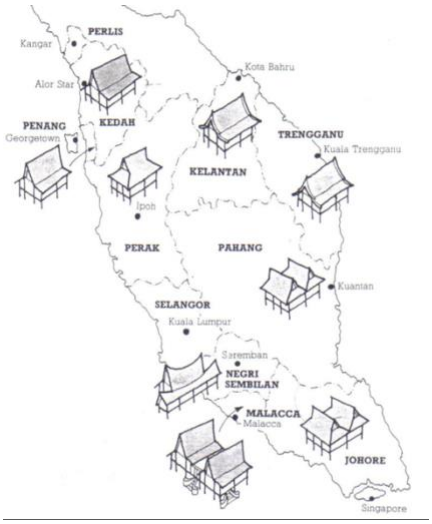


Fig. 2. Distribution of traditional house architecture in the Peninsular Malaysia [12].

There are various forms and planning in terms of the construction of a building due to the cultural influence and elements [13]. This diversity also occurs due to the use of building materials including the local climate, construction techniques of existing building material structures, skills of the 'tukang' (carpenter), or technology available at the time [14].

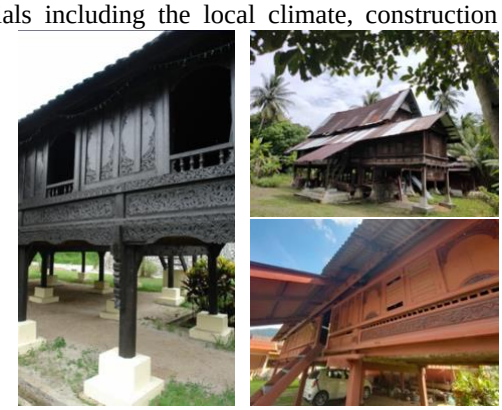


Fig. 3. The uniqueness of the architectural design of heritage houses local communities in Malaysia

A well and neatly designed mortise and tenon joint (‘tanggam’) structure that can easily be installed or removed one by one for renovation and subsequently re-installed has been vanishing and left behind due to the weakness of the nation that does not care about its own culture, along with the transformation into the original typology of the local architectural heritage [15]. The current work will discuss the mortise and tenon used in the traditional construction in Malaysia and overseas for a more holistic comparison towards upholding the nation's heritage.

3.1 Works Related to Mortise and Tenon on Buildings

To date, there has been no literature that specifically discusses the type and typology of the joint structural system of heritage houses in Negeri Sembilan, especially in the Rembau district. A study by Azmal Sabil and Nangkula U. (2013) entitled “Documentation and Analysis of Sustainable Design and Application of Tanggam System in Malay Traditional House” emphasizes the results of the typological mapping, showing the direct relationship between the design and the strength of mortise and tenon joints based on the data obtained from KALAM, UTM. Kamarul Afizi Kosman, Hamdzun Haron, Azimin Samsul Mohd Tazilan, and Nor Affian Yusof (2018) explained the system of the mortise and tenon structure construction for the design of Malay house architecture in general, but it is not specific to Negeri Sembilan. Meanwhile, Nurul Hamiruddin Salleh and Srazali Aripin (2018) found the typology of the mortise and tenon structural system found in Kutai house (‘Rumah Kutai’) in particular and Malay traditional houses in general. One of the works written by Mastor Surat entitled "Traditional Tanggam System - Its Use in the Architecture of Rumah Tiang Dua Belas in Kelantan" (1986) also focuses on the direct application of mortise and tenon in buildings. He explained its use in the main parts of traditional buildings in Kampung Laut Old Mosque, Istana Balai Besar, Istana Seri Akar, Kampung Pulau Panjang Malay Houses, Kampung Langgar Old Mosque, and Rumah Meleh Hajah Wan Mek, which includes the use of ‘tanggam’ on floors, columns, walls, and roofs. The use of mortise and tenon joints in floor construction was explained in three main sections, the floor structure, floor frame, and ‘bendul dan belira’ (the cross-beam supporting the floor). On the floor frame that consists of ‘gelegar’ (floor joists), ‘geta’, and ‘rasuk’ (floor beam), the author listed various types of mortise and tenon joints found in the construction of this structure. Some are known as ‘tanggam lekap’ and ‘tanggam lubang’, while the one used for the ‘bendul’ is known as ‘tanggam serong’.

In discussing the use of mortise and tenon in the construction of roofs, the author divided the main roof structure in certain parts that include ‘alang’, ‘tutup tiang’, ‘tapak alang’, ‘tutup kasau’, ‘tunjuk langit’, ‘buah butung/buton’, ‘kasau jantan’, ‘kasau lintang’, ‘tulang rabung’, ‘tutup tumpu kasau’, and ‘pemeleh’. According to the author,

all of these parts use mortise and tenon joints known as ‘tanggam lekap’ and ‘tanggam lubang dan puting’. Meanwhile, the author classified the wall components that serve as a barrier and building openings.

Some of the works discussing the use of mortise and tenon in traditional Malay buildings include a book written by Zulkifli Hanafi entitled “Construction of a Traditional Malay Building” in 1996. Generally, this book discusses the specific components that form the basis of Malay houses. The Malay house construction structures include the main structures, including roofs, floors, walls, stairs, joint system, openings at home, and decorations used in Malay houses. At the end of the discussion, the author also explained the tools used in the construction of traditional Malay buildings. Zulkifli Hanafi classified ‘tanggam’ as one of the joint systems between traditional Malay buildings in addition to the jointing technique used to combine components in these buildings. In his work, he explained the commonly used notions in joint components in the main structures of the buildings. These joints include ‘rasuk’ to ‘tiang’ (beam to column) (‘tanggam tebuk’), ‘alang’ to ‘alang’ (tie-beam to tie-beam) (‘tanggam lekap tebuk’; ‘tanggam lubang dan puting’), ‘bendul’ to ‘bendul’ (sill to sill) (jointing of ‘tanggam lubang’ and ‘tanggam runcing’), ‘kasau’ to ‘alang’ (rafter to beam) (‘tanggam berparit’), ‘dinding’ to ‘tiang’ (wall to column) and ‘tetupai’ (cleat) (‘tanggam berparit’). Meanwhile, ‘tanggam temu’ was used for the construction of floors.

‘Tanggam berparit’ is used to combine with timbers vertically and horizontally. In addition, ‘tanggam lekap’ is another basic mortise and tenon that is commonly used to join two short timbers. ‘Tanggam berparit’ has three main types: ‘tanggam parit tepat’, ‘tanggam bajang berparit’, and ‘tanggam parit bertakuk’. Others include ‘tanggam tebuk’ that is rarely used in modern construction but serves as the main mortise and tenon system in traditional Malay construction. It is also used to connect and support the main structure of the building, such as between ‘rasuk’ and ‘tiang’ (beam and post). The system for upright straight jointing is called ‘tanggam runcing pepenjuru’, which is commonly used in ‘bendul’, ‘tumpu kasau’, and many other joints. ‘Tanggam lubang dan puting’ is also unique due to its ability to prevent the joint of home components from moving. The last mortise and tenon type discussed in his book is ‘tanggam lidah dan alur’, which is used for the construction of floors and walls.

3.2 Types of Mortise and Tenon Joints and Their Uses

“Conceptual Modular System in Traditional Malay House” by Siti Aisyah Muhammad, Shah Nor Basri, and Nordiana Ab. Jabar (2018) has added the idea of replacing timber with alternative materials that fit the aesthetic value and identity of Malay houses. There is high potential in terms of the implementation of the modular system of traditional Malay houses in the current housing industry because the IBS has already been produced in Malaysia. The modular concept of the traditional Malay housing system will enhance the issue of the traditional Malay house identity in future development. Replacing timber as the main material from traditional Malay houses will serve as

alternative materials such as cement replacements and pre-printed concrete, which may suit the aesthetic value and identity of Malay houses.

Artur O. Feio, Paulo B. Lourenco, and Jose Saporiti Machado (2013) in their work entitled "Testing and Modelling of a Traditional Timber Mortise and Tenon Joint" studied the density and resistographs recommended for qualitative assessment of timber elements that contribute to the concept of prefabricated heritage buildings. Ultrasonic testing provides a reasonable correlation for joint strength. The results also showed that the velocity of ultrasonic pulses through the joints provides a reasonable estimate for the stiffness of the joints or the effectiveness of assembly between rafters and braces. In addition, a new linear regression has been proposed for the joints of interconnected chestnut mortise and tenon. The parameter that affected most of the ultimate load of the timber joint is the compressive strength of wood, which is perpendicular to the normal stiffness of the interface elements representing the contact between rafters and braces. It is different in Malaysia, which only uses the system in this study on the development of mortise and tenon joints.

Wai Sung Wong (1995) in "Malaysian Timber Construction and Structures" documented the use of timber structures in architecture and buildings into software for the importance of the design and construction of traditional Malay houses. Archive materials related to the use of timber are found to be very limited and incomplete. The main purpose of the study is to provide a broad overview of the influences that have shaped the timber usage structure in Malaysia from the 15th century until the present. Timber-related research is also more global and not specific to the consolidation of mortise and tenon structures in heritage houses in Negeri Sembilan or Malaysia.

Among the comparative studies that serve as a reference example of international research contributing to the jointing of the timber structure of mortise and tenon joints include Manqing Cao (2017), entitled "A Comparative Study of Traditional Jointing Techniques," which made a comparison of vernacular timber houses in New England and Jiangnan in the framing and jointing techniques with the function of wood joints as the basis for comparison with a fundamental consideration of different building cultures. Thus, two buildings - Horton House and Yin Yu Tang house - were chosen as traditional vernacular building paradigms in New England and Jiangnan. A detailed comparison was made between the method of framing and wood joints, as well as the solution to how the joints accomplished their building tasks. A similar study can be done for the mortise and tenon joint structural system in Malaysia to compare vernacular timber houses with different typologies including the related factors and how such designs affect the strength and age resistance of a traditional building.

Hua Ma, Xinyu Luan, Zhenbao Li, Haijian Cui, Wenjing Wang, and Jia Song (2019) in "Seismic Performance of Damaged Dovetail Joints with Different Damaged Degrees in Timber Frames" highlighted mortise and tenon as the main jointing form used in ancient wooden buildings, while the damaged joints have a critical impact on the safety of wooden structures. There are three main dovetail joint damage cases: pulling,

contraction, and mixing. In this study, using a theoretical analysis of the stress distribution in a mortise and tenon joint resulted from the pulling damage, a theoretical equation for the resisting moment of the joint was proposed. A finite element model was used to simulate the cyclic displacement loading of a frame with intact joints and with different levels of pulling and contraction damaged joints. The results showed that the moment capacities both for the test and the simulation were in good agreement with each other. The simulation results also showed no changes in the capacity and energy dissipation of the pulling damaged joint compared to the intact joint, and good seismic performance remains when the pulling damage was less than 2/5 of the joint length. However, the capacity of the contraction damaged joint was significantly reduced, and its seismic performance is lost. The seismic performance of a mixing damaged tenon with the same level of pulling damage was among the damaged tenons. The friction between the tenon and the mortise is the main source of resisting moment and energy dissipation ability. This study is more inclined to the concept of the consolidation of construction structures in earthquake areas, which have a comprehensive impact on the study and is different from Malaysia.

"Wood Joints in Classical Japanese Architecture" by Torashichi Sumiyoshi and Gengo Matsui (1990) emphasized the joint methods of traditional Japanese architecture with high technology together with full pictures and diagrams to show each other's relationship and to ensure that this skill will reach the next generation holistically. These methods can also be applied to contemporary buildings. Such methods are not found in the traditional mortise and tenon joint system in Malaysia as they are more detailed, innovative, robust, and stronger than the mortise and tenon joint system in Malaysia, which can be used to guide the current work.

Yulianto P. Prihatmaji, Akihisa Kitamori, and Kohei Komatsu (2014) reviewed the post-earthquake at the Javanese Joglo wooden house as a result of the Yogyakarta earthquake on May 27, 2006, in Java, Indonesia. Investigations on 20 damaged Joglo buildings indicated that the structural damage can be classified into 3 categories: slipping between column and concrete foundations, broken joints between outer ring beams and columns, and collapse of core structures. Four degrees of damage were defined: I) damage to the base joints of the side structure, II) fatal damage to the side structure, III) destroyed core structure, and IV) collapsed core structure. The side structure is rather weak, while the core structure can still guarantee the performance of the Joglo building structure. Different relationships have been identified between the extent of structural damage and the broad ratio of the core structure and the projection of the main column. This study confirms that the structural parts significantly contributed to the assessment of the damages. Joint failure represents an important point in terms of the maximum retention for conservation. This work provides suggestions for the maintenance of valuable structures from future earthquakes. Clearly, the mortise and tenon joint method can overcome structural problems during earthquakes and this can be referred to from this study.

Ronald W. Anthony (2019) in “Preservation Engineering and Timber” featured the timber preservation engineering method and covered the sustainability issues critical to the research and infrastructure needs of the United States in terms of economic competitiveness, health protection, life and property, and infrastructure reform. Research is needed to extend the lifespan of existing timber structures, especially in identifying unseen deterioration, planning structural repairs, and understanding the jointing and behavioural capabilities of the system. The study shows that the protection and conservation of mortise and tenon joints are still minimal and unavailable in Malaysia compared to a foreign country that highlights the uniqueness of this system.

Based on several studies on the mortise and tenon joints structural system in Malaysia, it is clear that the works on this system are still at a low level compared to the value of this system or technique in the construction of traditional Malay houses. One of the non-existing research areas on mortise and tenon joints is the typology of the actual mortise and tenon joint system. Research on the typology of mortise and tenon joints is important because it allows us to identify the design of the mortise and tenon joint system as well as the strength and application of this system on traditional Malay buildings/houses. In this article, the categories of mortise will be discussed in advance with the relevance of the design, strength, and application of the mortise and tenon joint system in traditional Malay houses before analysis of the Malay mortise and tenon typology can be translated in the next writing.

4 Research Methodology

The expertise of carpenters or ‘tukang’ in designing the jointing system of heritage house framework structures or better known as mortise and tenon joints evidences the early Malay traditional construction technology. The ingenuity of the ‘tukang’ has previously produced various designs based on functions and strengths that, in turn, have an impact on the heritage house architecture [16]. Neatly designed mortise and tenon joints can be installed or removed one by one for renovation purposes and can be easily reinstalled subsequently. However, it has been vanishing and left behind due to the weakness of the nation that does not care and love its own culture [17].

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The practice of the Negeri Sembilan community that is associated with the Perpatih custom influences the design of heritage houses in addition to its historical, customary,

and cultural backgrounds that are related to the Minangkabau community that came to Negeri Sembilan [18]. Its typology is different from the cultural elements, including the way of life, size, construction techniques, and the shape of heritage houses and columns. Rembau is the only district with many historical heritage houses and contributes valuably to the cultural heritage of Negeri Sembilan [19]. The history of the Minangkabau people's arrival to Negeri Sembilan dates from the 14th century CE through the Straits of Malacca, entering through the Linggi River in Rembau [20].

Fig. 4. The British had bordered the name of Negeri Sembilan with the name "Rambow" in 1862 (*National Archives of Singapore* (1968) [21]

Rembau district selected in this study consists of 17 mukim (sub-districts) and this district is the earliest Malay settlement in Negeri Sembilan. Moreover, there are still many heritage houses over 100 years old in this area. This study uses historical and descriptive qualitative methods. Through the historical approach, all related historical, cultural, and architectural evidence materials involving the main subject of the study are collected through secondary data sources with exploratory research of previous sources found locally and overseas. The descriptive approach involves field studies such as observation, photography, sketching, and case studies for all heritage Malay houses found in the Rembau district, Negeri Sembilan with a high impact in terms of fine art, design, and their unique mortise and tenon jointing techniques. Data were then collected and stratified to obtain the findings.

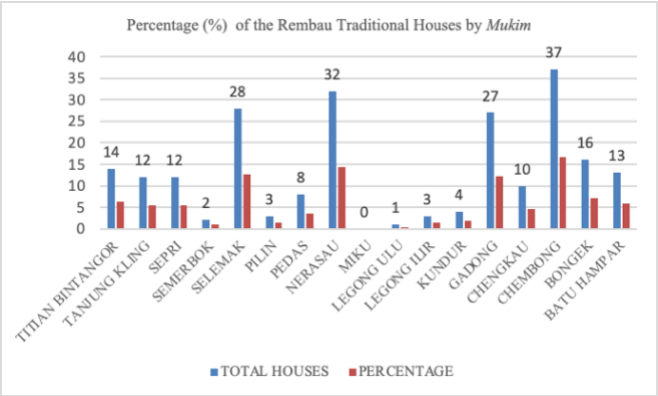

Fig. 5. Typology of Rembau Traditional House within 100-200 years old.

Figure 5 shows the development of all selected heritage houses obtained from the selection of houses over 100 years old in the Rembau district, Negeri Sembilan. The record ownership of more than 200 traditional houses over the age of 100 is a major justification for why this district was chosen as the study area. Data shows the diversity of the Rembau heritage house design typology, which has been classified into 8 (eight). The selection factor is based on the age of the house, the number of columns, the ownership status, and the typological form of the house identified. Of the 222 houses that were identified, 33 houses from 17 sub-districts aged 100 years and above were identified to have the potential to be used as the primary samples of the study.

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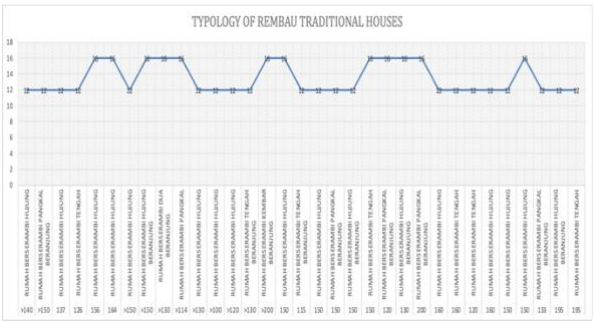


Fig. 6. Total number of Rembau Traditional Houses by *mukim* more than 100 years.

Figure 6 shows the number of houses identified for each sub-district in the oldest Rembau district to see more complex and high-tech jointing details, ownership status in terms of houses for the ordinary, the rich, or the aristocrats, which indirectly affects the design of frames, and finally the details of the houses that are more ethical, technological, and have more unique and interesting heritage values.

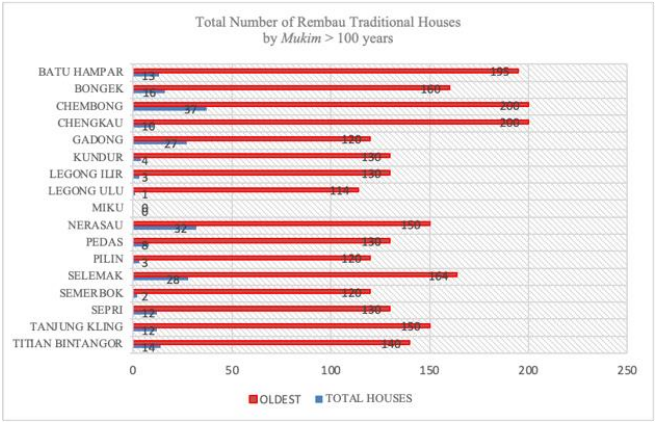


Fig. 7. Percentage of the Rembau Traditional House sub-district.

Figure 7 shows the percentage of each sub-district for the sampling selection at the preliminary stage of the study, which shows the Chembong sub-district with 16% involving 37 heritage houses over 100 years old, followed by Nerasau with 14%, and other sub-districts as shown in the data. The data also shows that only the Miku sub-district has heritage houses under 100 years old and are not included in this category.

Out of the 33 houses selected at the preliminary stage, 10 houses were recommended for a more specific study after undergoing the stratifying process through observation in the field by focusing on the age of the house, current condition, number of columns, ownership status, and the typological form of the house identified (Figure 8). The roof design concept of Negeri Sembilan heritage houses is also taken into account, as it exists from the assimilated culture as seen on the left and right ends of the roof edges.

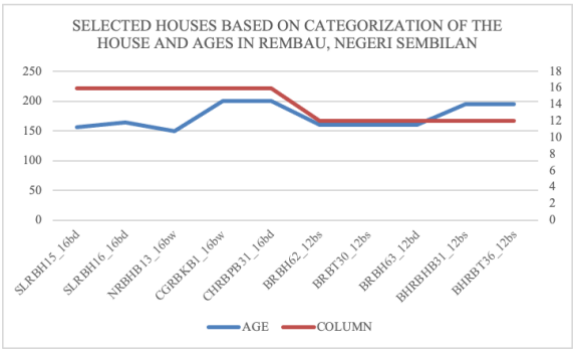


Fig. 8. Selected Houses based on Categorization of the House, Ages and Column.

The continuous ‘tulang perabung’ (ridge beam) makes it soft and produces a slightly curved roof, which slightly contrasts with Minangkabau houses that are more arched and rounded. The interpretation of Negeri Sembilan houses with Minangkabau houses is not alike or similar but rather due to their close relationships and resemblances. The

number of columns also distinguishes the ownership of the house by featuring larger space sizes and different ownership standards. The discovery of the typology of Rembau heritage houses that are more than 100 years old is commonly based on 12 columns; however, the increase in space in the 'serambi' section led to the increase of columns to 16 units. The variety of clans such as Semelenggang, Tiga Batu, Tiga Nenek, Biduanda, Batu Hampar Tani, Anak Melaka, Tanah Datar, Mungkal, Batu Hampar, Naning, Sri Selemak, Paya Kumbuh, Mungkar, Anak Acheh, Batu Belang, Lela Maharaja, and Minang makes the heritage houses in Rembau more unique and interesting. The Biduanda clan is also different from the rest of the clans as a result of mixed marriages, i.e. assimilation with the local inhabitants and can bear the Undang title. The ownership status (either ordinary, rich, or aristocrats) also affects the design of the house, thus impacting the type of mortise and tenon joints and the house layout.

Figure 9 shows the 10 houses that were previously suggested. After undergoing the stratifying process, the final study found that the current condition of the houses can be divided into several statuses: fully intact; 20% partially destroyed; 50% partially destroyed; and 90% completely destroyed. The results as shown in the graph show the condition during the sampling of houses where only 4 houses have been identified covering 80% of their good condition, while 20% of the destroyed parts encompass the kitchen space of the four houses (green label). One house (blue label) indicates only 10% of the remaining parts, i.e. the base and columns of the houses. 5 houses were (red label) with a 50/50 condition where parts of the houses still exist and some other parts have been destroyed (infested) and remodeled into concrete houses.

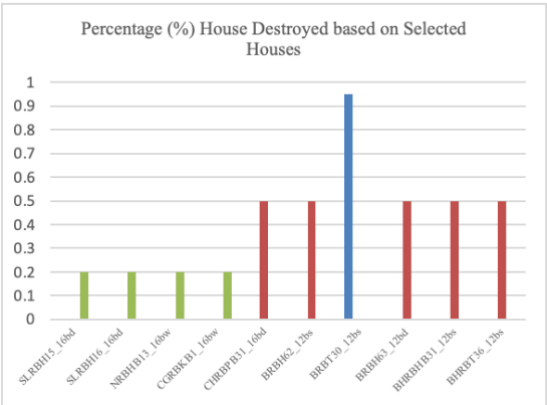


Fig. 9. Percentage of the House Destroyed based on Selected Houses.

Due to these situations, the final sampling was detailed on 4 houses with an 80% intact status as the next framework to obtain sustainable mortise and joint construction method/model for the preservation of Malay architectural heritage in Malaysia.

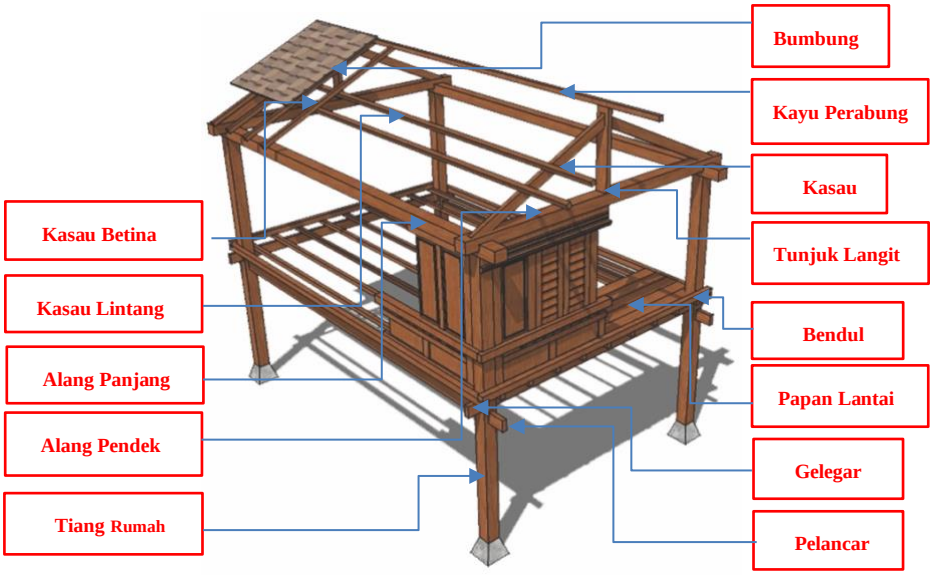


Fig. 10. Main structure of Malay Traditional House and its components

5 Categorization of Mortise and Tenon Joints in Negeri Sembilan Traditional Houses

The primary frame structure of Malay houses can be seen in Figure 10 above. The jointing that occurs in the Malay house buildings can be divided into two groups, the main jointing system and the secondary jointing system. Usually, the main jointing system is applied to the main structure in Malay traditional houses where the entire load supporting the building will move to the main structure [22]. Therefore, the mortise and tenon used in the jointing of the main structure should be designed with high durability and strength. The joints belonging to the main jointing system include those from 'rasuk' to 'tiang', 'alang' to 'alang', 'bendul' to 'bendul', 'kasau' to 'alang' and 'tetupai'. Meanwhile, the secondary jointing system encompasses the joints available in Malay houses that do not carry heavy loads as the main jointing system.

The designs of mortise and tenon joints used in the houses can be divided into several types. Usually, each design will directly affect the structural strength of the mortise. The mortise design also varies and is not limited to certain types only. For example, a joint can be installed in the middle part of a Malay house (wall). This includes the joints between wall panels as well as the use of joints in small construction components such as windows, doors, and others. By identifying the location and the use of mortise and tenon joints in traditional Malay house buildings, the strength of the joints can be deduced. This is because, when mortise and tenon joints are used in carrying heavy

loads, the mortise is designed to bear the loads to support the components. Thus, the heavier the load on the joints (mortise and tenon), the stronger the designed mortise.

Based on the results of the study conducted on the selected house samples in detail, mortise and tenon joints can be categorized into four main design groups based on how it is constructed and designed as follows:

Group 1 - Perforated and repeated component mortise. This mortise mechanism is designed with two components mounted with one component penetrating another and connecting with another component to form the strongest joint. For example, ‘tanggam tebuk’ and ‘tanggam lubang dan puting’ (Figure 11).

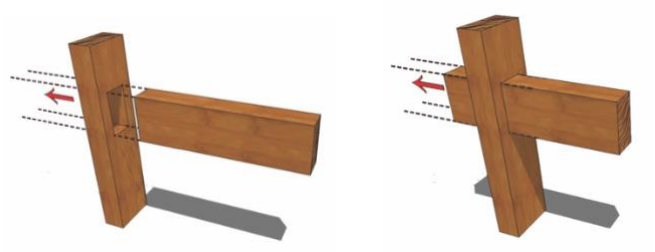


Fig 11. Group 1 Perforated and repeated component mortise.

Group 2 - Perforated component mortise. This type of mortise is designed with one component penetrating other components and components to form a joint. For example, ‘tanggam tebuk’ and ‘tanggam lubang dan puting’ (Figure 12).

Fig. 12. Group 2 - Perforated component mortise.

Group 3 - Partially perforated component mortise. This mortise mechanism is designed where both components are formed with small cuts on the extension area, or partially perforated. However, the two components do not penetrate each other but are tightly closed on both parts of the mortise and tenon joints. For example, ‘tanggam lekap’, ‘tanggam runcing’, and ‘tanggam berparit’ (Figure 13).

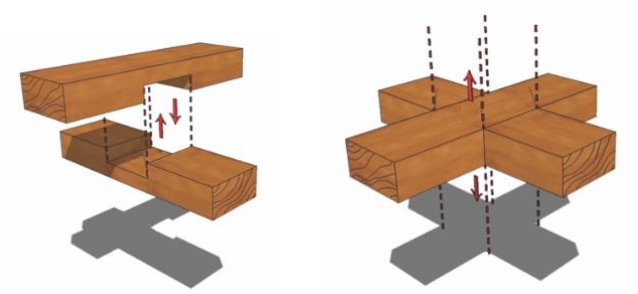


Fig. 13. Group 3 - Partially perforated component mortise.

Group 4 - Non-perforated component mortise. This mortise mechanism is designed by forming a small cut (trench/notch) in half of either one of the components. For example, 'tanggam lekap', 'tanggam lidah dan lurah', and many more (Figure 14).

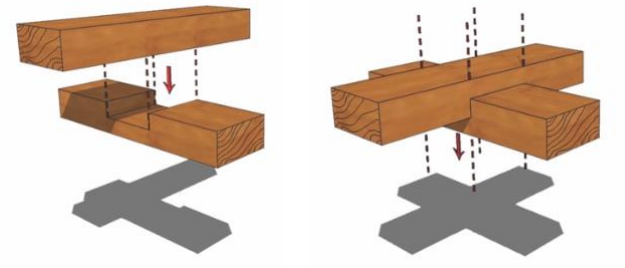


Fig. 14. Group 4 - Non-perforated component mortise.

TYPES	DESIGN PROPERTIES	SECTION	TYPE OF TANGGAM	STRENGTH
GROUP 1 	1. Perforated mortise design and repeated connection. 2. This mortise design mechanism is designed with two components assembled with one component penetrating into another component 3. 2nd last component connected with another component	Beams with beams, (alang/rasuk dengan alang/rasuk), beams and pillars/column (rasuk dan tiang), rafters with beams (kasau dengan alang), pendulums with pillars (bendul dengan tiang).	Perforated and repetitive mortise (tanggam tebuk) and Hole mortise and nipple (tanggam lubang dan puting).	
GROUP 2 	1. Mortise design with perforated components. 2. The mortise is designed with one component penetrating into another component and the components to form a connection between them.	Beams with beams, (alang/rasuk dengan alang/rasuk), beams and pillars/column (rasuk dan tiang), rafters with beams (kasau dengan alang), pendulums with pillars (bendul dengan tiang).	Perforated mortise (tanggam tebuk) and Hole mortise and nipple (tanggam lubang dan puting).	
GROUP 3 	1. Both components of the joint are perforated / grooved. 2. The two components of the joint stretch or intersect.	Skylights (kayu tunjuk langit), rafters (kayu perabung), joists (kayu gelegar) and beams (rasuk).	Mounted mortise (tanggam lekap), pointed mortise(tanggam runcing) and ditch mortise (tanggam berparit).	
GROUP4 	1. One of the components is perforated / indented / notched or not from one of them.	A large number of these notions apply only to wall components. Meanwhile, mounting mortise are used in the construction of doors and windows.	Mounting mortise (tanggam lekap), tongue and groove mortise (tanggam lidah dan lurah).	

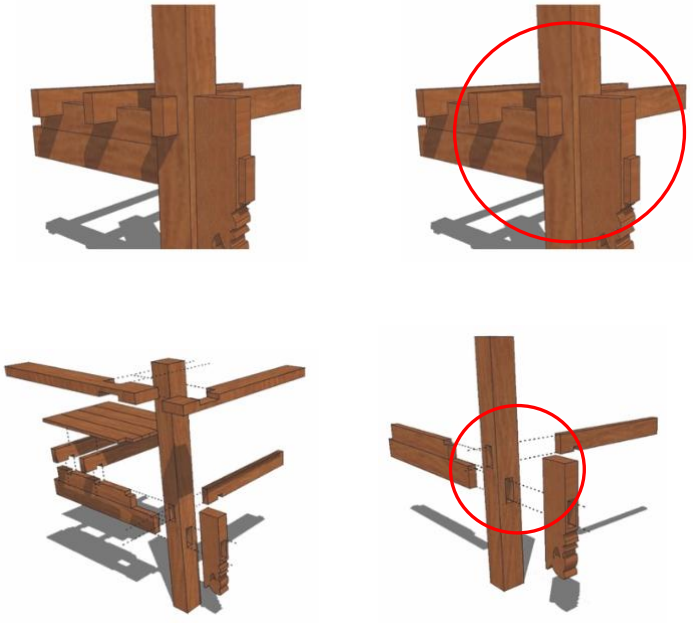
Fig. 15. Mortise placement and its function based on Categorization in Negeri Sembilan Traditional houses

In reference to Figure 15, these four categories encompass a variety of dominant mortise and tenon joints that have been identified for the use of different mortise

positions in terms of structural strength, positioning, and their functions. Basically, the types of mortise and tenon joints are influenced by the size of the built-up space as well as the roof type, while the function of the mortise and tenon joints is prone to accommodating the various loads including the floors, walls, and house roofs.

The study concludes that various types and uses of mortise and tenon joints were found in all of the house designs studied. This study also explains that the first mortise group (perforated and repeated component mortise) is classified as the strongest and sturdiest compared to other mortise groups as it is widely used in major jointing systems by connecting the main structures of the house carrying heavy loads as discussed previously (Figure 16). For instance, this includes the connections between ‘alang’ and ‘alang’ (tie-beam and tie-beam), ‘rasuk’ and ‘tiang’ (beam and column), ‘kasau’ and ‘alang’ (rafter and tie-beam), and ‘bendul’ and ‘tiang’ (sill and column) as stated by Zulkifli Hanafi. The mortise and tenon joints used in these connections are ‘tanggam tebuk’ and ‘tanggam lubang dan puting’.

The second mortise group is almost the same as the first group, the only difference is that there is no repetition of the use of perforated mortise on the other second components and this makes the joint strength slightly less compared to the first.



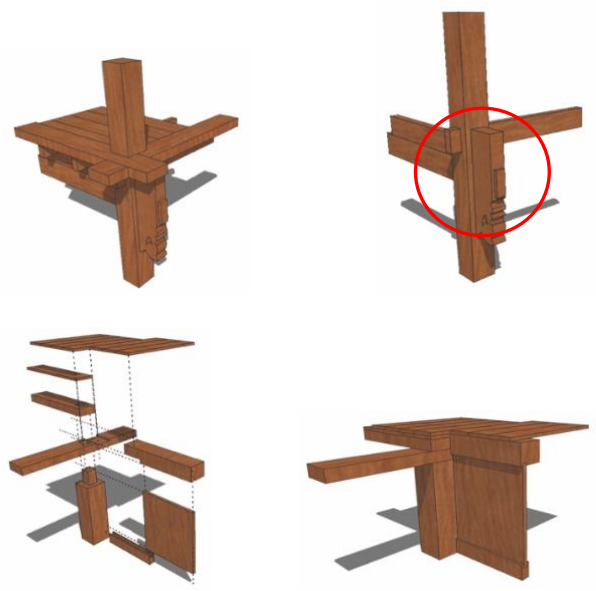
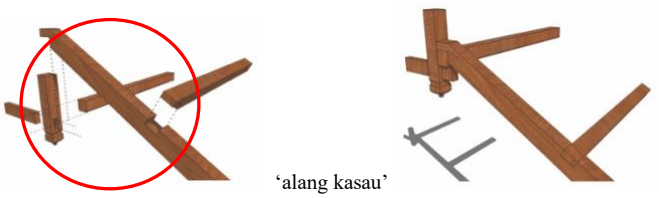


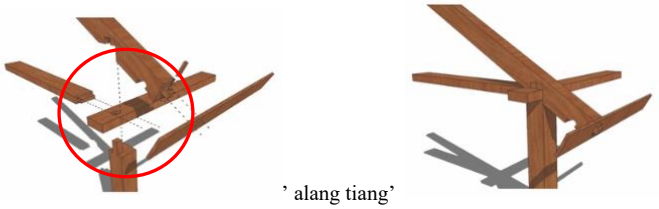
Fig.16. Group 1 Perforated and repeated component mortise.

The mortise classified in the third group (partially perforated) is stronger than the fourth group as shown in Figure 17. This mortise group is widely used in the secondary jointing system and slightly in the primary jointing system. Several mortises in this group are used in the main structural section. In addition, the connection between ‘kayu rabung’ (ridge) and the king post mostly uses ‘pelekap lekapan’ and ‘alur’. This mortise group is widely used to help support the main structure of the house frame.

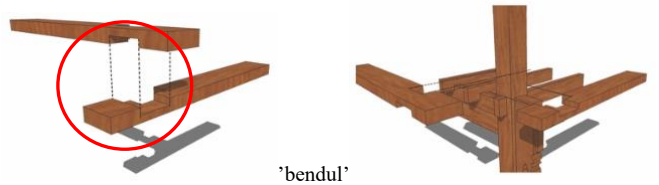
Examples of the use of mortise and tenon joints can be seen between the diagonal angles of 'bendul' (sill) using 'tanggam pepenjuru'. Additionally, the connections between ‘kayu tunjuk langit’ and ‘kayu perabung’ (king post and ridge) as well as ‘kayu gelegar’ and ‘rasuk’ (joist and beam) are based on ‘tanggam lekap berparit’. Compared to the first mortise group, the second mortise group is less robust as its installation method is simpler and uses smaller wooden slits.



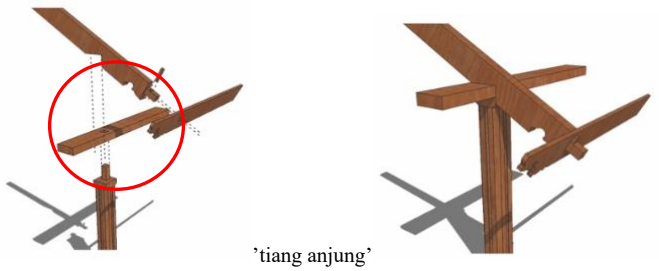
‘alang kasau’



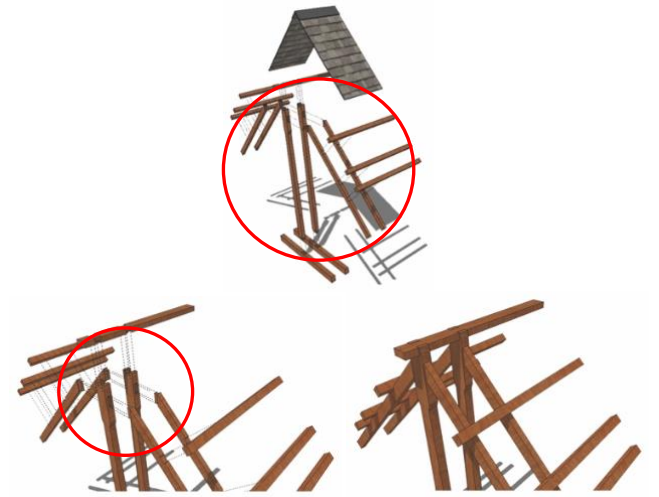
’ alang tiang’

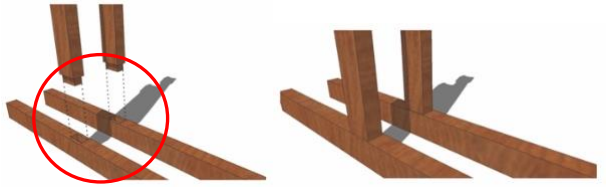


’bendul’



’tiang anjung’

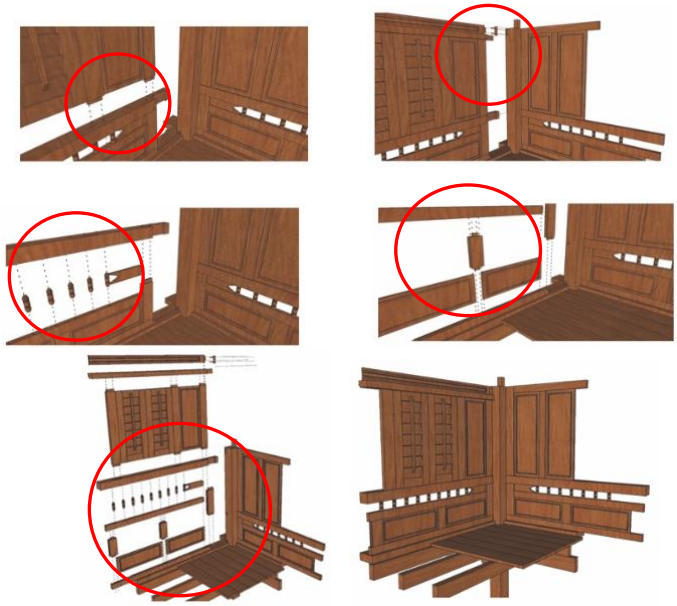




‘Tunjuk langit’

Fig. 17. Group 3 - Partially perforated component mortise.

The use of mortise and tenon joints in the fourth group (non-perforated) overall occurs in joint structures that are not directly related to the strength of the house structure. The mortise component classified in this group is used to connect structures that do not directly affect the stability of the house structure and it does not carry heavy loads compared to the other mortise groups (Figure 18). Most of these mortise and tenon joints are only used on wall components. For example, ‘tanggam lidah dan lurah’ used to join walls and columns including the wall panels. Meanwhile, ‘tanggam lekap’ is used in the construction of doors and windows.



‘Connection between wall and window’

‘Window Connection’

Fig. 18. Group 4 - Non-perforated component mortise.

6 Conclusion

Based on the analysis, several conclusions can be formulated. As a result of the Negeri Sembilan traditional house typological mapping and its relationship with the categories of mortise and tenon joints, we can see the direct link between the selection of the house type and its association with the design and strength of each mortise and tenon joint. The variety of mortise categories is classified into 4 (four) main groups, namely repeated perforated component mortise, perforated component mortise, partially perforated component mortise, and non-perforated component mortise. The finding concludes that various types and applications of mortise and tenon joints were found in all of the house designs studied.

This proves that the types of mortise and tenon joints have many important functions in timber construction. The sturdiness and strength of a building also depend on the jointing system, which makes the entire building structure strong and stable in facing many pressures. The main functions of joint in timber construction can be seen in terms of structural strength, component continuity, the flexibility of use in reducing construction costs, and consolidation of various parts of the building. Indeed, the types of mortise and tenon joints are not influenced by the roof type or house typology, but the mortise function is more prone to accommodating a wide variety of loads including the floor area, walls, and roofs. In addition, by conducting other studies on cultural technology across countries, we can gain discoveries and provide more opportunities for further research as a way of documenting and conserving our culture and traditions for future generations.

7 Acknowledgement

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